YouTransfer, YouDesign:

A participatory approach to design assistive technology for wheelchair transfers

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Declaration

I, Giulia Barbareschi, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Abstract

Transferring independently to and from their wheelchair is an essential routine task for many wheelchair users but it can be physically demanding and can lead to falls and upper limb injuries that reduce the person's independence. New assistive technologies (ATs) that facilitate the performance of wheelchair transfers have the potential to allow wheelchair users to gain further independence. To ensure that users' needs are addressed by ATs, the active involvement of wheelchair users in the process of design and development is critical. However, participation can be burdensome for many wheelchair users as design processes where users are directly involved often require prolonged engagement.

This thesis makes two contributions to facilitate wheelchair users' engagement in the participatory design process for ATs, while being mindful of the burden of participation. The first contribution is a framework that provides a modular structure guiding the participatory design process from initial problem identification and analysis to facilitating collaborations between wheelchair users and designers. The framework identifies four factors determining the need and adoption process for ATs: (i) *People* focuses on the target population, (ii) *Person* includes personal characteristics, (iii) *Activity* refers to the challenges associated with the task, and (iv) *Context* encompasses the effect of the environment in which the activity takes place. The second contribution constitutes a rich picture of personal and external elements influencing real world wheelchair transfers that emerged from four studies carried out to investigate the effect of the framework factors on the design process for ATs. A related outcome based on these contributions is a framing document to share knowledge between wheelchair users and designers to provide focus and promote an equal collaboration among participants.

Impact Statement

The work presented in this thesis and its contributions have had measurable impact both inside and outside of academia in several ways. A complete list of outputs from the work presented in this thesis is presented below.

Within academia, this thesis makes a number of direct contributions to the field of disability related research on how to better investigate the challenges faced by wheelchair users in their everyday lives and how to leverage research findings to improve the process of assistive technology design. The insight gained from findings in this thesis have been published and presented several times at relevant venues for the disability and assistive technology research community. Beyond publications, findings from this thesis have also been presented through a number of invited talks and lectures in UCL and other universities. The framework for participatory design illustrated in Chapter 4 is currently being taught in the Accessibility and Assistive Technology module of the MSc in Interaction Design as a good example of co- design of assistive technology with disabled users.

Outside of academia, the work presented in this thesis has attracted significant attention from disabled people organizations and charities. The co-design workshop illustrated in Chapter 9 was described as an “excellent introduction to co-design”, thanks to the emphasis given to the importance and benefits of actively involving disabled people in assistive technology design (see https://www.demand.org.uk/our-stories/everyone/youtransfer-co-design-workshop/ for the full report). I have also been involved in disseminating this work through public engagement activities and outreach with a particular emphasis on young people, through my activity as a STEM ambassador for the James Dyson Foundation Summer School on Redesign the Wheelchair in July 2017. Finally, thanks to the expertise I have developed when carrying out the research presented in this thesis, I was invited to collaborate with the NESTA’s Challenge Prize Centre during the initial conceptualization stages for the Mobility Unlimited Challenge sponsored by the Toyota Mobility Foundation in 2017.

“We can never go nowhere unless we share with each other” - 2PAC

Acknowledgements

Whenever I approach the end of one of the chapters in my life, I always find myself to be caught a bit off-guard. In many respects, this is no different from many others. In the midst of it, my PhD felt like a never ending journey. However, when I now think about the last three and a half years I struggle to see where the time has gone. But above anything else, when I look back I feel lucky and I am incredibly grateful for all the encouragement, support and laughter brought by the people who have crossed my path in these last few years.

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I am also grateful to all my colleagues in UCLIC who made me feel a part of their family and helped me to complete this journey. In particular, I want to thank Britta Schulte (for sharing my love for pie and my grumpiness), Amid Ayobi (for his unshakable cheerfulness), Nikki Newhouse (for giving me hugs whenever I wanted them or not), Dilisha Patel (for always being able to read my mood as soon as she stepped into the office) and Marta Cecchinato (for sharing with me the final pains of my PhD). I would also like to thank Louise Gaynor and Sarah Davies for their support in anything and everything. A special mention goes to two people who have become incredibly important to me over the last couple of years. The first one goes to Rhys Williams with whom I shared a supervisor, a business competition and countless other things (including several obsessive compulsive traits). Our catch-ups over pints and coffee are one of the things that kept me going throughout my PhD and you really helped me find my way when I was lost in the middle of my self-doubt. The second one goes to Aneesha Singh with whom I shared two offices, a remarkably similar sense of humour, and a number of stuffed toys/super heroes. You really made all the difference in the world to me in the last year and I can't even begin to tell you how much I am going to miss our chats over coffee runs/smoking breaks and walks around the block.

Despite the fact that I often don't feel like it, I also have a life outside the office and many people who helped me stay sane throughout my PhD. I want to thank my family for supporting me in this adventure and, as always, my biggest thank you goes to my sister who is my pillar in life and the person who I admire the most. I am also grateful to many old and new friends that have supported me in many ways in this and countless previous endeavours. Especially my gratitude goes to Elena (for always understanding my wicked sense of humour), Laura (because every time we hang out I feel like I never left Galway), Margherita (for dragging me away from my desk and never dropping me when I am dangling off a wall) and Levan (for helping me and Benen make London our new home).

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Publications and Awards

Contributing Publications

1. Barbareschi, G., Cheng, T. J., & Holloway, C. (2018). Effect of technique and transfer board use on the performance of wheelchair transfers. *Healthcare technology letters*, *5*(2), 76.
2. Barbareschi, G., & Holloway, C. (2018). An investigation of factors affecting the performance of wheelchair transfers. *Disability and Rehabilitation: Assistive Technology*, 1-10.

Paper 1 reports the findings from the observational study on wheelchair transfers presented in Chapter 5. Paper 2 reports the findings from the survey study presented in Chapter 6.

Awards

Winner of the London Health Tech Challenge. London Business School, Deloitte Institute of Innovation & Entrepreneurship & UCL (June 2015)

Awarded the UBI-HEALTH Pervasive health Research Exchange Funding (June 2016)

Awarded the Global Disability Innovation Hub Short Fellowship (February 2018)

List of Abbreviations

Abbreviation	Term
2PAC	People Person Activity Context
AAC	Alternative and Augmented Communication
ADL	Activity of Daily Living
AT	Assistive Technology
ATD	Assistive Technology Device
BBEE	Baker’s Basic Ergonomic Equation
BKA	Below Knee Amputation
BW	Body Weight
CP	Cerebral Palsy
CTS	Carpal Tunnel Syndrome
EDS	Ehlers-Danlos Syndrome
EMG	Electromyography
GRF	Ground Reaction Force
HAAT	Human Activity Assistive Technology
ICF	International Classification of Functioning
MPT	Matching Person and Technology
MRI	Magnetic Resonance Imaging
MS	Multiple Sclerosis
MWU	Manual Wheelchair Users
NMO	Neuromyelitis Optica
OT	Occupational Therapist
PAPAW	Pushrim Activated Power Assisted Wheelchair
PD	Participatory Design
QoL	Quality of Life
RoM	Range of Movement
SCI	Spinal Cord Injury
TAI	Transfer Assessment Instrument
UCD	User Centred Design
US	Ultrasound
WHO	World Health Organization
WUSPI	Wheelchair Users Shoulder Pain Index

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Chapter 1 Introduction

In the 2011 World report on disability, the World Health Organization (WHO) defines disability as a complex umbrella term that encompasses dynamic problems related to body functions, activities and participation (World Health Organization, 2011). These problems are the result of the interactions between the individual and contextual factors such as environmental and personal factors (World Health Organization, 2011). According to the same report, approximately 15% of the world population falls into this group, and the number is bound to rise as the average life expectancy increases (World Health Organization, 2011). When a person is born with, or acquires, a disability the combination of his/her reduced capabilities with a challenging environment can make everyday tasks extremely difficult.

One of the main concerns people have regarding disability is the loss of personal independence. Losing the ability to go wherever they wish whenever they wish; to communicate effectively; to take care of their most basic and personal needs is often seen as a loss of dignity for the person. Disability often decreases personal independence and it has a negative effect on the access to employment, education or leisure opportunities (Fanshawe, 1981; Loprest & Maag, 2007). Assistive technologies (ATs) are items, pieces of equipment or product systems, in physical or digital form, which can help bridge the gap between the capabilities of the individual and the capabilities required by everyday tasks (Tyler, 2011). When disabled people[1] are provided with ATs that match their needs and capabilities, their level of independence increases often resulting in better opportunities for education, employment and community participation (Stumbo, Martin, & Hedrick, 2009).

Despite their potential to improve the lives of people with disabilities, many ATs interventions tend to fail due to abandonment from the user. This often results in dissatisfied users and a loss of public or private money (Riemer-Reiss & Wacker, 2000). The abandonment of ATs is a pressing issue with an estimated rate ranging from 8% to 75% depending on the technology (Stefano Federici & Borsci, 2011; Tewey, Barnicle, &

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[1] Disabled People' is the term preferred in the UK by Disabled People's Organisations, rather than the UN favoured 'people/persons with disabilities'. 'Disabled people' is used to refer to the way in which society disables people with impairments, for instance by adding steps to a building, while that the latter term implies ownership of the 'problem' by the individual. I use the UK approach throughout, recognising that this is contested.

Perr, 1994). The scarce consideration of the needs and priorities of users is generally the strongest predictor of the abandonment of ATs (Phillips & Zhao, 1993; Riemer-Reiss & Wacker, 2000). The direct involvement of prospective users in the design of new product and services, an approach called participatory design (PD), will ensure that users' needs are not only included but at the core of the development of new ATs (LoPresti, Bodine, & Lewis, 2008).

In recent years, the application of PD techniques for the development of ATs has attracted increasing attention (Mayer & Zach, 2013; Moffatt, McGrenere, Purves, & Klawe, 2004; Robinson, Brittain, Lindsay, Jackson, & Olivier, 2009). The collaboration between users and designers offers the opportunity to develop ATs that truly respond to the needs of individuals, resulting in significantly lower chances of abandonment (Robinson et al., 2009). PD is only successful when there is a mutual learning environment that allows equal collaboration between all parties involved (Simonsen & Robertson, 2012). However, particularly for projects focusing on ATs, achieving a balanced power dynamic among the members of the design team is difficult due to the important background differences between disabled users and able bodied designers, which is often combined with unconscious bias that causes able bodied individuals to perceive disabled people as more vulnerable and less competent (Galli, Lenggenhager, Scivoletto, Molinari, & Pazzaglia, 2015; Kujala, 2003). Completing the initial design stages of PD projects might require several meetings that span across weeks or months, making recruitment of disabled people extremely complex (Petrie, Hamilton, King, & Pavan, 2006; Wu, Richards, & Baecker, 2004).

Wheelchair users comprise a large and diverse group of disabled people, accounting for nearly 70 million individuals worldwide (World Health Organization, 2010). Being able to transfer safely in and out of the wheelchair is an important skill for the independence of many wheelchair users (Slavin, Kisala, Jette, & Tulsky, 2009). Transfers are crucial for several everyday activities as they allow the person to move between the wheelchair and a bed, a car seat, a toilet or a bath tub. Unfortunately, performing wheelchair transfers is also one of the most challenging tasks for wheelchair users (Gagnon, Koontz, et al., 2009) and it has been linked to an increased risk of falling (Forslund et al., 2017). Additionally, the high forces generated during wheelchair transfers have been shown over time to lead to the development of upper limb injuries that could severely affect the quality of life of wheelchair users (Hogaboom, Diehl, Oyster, Koontz, & Boninger, 2016; Hogaboom, Worobey, & Boninger, 2016).

Despite their importance for the independence of the individual, wheelchair transfers have attracted significantly less interest than wheelchair propulsion in terms of both research and AT innovation. Research studies have mainly focused on measuring the biomechanics of wheelchair transfers performed by individuals with Spinal Cord Injury (SCI) in laboratory settings (Gagnon, Koontz, et al., 2009; Gagnon, Nadeau, Noreau, Eng, & Gravel, 2008; Gagnon, Nadeau, Noreau, Eng, et al., 2008). Laboratory based studies give researchers the opportunity to obtain very accurate measurements. However, they offer a poor representation of transfers performed in real world environments (Haubert et al., 2015; Kataoka et al., 2012). Currently available assistive devices, such as transfer boards and grab bars can facilitate the performance of wheelchair transfers (Boninger et al., 2005; Toro, Koontz, & Cooper, 2012). However, grab bars are usually fitted modifications with limited availability in selected environments, while the efficacy of transfer boards in facilitating independent wheelchair transfers has never been measured (Koontz, Toro, Kankipati, Naber, & Cooper, 2012). Crucially, if a person is not able to transfer independently there is currently no available alternative that can completely eliminate the need for human assistance.

The aim of this thesis is to develop a better understanding of wheelchair transfers and use this understanding to facilitate cooperative design of new assistive technologies that have the potential to be more acceptable and respond to users' real needs.

1.1 Research questions, objectives and contributions

Wheelchair transfers are one of the most important and difficult activities for wheelchair users and there is a gap for new assistive technologies designed with a participatory approach that respond to users' needs and promote the autonomy of the person. The work presented in this thesis aims to answer the following research question:

RQ: How can wheelchair users be engaged and empowered to contribute to the design of new assistive technologies for independent wheelchair transfers that respond to their real needs?

Addressing this research question requires a good understanding of wheelchair transfers, and the challenges and needs encountered by people during their performance, as well as a deeper knowledge of PD and the difficulties of implementing this approach in the context of AT design. For this reason, this question was divided in two sub-questions, each answered using a specific approach, leading to two different contributions.

RQ1: How can the impact of disabled users' participation in the PD of ATs be maximised?

As previously mentioned, establishing productive communication which allows for mutual learning between users and designers is essential to the success of any PD project. However this can be challenging, particularly due to the different experiences and expectations of disabled people and designers. Designers often lack a deep understanding of the challenges that disabled people have to face, while users often struggle to formulate their needs in a way that is meaningful to designers. Kensing (1983), highlighted how access to information which are relevant to the problem is key to successful participation of users in the design process. Additionally, when different members of design teams have different initial mental models, as would be expected in teams comprising both users and designers, sharing knowledge would facilitate the creation of common mental models that improve the performance of the design team as a whole (Badke-Schaub, Neumann, Lauche, & Mohammed, 2007). However, deciding what information should be collected and shared with all parties in order to facilitate the PD of ATs can be challenging.

To facilitate the meaningful engagement of people with disabilities in the PD of ATs while reducing the burden associated with the need for prolonged participation, I developed a new framework, called People Person Activity Context (2PAC). The focal point of the framework is that the collection and sharing of relevant information concerning the characteristics of the target population (People), the personal factors affecting the activity and the usage of ATs (Person), the challenges and difficulties associated with the task (Activity) and the effect of the environment in which the activity takes place (Context) can provide focus and structure to the PD process and facilitate the collaboration between the various members of the design team without influencing the decision making process (Chapter 4). The four core element of the 2PAC framework were articulated on the basis of a comprehensive revision of models which have been formulated to illustrate the important elements in the AT adoption process (Chapter 3). The need to investigate these four domains led to the second research question of what factors influence the performance of wheelchair transfers. The effectiveness of the framework was tested during the final PD workshop where all participants were provided with an accessible and easy to read handout that collated the information collected during the four studies. Throughout the workshop, I explored the dynamics between participants from team formation to prototype building and presentation. A triangulation between field notes, and transcripts from group discussions and semi-structured interviews was used to understand the effect of information on participant’s experience and generation of ideas. Findings from the workshop are presented alongside two design ideas for prospective assistive technologies for wheelchair transfers developed by participants (Chapter 9).

Finally, in the later stages of PD, one of the issues common to several projects is related to the difficulty of sustaining participation throughout the development of the technology, Ideally, the technology should also be evaluated and improved over time according to its impact on the targeted activity, thus promoting an iterative process even once the design is already in use. (Robertson & Simonsen, 2012). Based on related literature on PD and diffusion of AT, in Chapter 10, I extended the 2PAC framework to incorporate the steps which are necessary to make the transition from co-designed ideas to open and accessible AT that can be used and modified by users.

> *First Contribution (Chapters 3, 4, 9 and 10):* The development of framework that provides a modular structure guiding the PD process of ATs from problem identification and analysis to the sharing of information to facilitate the collaboration between disabled users and designers to ensure meaningful engagement while reducing the burden of participation. The framework also outlines the necessary steps to sustain disabled users' participation throughout the development and diffusion of the technology.

RQ2: What are the factors that influence the performance of wheelchair transfers that need to be considered when designing new assistive technologies?

Based on the four factors identified by the 2PAC framework I carried out a series of mixed-methods studies aimed at investigating relevant aspects of wheelchair transfer performance in the real world. This series of studies goes beyond the traditional approach of clinical and laboratory based studies of wheelchair transfers (Finley, McQuade, & Rodgers, 2005; Gagnon, Koontz, et al., 2009; McClure, Boninger, Ozawa, & Koontz, 2011) and allowed me to gain a deeper understanding of the real difficulties, risks and personal strategies of wheelchair users related to the performance of wheelchair transfers in their everyday lives.

The four studies presented in these chapters were developed in an organic fashion according to the four factors identified in the 2PAC framework. Biomechanics analysis and clinical scales were used to evaluate the effects of technique (Chapter 5) and environmental conditions (Chapter 7) on the quality of wheelchair transfers and to understand how these factors affect the risk of falling and the developing of upper limb injuries. A survey was developed and administered among wheelchair users to investigate the broader relationship between the characteristics of individuals, the type and number of wheelchair transfers that are performed daily and the difficulties that are commonly encountered (Chapter 6). Finally I carried out a series of interviews and focus groups with both occupational therapists and wheelchair users in order to explore the perspectives, needs and concerns that wheelchair users encounter when transferring in their everyday lives, not only due to the built environment or their impairment, but also in relation to their lifestyle and personal experiences (Chapter 8).

> *Second Contribution (Chapters 5-8):* Findings from the four mixed-methods studies present a rich picture of personal and external elements that influence the performance of wheelchair transfers in the real world for a diverse cohort of users. Implications for AT design extracted from each study were used to inform the PD workshop.

1.2 Scope

This thesis focuses on developing a way to facilitate the engagement of wheelchair users in the initial stages of the PD on wheelchair transfers for the design of new ATs that are both useful and more acceptable to prospective users. The approach developed in this thesis is also applicable to the design of different ATs and the involvement of different stakeholders in the PD process.

1.3 Thesis structure

This thesis consists of eleven chapters. **Chapter 2** introduces the reader to the wheelchair users' population and explains the importance of wheelchair transfers in their everyday lives. Biomechanics of wheelchair transfers alongside the risks of falling and developing upper limbs injuries that are associated with transfer performance are described next. **Chapter 3** presents an overview of the literature focussing on ATs. After explaining the potential of AT and the problem related to AT abandonment, I introduce models of AT adoption and, through their analysis, identify the most important elements that influence the need for ATs.

Chapter 4, provides an overview of PD and discusses the main issues and concerns associated with it. Afterwards, based on the analysis of AT adoption models illustrated in the previous chapter, I describe the framework used for collecting relevant information on wheelchair transfers for the PD workshop. Each step of the information gathering process is presented alongside suggested methodology for the investigation.

Chapters 5 to 8 describe the four studies conducted to analyse the factors that influence the performance of wheelchair transfers. **Chapter 5** illustrates an observational study I conducted to understand how different techniques (unassisted sitting, unassisted standing, sitting with transfer board) affect the load on the upper limbs and the quality of movement during the performance of wheelchair transfers. **Chapter 6** presents a survey that aims to investigate how factors such as individuals' characteristics, their motivation, the presence of upper limb pain, the use of ATs and environmental conditions affect the performance of wheelchair transfers. **Chapter 7** describes findings from a semi-controlled observational study that aims to explore how wheelchair transfer technique changes according to the transfer setting. I also explore the impact that different real world environmental conditions have on objectively measured transfer quality, subjective perception of difficulty, and the relationship between these two assessment tools. **Chapter 8** presents results from a series of interviews and focus groups, carried out with wheelchair users and occupational therapists (OTs). These qualitative studies were carried out in order to gain a deeper understanding of the perspectives, needs and concerns that wheelchair users encounter when transferring in their everyday lives, not only due to the built environment or their disability, but also in relation to their lifestyle and personal experiences.

Chapter 9 describes findings from the informed PD workshop I carried out. Design ideas generated from the workshop are presented alongside the feedback from participants and field notes on how the availability of relevant information, collected in the previous studies, influenced the design process.

Chapter 10 discusses reflections from the studies and the 2PAC framework based on the experience gained throughout the development of this thesis. Additionally, I reflect on the concept of participation and engagement of users within PD and discuss the changing role of the researcher throughout the various stages of this thesis. Finally, I present reasons and suggestions on how design ideas generated during the workshop can be developed into devices to be shared with the makers' community in order to allow prospective users to access and modify them.

Finally, **Chapter 11** presents the conclusions of this thesis and highlights the potential for future research.

Chapter 2 Wheelchair users and the importance of transfers

The aim of this thesis is to facilitate the engagement of wheelchair users in PD to develop new ATs that can help individuals when transferring in and out of their wheelchair. This chapter summarises relevant research on the topic of accessibility, wheelchair mobility and wheelchair transfers that lays the foundation for the work described in this thesis. The chapter begins by introducing wheelchair users and it brings a particular focus on the great diversity within the population. As the focus of this PhD is on wheelchair transfers, the following section highlights the importance of independent wheelchair transfers in the everyday life of wheelchair users. Next, I examine the literature that focuses on the biomechanics of wheelchair transfers and emphasise some of the shortcomings that will be addressed in the studies presented in the following chapters. Finally, in the last two sections of this chapter I analyse the relationship between the performance of wheelchair transfers, the development of upper limb injuries due to overloading and the occurrence of falls that will lay the basis for the design effort described in this thesis.

2.1 Wheelchair users: one symbol, many disabilities

Walking is among the first complex and most important abilities that children learn in their life. Human existence is dynamic in many aspects: going to work or school, meeting friends, practising sports, even moving between rooms inside the same house, requires us to walk from one place to another. Wheelchairs may be prescribed when people are unable to walk in a safe and functional manner due to congenital or acquired conditions (Trefler & Taylor, 1991). Overall, wheelchair users represent an estimated 10% of the disabled population worldwide (World Health Organization, 2010). However, this percentage varies greatly depending on the country. In the UK the number of wheelchair users is estimated to be 1.2 million, accounting for roughly 2% of the population (National Health Service England, 2017). In the USA the estimated number of wheelchair users is 2.2 million, approximately 0.7% of the total population,(National Institute of Health, 2016), with an increase of over 29% since 2000 (Kaye, Kang, & LaPlante, 2000). Wheelchair users are not only one of the most numerous and fast growing groups within the disabled community, they are also the most iconic.

Due to the immediate evidence of their AT and the ease of identification for the general public , wheelchair users were chosen in 1968 by Susanne Koefoed as a representative for the International Symbol of Access shown in Figure 2-1 (Ben- Moshe & Powell, 2007).

Figure 2-1 The International Symbol of Access showing the white outline of a wheelchair user enclosed in a bright blue square. Official design regulated by the ISO 7001:1990 public information symbols

The identification of all wheelchair users with their AT is also a source of many misconceptions. Wheelchair users are generally perceived as “wheelchair bound” due to their perceived complete inability to walk and are normally associated in people’s mind with neurologic conditions such as Spinal Cord Injury (SCI), stroke or Multiple Sclerosis (MS). However, reasons for wheelchair use are varied and can range from balance issues, to chronic pain, fatigue or limited mobility. In fact, a large proportion of wheelchair users are able to stand up and walk for short distances (Hoenig, Pieper, Zolkewitz, Schenkman, & Branch, 2002). Although neurological conditions are common among wheelchair users, orthopaedic, cardiopulmonary and other medical conditions are equally widespread (LaPlante & Kaye, 2010). The diversity of medical conditions, lifestyle, demographic and personal characteristics among wheelchair users, result in an incredibly diverse population whose members will have different needs, difficulties and aspirations.

2.2 Wheelchair transfers as a measure for independence

Whenever we think about a wheelchair user we are likely to picture an individual sitting in their wheelchair. For this reason, when we consider challenges that wheelchair users have to face in their daily lives we are likely to think about environmental barriers that might prevent access to a particular place for a wheelchair user or make propulsion more difficult such as steps, kerbs, narrow passages, steep slopes and uneven terrain

(Rimmer, Riley, Wang, Rauworth, & Jurkowski, 2004). Wheelchair propulsion is definitely a challenging and important activity, linked with both individual wellbeing and participation in social life (Chow & Levy, 2011; Hastings, Robins, Griffiths, & Hamilton, 2011). However, wheelchair propulsion is not the only activity with an impact on the independence and participation of wheelchair users, nor it is necessarily the most important for the population as a whole. The ability to transfer oneself between the wheelchair and other surfaces, is crucial for many Activities of Daily Living (ADLs). Common activities such as getting out of bed, taking a shower, driving a car, practising sports or using a toilet usually require the person to transfer out of their wheelchair. For example, if a person is unable to stand and take a few steps, they will probably transfer five or six times to complete a daily morning routine (e.g getting up, dressing, going to the toilet). The number of times that a person transfers to and from the wheelchair in a single day varies greatly and depends on habits, disability, environment, lifestyle and personal preferences (Gagnon, Nadeau, Noreau, Eng, et al., 2008; Sonenblum, Sprigle, & Martin, 2016).

Although the daily number of wheelchair transfers is considerably lower than the number of wheelchair pushes, there are several reasons why transfers might play an even bigger role than propulsion for the independence and Quality of Life (QoL) of wheelchair users. Firstly, wheelchair propulsion is only relevant to individuals who use a manual wheelchair as a means of mobility while transferring to and from the wheelchair is necessary for all wheelchair users. Although the majority of wheelchair users reports the primary use of a manual wheelchair, approximately 17% uses primarily electric wheelchairs and mobility scooters (LaPlante, 2003).

Secondly, if a person is unable to manually propel a wheelchair, an electric wheelchair, a mobility scooter or a pushrim activated power assisted wheelchair (PAPAW) can help bridge this gap and allow the person to independently move in the environment (Davies, Souza, & Frank, 2003). Therefore, technology exists to aid people who have difficulties or are unable to push their chair to overcome their difficulties independently. Although changing from a manual wheelchair to a powered wheelchair can have a negative effect on personal mobility and occupation, PAPAW can offer the possibility of maintaining functional independence without affecting individual participation (E. M. Giesbrecht, Ripat, Quanbury, & Cooper, 2009; Hastings et al., 2011). On the other hand, if a person is unable to transfer him/herself to and from the wheelchair, there is currently no available alternative that can completely eliminate the need for human assistance. Assistive devices such as grab bars and transfer boards, shown in Figure 2-2, can partially facilitate the performance of wheelchair transfers (Michael L. Boninger et al., 2005; Toro et al., 2012) but they have severe limitations. Grab bars are usually fitted modifications with limited availability in selected environments, whereas transfer boards are of limited use for several challenging transfers where there is a considerable height gap between the wheelchair seat and the target surface as the slope of the board becomes too steep.

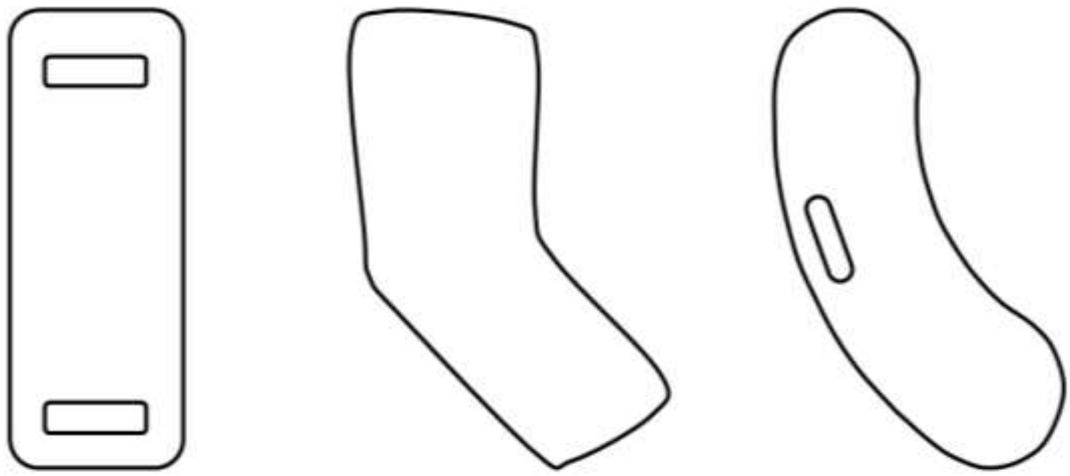

Figure 2-2 Transfer boards are assistive devices usually made in wood or hard plastic that can be positioned between the two transfer surfaces and used by the person to slide across. The most common shapes in which they are available are straight boards (left), boomerang boards (centre) and banana boards (right). Transfer boards can be manufactured in different sizes depending on the needs of the person and they can feature holes to facilitate hand carrying and positioning.

Although researchers might, at times have underestimated the importance of transfers, wheelchair users did not. In a survey carried out by Fliess-Douer, Vanlandewijck, & Van Der Woude (2012), involving 79 Paralympic athletes and 47 regular wheelchair users with SCI, both tetraplegic (n = 15) and paraplegic (n = 101), the ability to transfer between the wheelchair and a car seat was rated the most essential activity for daily life (4.7 ± 0.7 on a 5-point scale) by both groups. Being able to propel the wheelchair forward for 50m was ranked 2nd with an average score of 4.4 ± 1.0. Two other transfer skills such as transferring between two wheelchairs and transferring from the floor to the wheelchair were ranked respectively 6th and 7th ahead of other propulsion skills such as ascending/descending a 5cm sidewalk and propelling on uneven terrain. Finally, the importance of wheelchair transfer is also demonstrated by the fact that transferring skills are included in most wheelchair skills assessment tests (Fliess-Douer, Vanlandewijck, Manor, & Woude, 2010).

2.3 Techniques and biomechanics of wheelchair transfers

According to their technique, transfers between the wheelchair and another surface can be classified in three different ways: unassisted sitting pivot transfers (sometimes called pop-over transfers), unassisted standing pivot transfers and transfer board transfers

(Audrey Natale PT et al., 2009). In the following three subsections I describe the overall movement strategy and the biomechanics implications associated with each transferring technique.

2.3.1 Unassisted sitting pivot transfers

When performing an unassisted sitting pivot transfer the person will first position their wheelchair close to the surface on which he/she wishes to transfer to. Clinicians recommend the wheelchair be placed at an angle of 20°– 45° in respect to the other surface and for the person to move his/her buttocks towards the front of the seat (this movement is called scooting) (Tsai, Rice, Hoelmer, Boninger, & Koontz, 2013). Some users will place both feet on the floor while others might prefer to leave them on the footplate. The person will then place one hand (the leading hand) on the target surface and will then leave one hand (the trailing hand) on the starting surface. The transfer itself is usually achieved with a quick forward lean of the trunk while the person pushes with the upper limbs. This releases weight from the buttocks and is accompanied by a pivoting motion that rotates the trunk so that the shoulders point in the opposite direction to the direction of travel of the transfer. This motion might seem counter intuitive; but, it is critical to a successful transfer. This 'head-hip relationship' as it is called, means the head will move in the opposite direction to the hips during transfer. Similar description of unassisted sitting transfer technique can be found in Perry, Gronley, Newsam, Reyes, & Mulroy (1996) and Gagnon et al. (2008). The sequence of events for an unassisted sitting transfer is shown in Figure 2-3.

Several authors have conducted laboratory studies to understand the different biomechanics aspects related to the performance of unassisted sitting pivot transfers (A. Koontz et al., 2012; Nyland et al., 2000). Gagnon et al. (2008) monitored kinematics of trunk and both upper limbs during wheelchair transfers of 10 males with thoracic SCI. Subjects were asked to perform three transfers in three different conditions: level seat, higher seat (10cm difference) and lower seat (10cm difference). Results showed the leading shoulder being subjected to extension and adduction during initial transfer phases while, due to the person pushing himself away from the starting surface, the trailing shoulder is flexed and progressively abducted. This opposite movement pattern was also observed at the elbow where the leading arm showed rapid elbow flexion towards the end of the lift while the trailing elbow extends indicating the different pushing and pulling roles of trailing and leading upper limbs during transfers. The high velocity of trunk flexion seems to suggest its importance in generating momentum that facilitates transfer. However, the trunk's displacement velocity was not affected by the height difference between the two surfaces. On the other hand, increased joint magnitude and velocity were observed for shoulder and elbow of both leading and trailing arm when the participant was asked to transfer to a higher seat. Regardless of the height of the target seat high values of wrist extension, exceeding the normal active Range of Movement (RoM) were observed for both upper limbs.

Figure 2-3 Sequence of movements used to perform an unassisted sitting pivot transfer

The effect of three different sitting transfer techniques on the kinematics of the upper limbs (Head-Hip method with leading hand close, Head-Hip method with leading hand far and Trunk Upright) for 20 individuals with SCI were investigated by Kankipati, Boninger, Gagnon, Cooper, & Koontz (2015). Positioning the leading hand further away decreased the ability of the leading arm to pull effectively, destroying the synergy between leading and trailing arm described above. This resulted in increased load on both upper limbs. As expected, the absence of trunk flexion was also found to increase the load on the upper limbs. Consequentially the Head-Hip method with leading hand placed closer to the body was found to be more efficient when performing wheelchair transfers.

Rather than focusing on the kinetics and kinematics of trunk and upper limbs, both Forslund, Granström, Levi, Westgren, & Hirschfeld (2007) and Gagnon, Nadeau, Noreau, Dehail, & Gravel (2008) focused instead on the ground reaction forces (GRFs) generated underneath the person's hands, buttocks and feet when performing unassisted sitting wheelchair transfers. The GRF is the force exerted by the ground on a body in contact with it, and can be used to estimate the load sustained by the joints of the body. Forslund et al. (2007) reported significantly higher vertical GRF underneath the trailing hand, around 32% of the individual's body weight (BW) for men and 27% BW for women, compared to the leading hand 24.5% BW for men and 23% BW for women, during level transfers. When the GRF is examined during the lift phase only, between seat-off and landing, the leading hand exhibited higher GRF 31.9% BW compared to the trailing hand 29.4% BW. However, transferring to a 10cm higher seat resulted in an inverse relationship with GRF of 34.1% BW under the trailing hand and 30.3% BW under the leading hand (Gagnon, Nadeau, Noreau, Dehail, et al., 2008). Both studies described similar GRF patterns underneath participants' hands during the transfer, with the trailing hand exhibiting the peak around seat off, followed by a progressive decrease during lift phase. In contrast, the leading hand showed an increasing trend from seat off with the GRF peak occurring shortly before landing (Forslund et al., 2007; Gagnon, Nadeau, Noreau, Dehail, et al., 2008). Although all 12 recruited participants had a thoracic SCI, (Gagnon, Nadeau, Noreau, Dehail, et al., 2008) described mean GRF of 22.9% underneath the feet during level transfers. This suggest that, despite the person's inability to bear weight on their lower limbs, correct positioning of the feet still plays an important role during wheelchair transfers.

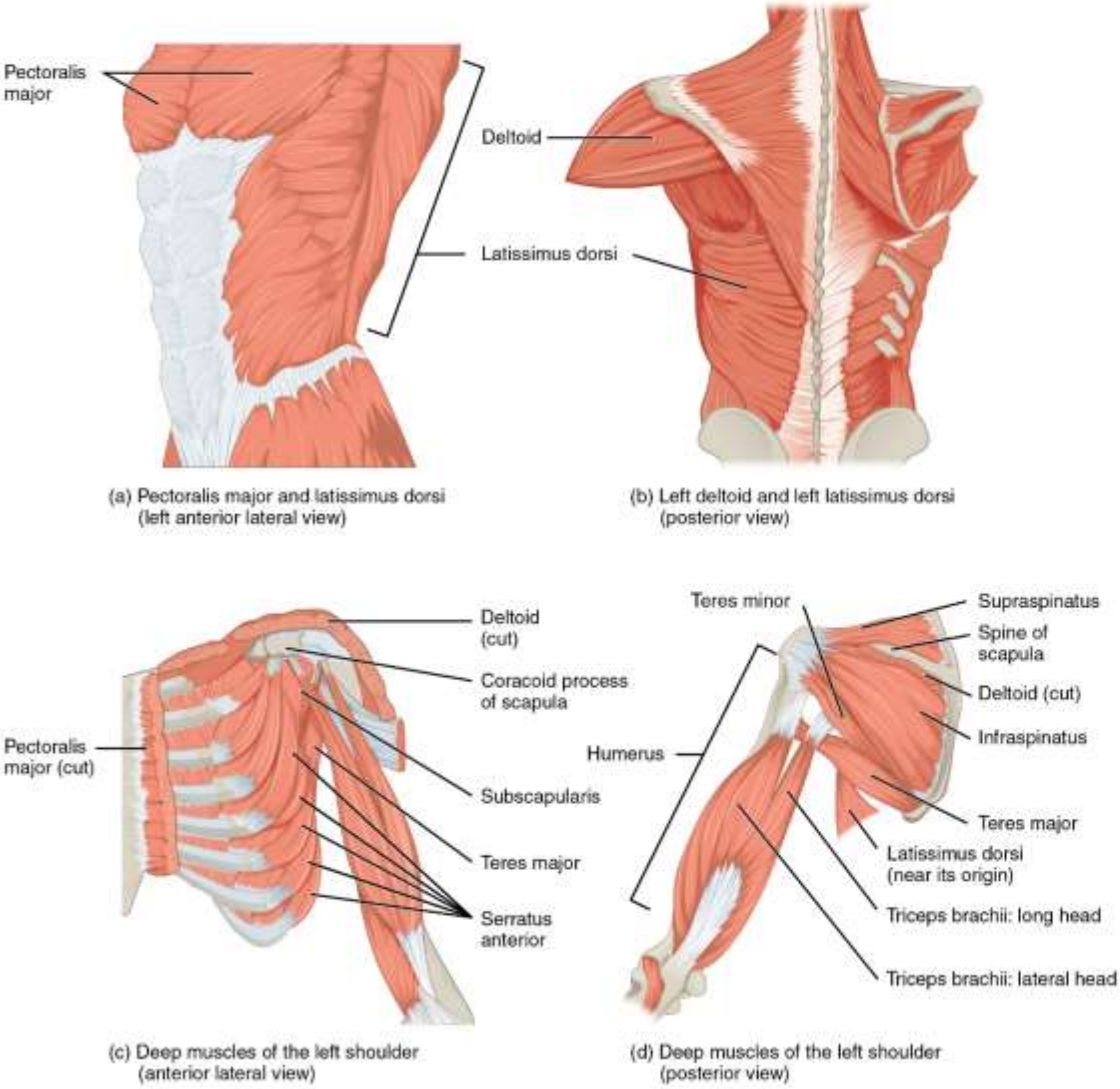

Figure 2-4 Series of diagrams illustrating the muscles of the shoulder. Image by OpenStax, distributed under a CC-BY 2.0 license.

Finally, studies were also carried out to monitor the activity of shoulder muscles during the performance of unassisted sitting wheelchair transfers (Gagnon, Nadeau, Noreau, Eng, & Gravel, 2009; Perry et al., 1996; Wang, Kim, Ford, & Ford, 1994). Figure 2-4 shows a series of illustrations showing both anterior and posterior view of the major deep and superficial muscles of the shoulder. The timing of peak electromyographic (EMG) activity for leading and trailing arms were shown to be similar to the pattern of GRF, with peak activation patterns around seat-off for the trailing arm and towards the end of the lift for the leading arm (Gagnon, Nadeau, et al., 2009). Perry et al., (1996) recorded moderate to high intensity activation of the pectoralis major throughout the whole duration of the transfer. The latissimus dorsi, the other muscle responsible for the trunk elevation that allows the subject to lift him/herself during transfers, was significantly lower due to the forward position of the trunk. Moderate activity from the rotator cuff muscles was observed during the transfer in order to stabilize both shoulders during the transfer and it was particularly intense during lift for the trailing arm (Perry et al., 1996). Greater force was required from the frontal shoulder muscles when transfers were performed towards a higher seat, while transferring to a lower seat seemed to shift the muscular demands towards the posterior deltoid and the triceps muscles (Gagnon, Nadeau, et al., 2009; Wang et al., 1994). Finally, level transfers were found to be generally less demanding for both upper extremities (Wang et al., 1994).

Despite the number of studies investigating kinematics, kinetics and EMG aspects of unassisted wheelchair transfers, the insights they provide have limited generalisability to real-world settings. Studies performed in biomechanics laboratories often feature highly structured experimental protocols and constrain the positioning of the wheelchair, and the placement of hands and feet to selected area due to the need for obtaining a “clear reading” from force sensing equipment or to keep retroreflective markers visible during movement. However, in reality, wheelchair transfers are performed in a great variety of different environments that could have a great effect on the movement strategies adopted by the individual (Crytzer, Cooper, Jerome, & Koontz, 2015). Recently, researchers observed movement strategies of both paraplegic (Haubert et al., 2015) and tetraplegic (Kataoka et al., 2012) participants during car transfers. A great variability of leg and hand positioning was reported by both studies, which would likely result in changes of muscular activity and force generation (Haubert et al., 2015; Kataoka et al., 2012).

2.3.2 Unassisted standing pivot transfers

To perform an unassisted standing pivot transfer, once the wheelchair is positioned close to the target surface, the person will scoot towards the front of the chair. Most users will then lean forward with the trunk while simultaneously pushing down on the wheelchair wheels (or armrest) to get up. Once standing, the person will take a few steps to pivot in the desired direction. Even if able to stand unsupported, users generally use their hands to hold onto nearby supports to increase their balance. To safely sit down on the target surface, the person generally must bend his/her knees while flexing the trunk slightly forward. Often, one or both hands will be placed on the target surface or on nearby supports to help control the descent. Movement strategies for sit to stand and stand to sit movements are also described in Kerr, White, Barr, & Mollan (1997) and standing pivot transfer technique is illustrated by Kirby et al. (2015). The sequence of movements for an unassisted standing transfer is shown in Figure 2-5.

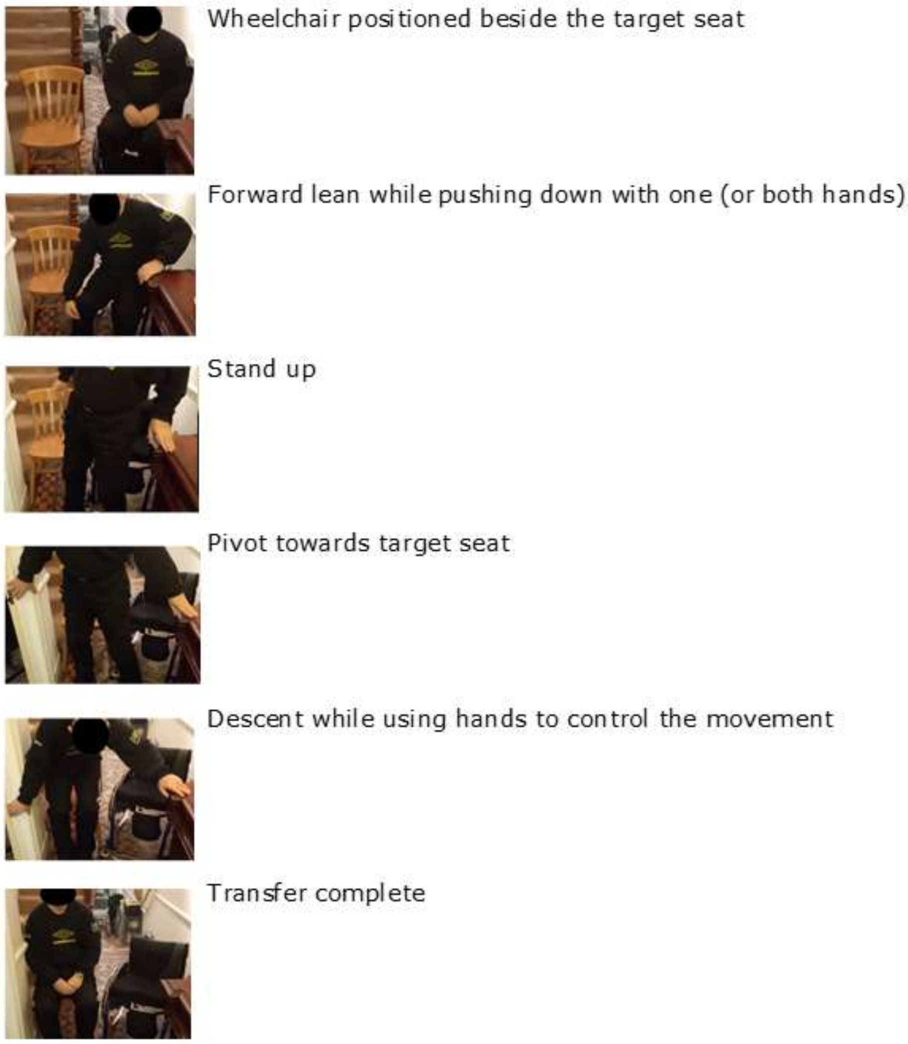

Figure 2-5 Sequence of movements used to perform an unassisted standing transfer

In comparison to sitting pivot transfer there is far less research that looks specifically at the biomechanics of unassisted standing wheelchair transfers. However, several authors have investigated the biomechanics aspects of sit to stand movements (Doorenbosch, Harlaar, Roebroeck, & Lankhorst, 1994; W. G. M. Janssen, Bussmann, & Stam, 2002; Kamnik, Bajd, & Kralj, 1999) and stand to sit movements (Anglin & Wyss, 2000; Faria, Saliba, & Teixeira-Salmela, 2010; Kerr et al., 1997). Nonetheless, it should be noted that most of these studies are focused on elderly people and not on wheelchair users.

Due to their greater impact on the sit-stand-sit cycle, most researchers focused their effort on measuring the biomechanics of the lower limbs, rather than the upper limbs. When the person initiates the sit to stand movement, kinematic data show a progressive bilateral hip flexion (from 80° to 120°) that lasts until seat-off (Mak, Levin, Mizrahi, & Hui-Chan, 2003). This is due to the trunk's lean used to shift forward the centre of mass

(Roebroeck, Doorenbosch, Harlaar, Jacobs, & Lankhorst, 1994). During the rising phase both hips and knees progressively extend until the person reaches a full standing position (Mak et al., 2003). Analysis of the GRF underneath the feet shows a posteriorly directed force during preparation, as the person's centre of mass moves forward, while seat off was characterized by a sharp change of direction where the antero-posterior GRF becomes positive and the vertical component suddenly increases (Mak et al., 2003). Figure 2-6 shows a diagram illustrating the principal muscular groups of the lower limb categorised by function. Moderate muscular activity was observed during sit to stand for the hip extensors while knee extensor were found to be the most active reaching over 80% of their maximal activity level (Roebroeck et al., 1994). As illustrated by Janssen et al. (2002) and Doorenbosch et al. (1994) technique and environmental factors can both greatly affect the biomechanics of sit-to-stand movements. Increased trunk flexion increased both hip and ankle moments while reducing the extension moment at the knee and, as a consequence, reducing the activation of knee extensors but increasing the muscular demand on hip extensors and ankle plantar flexors (Doorenbosch et al., 1994). On the other hand, other compensation mechanisms such as posterior feet positioning, greater seat height and use of the armrests were found to be more effective, resulting in decreased extension moments at both hips and knees (Janssen et al., 2002).

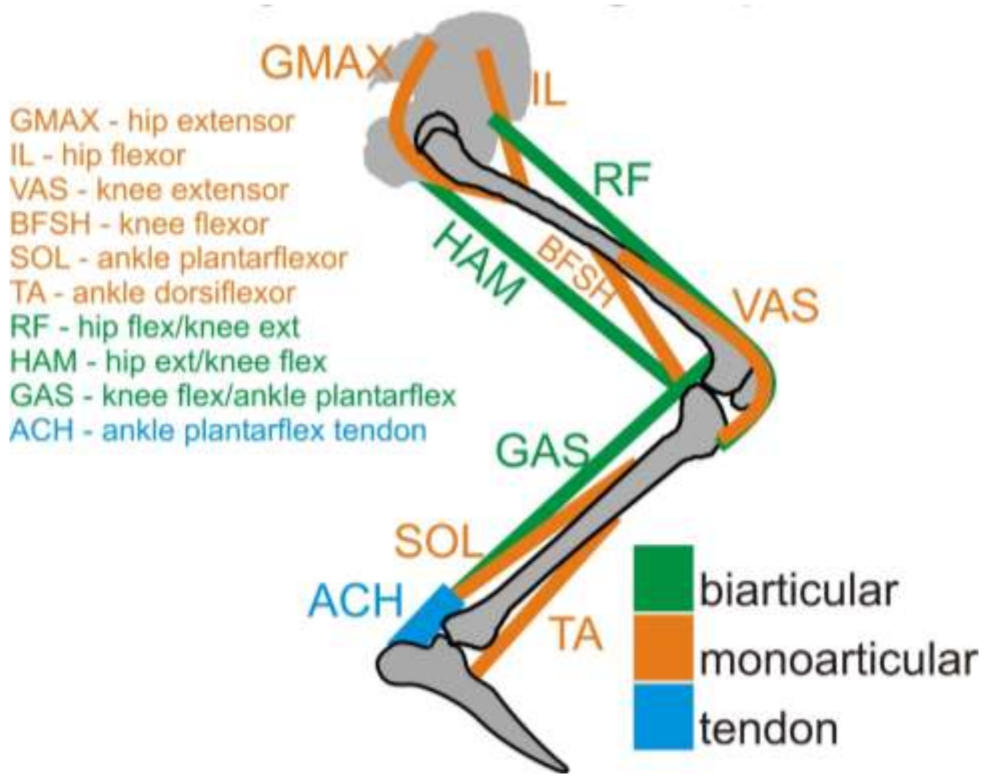

Figure 2-6 Major muscular groups of the lower limb. Image by Danjo Paluska, distributed under a CC-BY 2.0 license.

The descent phase during stand to sit is also initiated by a forward lean of the trunk, which is both slower and less pronounced than the one observed during rising (Kerr et al., 1997). Lower limb kinematics is similar, if opposite in sequence, to the one observed during sit to stand with progressive hip, knee and ankle flexion while the subject lowers him/herself onto the seat (Kerr et al., 1997). Furthermore, EMG analysis of the lower limbs for 10 young healthy participants showed similar activation patterns for several muscles during standing up and sitting down (Kerr et al., 1997). However, the functional implications of bi-articular muscle activation is often opposite in nature, with the biceps femori acting as a hip extensor during sit to stand and as a knee flexor during stand-to-sit. Similarly, the rectus femori main function during raising phase is to extend the knee, while its eccentric activation during sitting down helps control the person's descent. Despite the similarities between these two actions, Mourey, Pozzo, Rouhier-Marcer, & Didier (1998) found that sitting down onto a chair required significantly longer time than standing up and it was characterised by a sharp decrease in knee flexion velocity as the subject approaches the seat.

Although the contribution of the upper limbs during the sit-stand-sit cycle is rarely investigated, the load withstood by them can be demanding. Average GRFs measured underneath the hands of a person using chair armrests during sit to stand and stand to sit reached, respectively 19% and 16% of the individual's BW with the hands positioned approximately in line with the shoulder (Anglin & Wyss, 2000). However, the load on the upper limbs is considerably higher when the person is unable to fully support their own body weight during sit to stand reaching 85%BW for paraplegic individuals (Bahrami, Riener, Jabedar-Maralani, & Schmidt, 2000; Kamnik et al., 1999). As shown by Bahrami, Riener, Jabedar-Maralani, & Schmidt (2000), a strong contribution from the upper limbs has significant effect and can reduce the hip and knee torque up to 50%.

2.3.3 Transfer board transfers

In many respects, transfer board sitting transfers are very similar to unassisted sitting transfers. Once the person places the wheelchair in the desired position, they lean laterally away from the target surface in order to slide the board underneath the opposite buttock. Only when the transfer board is securely placed, the person positions leading and trailing hands respectively on the target surface and the wheelchair. The technique for the transfer itself is then comparable to the one illustrated for unassisted sitting transfers. The only difference is that, when a person transfers using a transfer board, they don't move across the whole board in a single fluid motion, but they move across bit by bit until they reach the target surface. A similar description of the technique used for transfer board transfers can be found in Kirby et al. (2015). The sequence of movements for a transfer board transfer is shown in Figure 2-7.

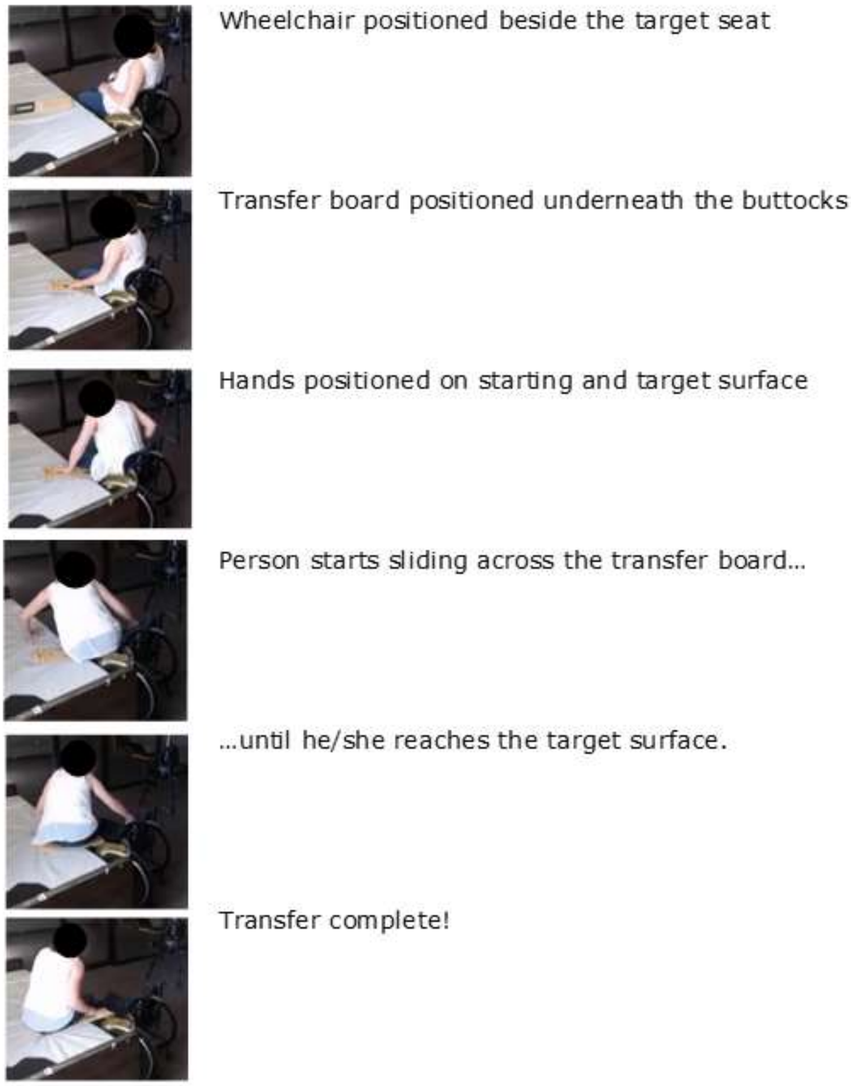

Figure 2-7 Sequence of movements used to perform a transfer board transfer

Although the use of transfer boards is commonly reported as a way to facilitate transfer performance for individuals with reduced upper limb strength (Koontz et al., 2012), no study investigates the impact of transfer boards on the biomechanics of wheelchair transfers. The use of transfer boards is often recommended by clinicians to reduce the muscular demand on the upper limbs during transfers and allow the transfer to be broken into a series of smaller movements, which are potentially less injurious than the ones required when performing unassisted sitting transfers (Boninger et al., 2005). However, their efficacy on reducing muscular demands has only been tested for assisted wheelchair transfers and involving able bodied participants during testing (Butler, Sabelman, & Kiratli, 2000; Grevelding & Bohannon, 2001), considerably weakening the reliability of such recommendations.

2.4 Wheelchair use and upper limb pain and injury

2.4.1 The problem of upper limb pain among wheelchair users

The integrity of the upper limbs is of crucial importance for wheelchair users, and particularly manual wheelchair users (MWU), as they will rely on their upper limbs for most of the ADLs (Pentland & Twomey, 1994). Thus, the presence of upper limb pain and injuries can pose severe threats to their functional independence and significantly decrease their quality of life (Ballinger, Rintala, & Hart, 2000). Several studies have documented the high prevalence of upper limb pain and injury among manual wheelchair users, with shoulder and wrist being the most affected joints (Dalyan, Cardenas, & Gerard, 1999; Jensen, Hoffman, & Cardenas, 2005; Sie, Waters, Adkins, & Gellman, 1992; Subbarao, Klopfstein, & Turpin, 1995).

Wrist discomfort is reported in between 49% to 74% of the total MWU population (Ballinger et al., 2000). Researchers generally agree Carpal Tunnel Syndrome (CTS) is the major cause of pain and discomfort at the hand and wrist and rates of reported symptoms drop to 11-13% when CTS is not considered (Boninger, Cooper, Robertson, & Rudy, 1997). In ergonomic literature incidence of CTS has been related to high forces and high repetition tasks (Silverstein, Fine, & Armstrong, 1987). Mechanical load due to high force activities can result in ischemic traumas due to the elevated intra–articular pressure and thickening of the synovial lining associated with repetitive movements. These can all result in compression and damage to the medial nerve, particularly when associated with a large RoM or extreme joint positions (Werner & Andary, 2002).

The range of reported shoulder pain is much wider than that of the wrist, with prevalence varying from 37% to 80% (Curtis et al., 1999; McCasland, Budiman-Mak, Weaver, Adams, & Miskevics, 2006; Samuelsson, Tropp, & Gerdle, 2004). Although injury classification appears more complex and not as well defined as for the wrist, researchers generally agree the combination of high load and frequent repetition of various wheelchair activities is a primary contributor to the development of shoulder injury (Bayley, Cochran, & Sledge, 1987; M. L. Boninger, Cooper, Robertson, & Shimada, 1997; Finley & Rodgers, 2004; van Drongelen, van der Woude, & Veeger, 2011). A representative etiological analysis of shoulder injury specific for MWU has been proposed by Lee & McMahon (2002). They stated that the increased load on the shoulder, brought about by wheelchair activities, leads to muscular imbalance and abnormal glenohumeral and scapular kinematics. This will consequentially cause shoulder instability and reduction of the sub-acromial space, resulting in impingement syndrome. Mechanical compression will result in both rotator cuff tears and degenerative joint disease. According to Lee & McMahon (2002), once primary conditions related to the anatomical conformation of the acromion are excluded, all the other injury mechanisms can be caused by the excessive demand placed on the shoulder complex due to wheelchair activities (Lee & McMahon, 2002). A representation of the structures of the shoulder joint is shown in Figure 2-8.

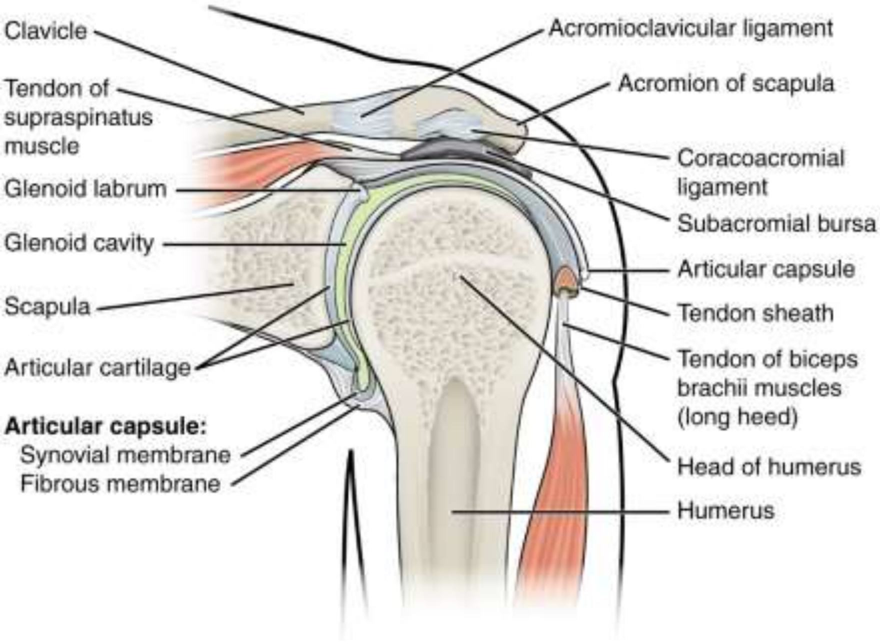

Figure 2-8 Musculoskeletal structure of the shoulder joint. Image by OpenStax College, distributed under a CC-BY 2.0 license.

2.4.2 Upper limb pain and wheelchair propulsion

Most researchers interested in upper limb pain and injury have focussed their attention on the relationship between manual wheelchair propulsion, shoulder injury and median nerve function using different medical imaging techniques or nerve conduction analysis (Boninger et al., 2003; Boninger, Impink, Cooper, & Koontz, 2004; Collinger, Impink, Ozawa, & Boninger, 2010; Gil-Agudo et al., 2014; Mercer et al., 2006). Results from Boninger et al. (2004) suggest the presence of a relationship between stroke frequency, resultant force, median and ulnar motor amplitude (potentially indicating decreased nerve health). However, the authors were unable to establish a causal relationship or evaluating the impact of propulsion alone on nerve conduction.

Findings from shoulder studies were also unable to present a definitive conclusion. No significant correlation was found between mechanical loading during wheelchair propulsion and the appearance of the supraspinatus tendon under Ultrasound (US)

(Collinger et al., 2010; Gil-Agudo et al., 2014). However, higher pushrim resultant forces, stroke frequency, increased medial and inferior shoulder forces were significantly related to US abnormalities of the long biceps tendon (Collinger et al., 2010; Gil-Agudo et al., 2014). Mercer et al. (2006) were able to highlight some specific correlations between shoulder biomechanics and shoulder pathology. Coracoacromial ligament oedema was linked to increased posterior forces, lateral forces and extension moments; while people experiencing higher lateral forces and abduction moment were more likely to have signs of coracoacromial ligament thickening. Subjects generating greater internal rotation moment and superior forces were more likely to exhibit signs of shoulder pathology during physical examination (Mercer et al., 2006). However, due to their cross-sectional design, none of the studies was able to establish a causal relationship. No link between shoulder injury and wheelchair propulsion were found by the only longitudinal study, carried out by Boninger, Cooper, et al. (2004) examining the relationship between pushrim kinetics and Magnetic Resonance Imaging (MRI) shoulder abnormalities in a two year period.

2.4.3 Upper limb pain and wheelchair transfers

More recently, researchers have started to investigate the link between the development of upper limb injuries and the performance of independent sitting wheelchair transfers and results suggest the presence of a strong relationship (Hogaboom, Huang, Worobey, Koontz, & Boninger, 2016; Hogaboom, Worobey, et al., 2016, 2016; Hogaboom, Fullerton, Rice, Oyster, & Boninger, 2013). Studies from Dalyan et al. (1999) and Samuelsson et al. (2004) reported that presence and the intensity of upper limb pain interfered with the performance of wheelchair transfers for respectively 74% and 62% of the respondents. Additionally, Alm, Saraste, & Norrbrink (2008) have classified wheelchair transfers, particularly transferring into and out of a car, as one of the items on the Wheelchair Users Shoulder Pain Index (WUSPI) where people reported the highest intensity of pain. This is not surprising as the performance of wheelchair transfers is associated with the generation of joint forces that are much higher than the ones normally measured during wheelchair propulsion (Gagnon, Nadeau, Noreau, Dehail, et al., 2008; C. S. Holloway et al., 2015). Transferring also requires important muscular effort and can cause the shoulder to assume positions that can lead to the development of impingement syndrome (Nawoczenski et al., 2003).

A recent study by Hogaboom, Worobey, et al. (2016) has demonstrated a link between the techniques adopted during the performance of wheelchair transfers and signs of shoulder pathology. Although the causal direction of this relationship has not yet been explored, the authors hypothesize that improving the wheelchair transfers' technique might delay the onset of shoulder degeneration. Furthermore, repeated transfers were shown to lead to increased biceps tendon thickness (Hogaboom, Huang, et al., 2016). Although supraspinatus' tendon appearance was not acutely affected by the performance of repeated wheelchair transfers, subjects that transferred positioning their hands correctly on both surfaces exhibited better baseline US score for both biceps and supraspinatus tendons (Hogaboom, Huang, et al., 2016). Additionally, repeated wheelchair transfers also caused an increase in the cross sectional area of the median nerve at the pisiform level (Hogaboom, Diehl, et al., 2016). Again, correct hands positioning was also shown to lead to decrease the swelling ratio of the median nerve indicating a lower risk of compression potentially leading to CTS.

As expected, due to the weight bearing nature of wheelchair transfers, both the above mentioned studies reported increased tendon damage after repeated transfers for subjects of greater body weight (Hogaboom, Diehl, et al., 2016; Hogaboom, Huang, et al., 2016). The negative effects on the median nerve related to the increased body weight were somehow mitigated by a better transferring technique (Hogaboom, Diehl, et al., 2016). However, the same was not true for what concerned the shoulder tendons (Hogaboom, Huang, et al., 2016). On the other hand, an intervention study by Tsai et al. (2016) reported that improvements in transferring technique resulted in decreased shoulder and wrist forces alongside reduced elbow RoM. This suggests that, although improving the unassisted sitting transferring technique might offer some benefits in reducing the load associated with wheelchair transfers, it still might not be sufficient in order to effectively prevent upper limb pain and injury.

Despite the positive results of the existing body of knowledge pointing towards an increasingly strong link between the performance of unassisted sitting transfers and the development of upper limb pain and injuries, there are still some major gaps that need to be addressed. Firstly, all the studies we found presented a cross-sectional design that allows the researchers to identify the presence of a relationship, but prevents them from drawing any conclusion on its causal direction. Secondly, all published studies focus solely on the performance of unassisted sitting transfer. Although we hypothesised reduced upper limb demand for standing and transfer board transfers compared to unassisted sitting transfers, the associated load might still cause joint damage over time. Thirdly, studies from both Hogaboom, Diehl, et al. (2016) and Hogaboom, Huang, et al. (2016) featured highly controlled experimental designs with a high number of transfers in a short period of time. Repeated transfers allow researchers to observe acute changes, and controlled settings facilitate internal consistency and repeatability of the results. However, they offer a poor representation of real world circumstances where transfers are performed less frequently and across different environments. Finally, the majority of the subjects involved in all the examined studies had SCI. Individuals with SCI have specific motor impairments depending on their level of injury and only represent a portion of the wheelchair user population and this makes the generalisation of results difficult (Fitzgerald et al., 2007).

2.5 Wheelchair transfers and the risk of falling

The long-term risk of potentially developing upper limb injuries is not the only hazard connected to the performance of independent wheelchair transfers. Concerns about falls that might occur while a person is transferring in and out of his/her wheelchair are extremely relevant for both users and clinicians (Nyland et al., 2000). Falling while performing a transfer can not only result in a serious injury but also decreases the individual's level of confidence which, in turn, can have a negative effect on transferring ability (Akhigbe et al., 2015; Jørstad, Hauer, Becker, Lamb, & on behalf of the ProFaNE Group, 2005).

Several reports have looked at the incidence of falls among wheelchair users and the strength of the relationship between the occurrence of falls and the performance of independent wheelchair transfers varied greatly depending on the population included, the setting and the source of the analysed dataset (Forslund et al., 2017; Nelson et al., 2010; Opalek, Graymire, & Redd, 2009; Ummat & Kirby, 1994).

Ummat & Kirby, (1994) looked at 2066 cases of non-fatal wheelchair accidents reported between 1986 and 1990 (inclusive) to the National Electronic Injury Surveillance System. Data were collected from over 60 emergency departments across the USA. Transfers were found to be one of the most common causes of falls and accounted for 16.9% of the reported accidents. Of the 350 reported falls, 50.3% were generally reported as falls occurring when transferring from the wheelchair (28.0%) or to the wheelchair (22.3%). The remaining cases were categorized for type of transfers with falls occurring more frequently for bed (24.9%) and toilet (13.7%) transfers rather than chair (4.0%) and car transfers (3.4%). Although these findings offer some interesting insights on the occurrence of transfers related falls, caution needs to be applied in the generalization of the results. Due to the nature of this dataset, only falls that resulted in a visit to the emergency department were included in the study. Furthermore, no information on individuals' transferring technique was included in the data making it impossible to categorise falls occurring during independent, assisted or dependent transfers (Ummat & Kirby, 1994).

Similarly, Opalek et al. (2009) examined 30 cases of wheelchair falls that resulted in admission to the Columbus, Ohio trauma centre between 2003 and 2007. Falls during transfers were indicated only for 3 cases. However, for 60% of the patients, falls were simply described as “falls from the wheelchair” with no indication of the specific cause. Even for this study, only falls that resulted in hospital treatment were considered. Additionally, over 33% of the included cases referred to falls that occurred in residential institutions where patients are often unable to transfer independently.

Nelson et al. (2010) and Forslund et al. (2017) collected self-reported falls occurrences from a group of respectively 702 and 149 community-dwelling wheelchair users with SCI over a one year period. Although both studies had similar inclusion criteria, findings from questionnaires and interviews are substantially different. Only 31% of participants in Nelson et al. (2010) reported at least one fall throughout the 1 year period. However, 64% of the included population in the study carried out by Forslund et al. (2017) experienced at least one fall, and for 32% falls were found to be recurrent with more than two occurrences in the year.   Over 34% of the falls reported in the study by Forslund et al. (2017) occurred during wheelchair transfers, making the transfers the most common activity related to wheelchair falls. Fifty-five falls were reported for bed/sofa/chair transfers, 27 for car transfers and 23 for toilet/commode transfers. Unfortunately, Nelson et al. (2010) did not report circumstances of wheelchair falls making it impossible to compare data on transfer related falls between these two studies.

In a systematic literature review on the risk factors, outcome measures and interventions associated with wheelchair falls conducted by Rice, Ousley, & Sosnoff (2015) wheelchair transfers were identified as one of the main risk factors for falls. Despite this, of the 21 studies included, only 2 evaluated outcome measures aimed at assessing the risk of falling while transferring to and from the wheelchair. The first study by Gagnon, Duclos, Desjardins, Nadeau, & Danakas (2012) measured the required stabilizing force to maintain the centre of pressure within the base of support during independent sitting transfers. Transition phases, seat-off and landing, were identified as the most unstable phases of sitting wheelchair transfers and required considerably higher stabilizing forces compared to all other transfer phases. Despite the importance of their results, the method proposed by Gagnon et al. (2012) requires sophisticated equipment and complex calculation, which makes it unsuitable for “out of the lab” studies. Additionally, their dynamic equilibrium model is only applicable to unassisted sitting transfers. On the other hand, McClure et al. (2011) developed a clinical tool called Transfer Assessment Instrument (TAI), successively refined by Tsai et al. (2013), aimed at evaluating the overall quality of wheelchair transfers performed independently or with assistance and using different transferring techniques. The TAI provides an instrument able to assess quality of different aspects of wheelchair transfers and give insights on the safety of the technique adopted by the person. None of the studies included in the review evaluated the effect of targeted interventions to reduce fall risk during transfers (Rice et al., 2015).

2.6 Chapter summary

The research presented in this chapter shows the importance of preserving transfer independence among wheelchair users. Transferring is a key to the autonomy during many ADLs which are essential to the person's wellbeing in everyday life. Depending on their physical capabilities, their preferences and the surrounding environment people will perform independent wheelchair transfers using one of three techniques: sitting, standing or with a transfer board. As expected, sitting wheelchair transfers pose greater demands on the person's upper limbs with GRF around 30%BW for the trailing hand and 25%BW for the leading hand. In spite of the importance of lower limbs muscles during standing transfers, GRF under the hands during sit-to-stand were found to be on average 19%BW and could significantly increase as the strength in the lower limbs decreases.

The overview of biomechanics studies presented in relation to each transferring technique already identifies gaps in the literature around wheelchair transfers. Several studies have explored the kinematics, kinetics and electromyographic aspects of unassisted wheelchair transfers performed in standard laboratory settings. However, these studies seem to offer a poor representation of wheelchair transfers performed in real-world settings as shown by Haubert et al. (2015). Despite the high number of partially ambulatory wheelchair users, we found no specific studies that focussed on the biomechanics of standing wheelchair transfers. Finally, although the use of transfer boards is recommended by clinical practice guidelines in order to reduce the amount of force needed to perform a wheelchair transfer (Boninger et al., 2005), no study investigated the biomechanics of transfer board transfers.

Next I examined the link between the performance of independent wheelchair transfers, the development of upper limbs injuries and the occurrence of falls. As expected, the high mechanical load associated with wheelchair transfers was found to be potentially damaging to both the median nerve at the wrist (Hogaboom, Diehl, et al., 2016) and the long head of the biceps tendon at the shoulder (Hogaboom, Huang, et al., 2016). Better transfer technique was also found to be associated with reduced pain and signs of shoulder pathology among individuals with SCI (Hogaboom, Worobey, et al., 2016). Wheelchair transfers were also found to be one of the most common activities associated with the occurrence of wheelchair related falls. Although no outcome measure specifically aimed at evaluating the risk of falling during wheelchair transfers was found, the TAI developed by Tsai et al. (2013) offers the opportunity to evaluate the quality of wheelchair transfers in a standardized manner regardless of the individual's technique and the level of assistance required to complete a transfer.

Gaps similar to the ones identified in the literature related to the biomechanics of wheelchair transfers were identified for studies investigating the risk of upper limb injury and pain in relation to wheelchair transfer performance. Although unassisted sitting transfers are likely to be more burdensome for the upper limbs joints, standing transfers can still pose significant demands that could facilitate the development of shoulder and wrist injuries. Furthermore, the potential efficacy of transfer boards to reduce the load on the upper limbs and help prevent or delay the development of injuries and/or painful symptoms should be evaluated.

Instead, studies focusing on the occurrence of falls during wheelchair transfers are generally more inclusive. However, they often lack the specificity that would make some of their insights more valuable from a practical perspective. Although some researchers reported the number of falls in relation to the different types of transfers (bed, car, toilet…), none of the studies stratified the number of reported falls according to the person's transferring technique or the need of assistance during the transfer itself. Without these additional insights it is impossible to identify risk factors that might be specific to one particular transferring technique or that might be only related to transfers performed with the assistance of an untrained carer.

Independent wheelchair transfers are both important and difficult for many wheelchair users and are associated to risk factors that might have a negative impact on the capabilities of the individual. New ATs might facilitate the performance of wheelchair transfers, improve safety and help reduce the mechanical load sustained by the upper limbs.

In the next chapter I will discuss the overall benefit of ATs, issues related with AT non-use and abandonment and examine different AT adoption models in order to understand what factors should be taken into consideration when designing AT for wheelchair transfers.

Chapter 3 Assistive Technologies: Understanding Adoption and Abandonment

The previous chapter illustrated the importance of transfers in the context of wheelchair users' everyday lives. It also explained how transfers can be challenging and expose users to the risk of falling and developing upper limb injuries that will hinder their independence and negatively affect their quality of life. The combination of both their importance to users and the difficulties associated with their performance makes wheelchair transfers ideal candidates for design efforts focused on the development of new ATs aimed at facilitating users, reducing the burden on the upper limbs and improving safety.

ATs are items, pieces of equipment or product system that aim to support and enhance the capabilities of disabled individuals in order to allow them to complete tasks independently and live more fulfilling lives. However, despite their incredible potential, many ATs are abandoned shortly after being prescribed (Phillips & Zhao, 1993). When ATs interventions fail, the result is not only abandoned devices and a waste of public or private funds. Discarded technologies also leave behind a discouraged user that often loses confidence in their abilities to live a more independent life (Bühler & Knops, 1999; Riemer-Reiss & Wacker, 2000). In this chapter I will explore the literature that focuses on estimating the size, impact and reasons behind the phenomena of AT non-use and abandonment.

When attempting to understand reasons for AT discontinuance, it is crucial to examine the complex, opposite phenomena of AT adoption. Over the years, several researchers in the field of ATs and beyond have formulated conceptual models to explain the complex interaction between the person and the assistive device. However, researchers have yet to agree on a dominant model of AT adoption (Lenker & Paquet, 2003). Although designing ATs that are new to all users or prescribing an existing AT to a new user are different activities, they will involve a complex evaluation of the user values, personal preferences and needs in relation to both the task that the AT aims to facilitate and the environment in which the task is carried out. In this chapter I will analyse different AT adoption models formulated over the years with the aim of identifying the main common factors that will determine the success, or failure, of new ATs.

3.1 The potential of assistive technology

Assistive technologies are defined by the Tech Act of 1988 United States Public Law (PL) 100–407 as "*any item, piece of equipment, or product system, whether acquired commercially off the shelf, modified, or customized, that is used to increase, maintain, or improve functional capabilities of individuals with disabilities*" (29 U.S.C. Sec 2202(2)). Despite their definition, ATs are not the only kind of technology that can support disabled people when carrying out everyday activities. Mainstream technologies such as contactless bank cards, mobile phones, elevators or Velcro straps were not originally designed to specifically target disabled users. However, their usefulness made them as essential as many ATs (Institute of Medicine (US) Committee on Disability in America, 2007). Regardless of the efforts of universal designers and product designers to incorporate the needs of the disabled population into mainstream products, ATs are still necessary, as nearly 50% of disabled people rely on them for important ADLs (Stumbo et al., 2009).

When an AT matches the needs of an individual, it will extend their capabilities and allow the person to complete tasks and participate in activities that can have a dramatic impact on his/her life. For example, a person with a severe impairment in hand dexterity might be able to effectively use a computer thanks to a speech recognition software. Furthermore, the effective use of the computer could enable the person to attend and complete a college degree. This in turn could lead to increased vocational choices and better chances of employment. Finally, if the person has a more satisfying and well-paid job he/she will be less likely to incur mental health issues and they would be more likely to be able to provide for him/herself without depending on government benefits. Although the increased independence achieved in a single task might not appear ground breaking when considered on its own, the implications of successful AT interventions can be huge and result in a positive impact that affects society as well as the individual (Stodden, Conway, & Whelley, 2002). Additionally, becoming proficient in the use of ATs rather than relying on somebody else's help can help disabled people feeling more competent and increase their self-confidence level (Verbrugge & Boynton, 2002).

On the other hand, the inability to acquire or use an AT that could help the person to become more independent will be likely to have a negative effect that goes beyond the immediate loss of opportunities. For example, when a wheelchair user is not provided with an appropriate pressure relief cushion the amount of time that he/she will be able to spend on the wheelchair and be active will be considerably reduced. This could lead to several secondary risks such as increased weight gain, reduced cardio-respiratory capacity and reduced mental health alongside the risks to develop pressure sores (Kirshblum, 2004).

Despite their potential, ATs are often unable to provide complete solutions to many problems that disabled people face. As highlighted by Hoenig, Taylor, & Sloan (2003), the use of ATs to carry out basic ADLs can effectively reduce the amount of help that the person needs on a regular basis. However, 77% of the elderly individuals who responded to the survey stated that they relied on a combination of both human and technological assistance for completing basics ADLs, and the rate increased to 83% among respondents with more severe impairments (Hoenig et al., 2003). This could indicate that, for more disabled individuals the increased capabilities resulting from the use of the AT are less likely to be sufficient for satisfying the demand posed by a specific task. Regardless of their limitations, ATs still represent one of the most important resources available to disabled people and have made important contributions in enhancing individual capabilities, providing a means for independence and offering opportunities for participation that might otherwise be impossible (Finlayson & Hammel, 2003).

3.2 Rejection and abandonment of assistive technology

When an AT correctly matches the needs of a disabled user and can significantly extend his/her capabilities the results can be life changing. Unfortunately, many users find themselves dissatisfied with their ATs causing them to discontinue their usage and ultimately abandon them. The non-use and abandonment of AT are common phenomena that can have negative repercussions at both individual and society level (Verza, Carvalho, Battaglia, & Uccelli, 2006). Over the years many researchers have carried out studies aimed at investigating both the size and the implication of AT non-use and abandonment (Stefano Federici & Borsci, 2011; Phillips & Zhao, 1993; Riemer-Reiss & Wacker, 1999, 2000; Wessels, Dijcks, Soede, Gelderblom, & De Witte, 2003).

The estimated rate of unused AT varies greatly depending on several factors and according to a study by Scherer (1996) can be as high as 75% for hearing aids or as low as 8% for life supporting aids. ATs for mobility are among the most frequently discontinued with abandonment rates ranging from 43% for quad canes to 36% for manual wheelchairs (Cushman & Scherer, 1996). A few selected studies present more conservative estimates with abandonment rates between 8% and 18% (S. Federici, Meloni, & Borsci, 2016; Kittel, Marco, & Stewart, 2002). However, most studies agree on an approximate abandonment rate of 30% across various kinds of ATs within a three-year period from procurement (Phillips & Zhao, 1993; Riemer-Reiss & Wacker, 2000; Verza et al., 2006).

It should be noted that estimating general abandonment rates of AT across multiple studies is extremely complicated and can produce misleading results (Wessels et al., 2003). Firstly, individual studies, might focus on the same category of AT (mobility aids, communication aids…) but they often include populations with different demographics and clinical characteristics. As the functional implications of various medical conditions are often unique, attempting to merge data from different studies could generate inaccurate results. Additionally, authors have conflicting opinion on the definitions of AT non-use and abandonment. For example, Phillips & Zhao (1993) rely on a dichotomous classification where the device is either in use or abandoned. On the other hand, Parker & Thorslund (1991) prefer to focus on the appropriateness rather than the frequency of use and categorise ATs as correctly used, incorrectly used or non-used. Scherer (1996) provides a more complex categorization where AT can be used full-time, part-time or completely non-used and this choice can be either voluntary or not. Similarly, Garber & Gregorio (1990) asked participants if they were using their ATs for all the activities they were originally prescribed for.

The abandonment of ATs is not always a negative or preventable phenomenon. Phillips & Zhao (1993) identifies changes in the needs of the user, as the strongest predictor of AT discontinuance. It should be noted that the definition provided in this study for "changes in user needs" is very broad, as it includes changes related to the improvement or worsening of the individual's medical condition. In contrast, Verza et al. (2006) reported that 36.4% of prescribed ATs were abandoned due to worsening of physical abilities among 54 patients with MS. Other factors that were found to favour non-use and abandonment of ATs were: poor device performance, poor consideration of user's needs during AT selection, insufficient relative advantage, lack of training, perception of stigma and incompatibility with personal needs (Kittel et al., 2002; Phillips & Zhao, 1993; Riemer-Reiss & Wacker, 2000; Verza et al., 2006; William C. Mann, Sara Goodall, Michael D. Justiss, & Machiko Tomita, 2002).

Unfortunately, in many cases the abandonment of ATs is only part of a much larger problem which is users' dissatisfaction with ATs. The study carried out by Mann et al (2002) shows that in many cases the rate of users who abandoned an AT was considerably lower than the rate of users who were unhappy about the same AT. For example, only 12.9% of the users who were prescribed a wheelchair stopped using them within a three-year period. On the other hand, 30% of wheelchair users reported being dissatisfied with their device. Unfortunately, most studies do not examine these two issues separately and the dissatisfaction with AT is mainly reported as a factor in AT abandonment (Phillips & Zhao, 1993; Riemer-Reiss & Wacker, 2000).

The reason for the discrepancy between the rate of dissatisfaction and rate of abandonment of AT can be explained using the social cognitive model formulated by Roelands et al. (2002). The model describes AT use as a result of the interaction between the intention to use the AT and the functional needs of the individual. If the capabilities of the individual are sufficiently high or if the user can rely on alternative measures to meet his/her functional needs, dissatisfaction will probably lead to the abandonment of the AT. On the other hand, if the user is otherwise unable to meet their functional need, they will likely keep using the AT regardless of their dissatisfaction.

Interestingly, the main factor that was found to be a predictor for both AT abandonment and dissatisfaction is the lack of user consultation during selection process (Kittel et al., 2002; Phillips & Zhao, 1993; Riemer-Reiss & Wacker, 2000). In an in-depth wheelchair study with 3 manual wheelchair users with SCI, participants reported that one of the main reasons for abandonment was related to the perception that the wheelchair had been selected by their therapists based on an assumptions of their requirements. This led to the prescription of a wheelchair that didn't really match their needs and resulted in feelings of disempowerment, so, as might be expected, the wheelchair was abandoned shortly afterwards (Kittel et al., 2002). Additionally, as they were first time wheelchair users, participants were uncertain about what their needs would be once they were discharged from the hospital. The lack of confidence in their own opinion hindered their ability to make an informed choice and take a stronger stand during the selection process (Kittel et al., 2002).Similar findings were shown in the survey of 145 AT users carried out by Martin et al (2011). Participants who reported that they felt confident about their ability to make an informed choice at the time of selection were more likely to be satisfied with the AT and, consequentially, less likely to discontinue their use of the AT in the future.

The abandonment of AT has several negative consequences. The most commonly reported and easily understood are the loss of opportunities for the individual and the waste of public and private money (Phillips & Zhao, 1993). Moreover, the AT selection process usually requires a considerable investment of time, money and effort from the user and other stakeholders and expectations on potential benefits are often high (King, 1999; Kintsch & DePaula, 2002). When a person decides to discard an assistive technology, he/she can become frustrated and end up blaming him/herself for the failure of that technology (Clare Hocking, 1999). Disappointment in the performance can lead to a feeling of helplessness and frustration, lowering the expectations and extending the negative judgement the users have towards the possibility of any AT at all to have a positive impact on their lives (Bühler & Knops, 1999; King, 1999).

3.3 The adoption of assistive technology

In order for an AT to provide any benefit to the disabled user, it has to be adopted and become an integral part of the user's everyday life. The adoption of ATs by the individual is a highly complex phenomenon involving several factors. In addition to any issue of usability, efficiency, learnability and memorability common to most mainstream devices, ATs have a fundamental link to the impairment affecting the individual and this results in the attribution of additional meaning, which can shape both self-perception and the perception of others (Pape, Kim, & Weiner, 2002). Various conceptual models have been formulated over the years to explain the elaborate interaction between the person and the assistive device. However, researchers have yet to agree on a dominant model (Bernd, Pijl, & Witte, 2009; Lenker & Paquet, 2003). In the following subsections I will provide an overview of the most significant models of AT adoption that have been formulated over the years and highlight the main elements, identified by each model, that influence the person's decision to adoption or reject an AT.

3.3.1 Rogers's theory of perceived attributes

One of the leading and most influential models of technology diffusion and adoption was the *Diffusion of Innovations* formulated by Rogers, in 1957 (Rogers, 2010). The first part of Rogers's framework focused on how technology spreads among people across five stages: knowledge, persuasion, decision (or rejection), implementation (or re-invention) and confirmation (or reversal). The final stage of the process is reached when the person decides to adopt the technology and uses it regularly in his/her everyday routine. In Roger's opinion, this decision is influenced by 5 separate factors that he defines as perceived attributes: relative advantage, compatibility, complexity, trialability and observability. Although Roger's Theory of Perceived Attributes was not specifically aimed at ATs, it is, nonetheless, applicable to them (Riemer-Reiss, 1999).

The concept of *relative advantage* is probably the most intuitive to understand. In order to increase the likelihood of adoption the technology has to offer some form of benefit for the task concerned. If the use of a device will make the task faster, more effortless or in any way "better" in the eyes of the user, the user will be more likely to use the device on a regular basis. However, the presence of relative advantage does not represent a sufficient condition for technology adoption. Many technologies are used in combination with each other and they have to properly "fit" in the user's life. Inventions that mesh well with the user's routine, strategies and beliefs are called *compatible* and they are more likely to be adopted in comparison to others that might clash with the user's practices or values. The *complexity* of a technology is referred not only to the difficulties that the person might encounter when attempting to use it, but also to the clarity of its value. A device might be simple to use and offer significant advantages, but, if we fail to convince the users that these advantages are important, the technology will most likely be ignored or discarded. Giving prospective users the possibility to experience the innovation before fully committing to it is also an effective way to increase adoption rates. This attribute is defined by Rogers as *trialability*. One of the most powerful factors that can increase the willingness of prospective users to adopt a new technology is *observability*. The more one person sees other people successfully using a technology, or hear about the positive impact that it has on the life of peers, the more he/she will be convinced of its value.

Overall, Rogers's theory of perceived attributes focuses mainly on the features of the technology itself, to the point at which it seems to de-individualise needs of users. Although the concept of the average user is usually successful for the design, diffusion and adoption of mainstream technologies, the same is not true for ATs targeting people with disabilities that might have highly specialized needs (Marcia J. Scherer, Sax, Vanbiervliet, Cushman, & Scherer, 2005). Additionally, the value of observability for the diffusion and adoption of ATs is often a controversial theme. ATs are often attributed an invisible link with the person's disability (Pape et al., 2002). Given the attractive look of an AT, some people might be willing to show it off in order to highlight certain tracts of their personality while others might prefer to hide it as they do not feel comfortable disclosing their disability status (Shinohara & Wobbrock, 2011). Regardless of its shortcomings, Rogers's theory highlights some important aspects for the process of ATs adoption.

3.3.2 Baker's Basic Ergonomic Equation

Baker's Basic Ergonomic Equation (BBEE) was originally formulated in relation to the use of alternative and augmented communication (AAC) devices in the form of the following equation (Baker, 1986):

$$Message\ Length \propto \frac{Task\ Motivation}{Time + Physical\ Effort + Cognitive\ Effort}$$

The equation states that the length of a message communicated by people using AAC could be considered as the ratio between the importance of the message for the user and the sum of time, physical and cognitive effort required to communicate the message. A revised version of Baker's equation which is applicable to a wider range of ATs was proposed few years later by King (1999). King, not only expanded the scope of BBEE to include all ATs, but also separated the cognitive effort from the linguistic one transforming the original equation to the following one:

$$P(usage) \propto \frac{Task\ Motivation}{Time + Physical\ Effort + Cognitive\ Effort + Linguistic\ Effort}$$

In King's equation, the dependent variable changes from the length of a message to the probability of use of a specific AT. However, the presence of the linguistic effort as one of the determinants of AT use highlights how the focus of the modified equation is still on the use of AAC devices rather than more general ATs. To this end, Deibel (2013) proposed a heuristic model for the adoption of ATs derived from BBEE and based on King's attempt of generalization. The resulting equation is:

$$P(usage|context) \propto \frac{Device\ Necessity\ (context) \times Task\ Motivation(context)}{\begin{array}{c} Time(context) + Physical\ Effort(context) + \\ Cognitive\ Effort\ (context) + Social\ Weight(context) \end{array}}$$

Firstly, in addition to the removal of the linguistic effort factor, Deibel introduces terms for the device necessity and the social weight of the AT. Secondly, in the current equation, the context in which the task is performed is of prime importance as it affects all the other elements in the equation.

Similarly to Rogers's theory, Deibel's heuristic model is still heavily focused on the characteristics of the AT itself. However, it also highlights the importance of the context, both physical and social, in which the activity takes place as it will have a great impact on the AT, the user and the activity itself.

3.3.3 The Human Activity Assistive Technology Model

The Human Activity Assistive Technology (HAAT) model (Cook & Polgar, 2014), is based on the WHO's International Classification of Functioning, Disability and Health (ICF) (World Health Organization, 2001). In the HAAT the focus is on the person performing an activity in a specific context. The AT is only an enabling agent and the measure of its success is given by the evaluation of the performance of an AT system composed by the person, the activity, the context and the AT. Although the 4 elements are presented separately, Cook & Polgar (2014) remind us that they are inherently connected and that only by understanding their mutual interactions we can hope to design and prescribe the correct AT for an individual. In addition to identifying the 4 relevant elements that affect the adoption of ATs, Cook & Polgar (2014) also provide us with recommendations on the order in which these factors need to be analysed to guarantee the best possible outcomes.

As ATs are usually designed to help people perform a specific task, the HAAT models starts the analysis from the activity component. Establishing the procedural order of the various actions that are performed to complete the task is only one of the aspects taken into consideration. In fact, Cook & Polgar (2014) highlight the importance of taking into account both the frequency and the meaning of the task. Progressively, important factors concerning the human are integrated in the model. Again it is important to remember that this evaluation has to be as comprehensive as possible. The capabilities and functional limitations are a crucial point of interest, but so are the expectations and the motives of the user. If carrying out a specific activity is particularly important in the eyes of the user he/she might be willing to accept an AT more easily and tolerate potential compromises that derive from the use of the AT itself. Afterwards, researchers are invited to look at the elements of the context that can affect both the user and the activity. As specified by Deibel (2013), the concept of context goes beyond its physical dimension and encompasses aspects of social, cultural and institutional nature. Finally, the AT is incorporated into the model and its effect and interaction with the other elements is analysed in order to understand their collective impact.

When compared with both Rogers (2010) and Deibel (2013), the HAAT model undertakes a more holistic approach. Although, all three models include elements concerning the activity, the context and the user, the order in which these factors are presented in the HAAT shifts the focus from the AT itself towards the interactions between the various factors. Several researchers have successfully applied the HAAT model to define the methods and interpret results of studies on the provision and evaluation of ATs (Giesbrecht, 2013).

Despite its numerous strengths, the HAAT model has not been immune to criticisms. Both Lenker & Paquet (2003) and Bernd et al. (2009) highlight the fact that, despite providing detailed explanations of the single components of the models and how they relate to each other, the HAAT fails to make clear how they impact the final decision of the user to adopt or reject an AT. A further complicating aspect is given by the confusion surrounding the concept of activity. In the HAAT the activity is defined as one of the four components of the AT system. However, the success or failure to perform an activity is also the parameter used to measure the outcome of the AT intervention. Finally, considering the complexity of the interaction between the user and the AT, the choice of an activity-centred outcome evaluation seems reductive if not misleading.

3.3.4 Kintsch and DePaula's Adoption Framework

The AT adoption framework developed by Kintsch & DePaula (2002) is composed of four iterative stages: development, selection, learning and integration. Additionally, they identify four key stakeholder groups that will play a major role across all stages of the process: users, caregivers, AT specialist and developers. One of the most valuable aspects of this framework is the detailed description of the contribution that each stakeholder group delivers at each phase. As expected, developers and AT specialist are considered to be most important during development and selection stages respectively as their expertise can make them the most valuable counsellors for the users and their families. More surprising is the fact that, throughout most of the framework the caregivers, rather than users, are given the leading role.

For example, during the selection phase, Kintsch & DePaula (2002) recommend a comprehensive consultation process that involves not only the users and their family, but also other caregivers, therapists, educators, employers and doctors. The goals considered during the assessment should not just be the ones of the user, but include the goals of family members and caregivers as they will play in important part in the following stages of learning and implementation. If this feature allows the framework to be still applicable to the adoption of AT for a wide range of disabilities, the over-privileged role of caregivers during the learning stage considerably restrict its scope. According to the framework, during learning stage the caregiver is supposed to learn how to use, customise and maintain the AT. Only once the caregivers themselves become comfortable using the device they will train the user on how to operate the AT. Similarly, during the integration phase the caregiver is described as the person responsible to "find the times and places" where the user can begin to use the AT in real life situations.

Overall, the main weakness of this framework is related to the lack of specificity about when it is appropriate for the caregiver to dominate the AT adoption process. There could be circumstances where the caregiver has to be main decision maker (e.g. where the user experienced a significant loss of cognitive competence). However, over-reliance on the caregiver is not good where it is not necessary. Due to these characteristics, this model appears to be appropriate only in describing AT adoption among users that have limited power to express their opinion and need constant and extensive support due to cognitive disabilities or young age. Regardless of its shortcomings, Kintsch and DePaula's framework brings to the reader's attention the importance of considering the potential impact of caregivers on the adoption of AT, an element that is often overlooked by other models.

3.3.5 Gitlin's Career Model

The needs of disabled people are rarely unaltered over long periods of time, and the journey of first time AT users is often shaped by the person's changing circumstances. Gitlin (1998) further elaborates the concept of change in the individual's abilities, needs and circumstances in respect to ATs by introducing the concept of "careers". Gitlin's model begins in the hospital and, over time, follows the user throughout his/her learning progress from novice to early then experienced and finally expert user. Particular attention is also placed on the transition moments (discharge from hospital) that will generate a substantial change in the life of the person and consequentially affect the use of the AT.

The dynamic nature of Gitlin's career model is its most important feature. The analysis proposed by most other frameworks is often presented as a static or, at best, iterative process where the person's needs are evaluated at specific assessment and follow-up stages. On the other hand, Gitlin's career model brings to attention the fact that the relationship between the person and the AT will continue, in most cases, over a long period of time. During this time the needs of the person are likely to change and so are the environmental constraints associated to the task targeted by the AT. Often the change in environment will not only affect the physical context of the task but also the social one. For example, while the person is admitted to the hospital, he/she might be willing to use an AT with a distinctive "medical look". When the person is discharged, the AT might not functionally be affected by the change in the physical environment, but its "medical look" is likely to become a social deterrent as the user finds it stigmatizing. Additionally, as time passes and the person becomes more comfortable and skilled in using the AT his/her goals might become more ambitious and this could increase the demands on the AT. Follow ups are definitely important, but the implications of this prolonged relationship and the effect that foreseeable changes will have on the circumstances affecting the user should be taken into account from the beginning.

Despite the strength of his dynamic nature, Gitlin's career model also features some important flaws that significantly limit its application. Firstly, although great emphasis is placed on the temporal evolution of the AT career, the characteristics that would identify users at every stage are never defined. Secondly, the evolution of the environments in the model is strictly defined as hospital, for novice users, and home, for the more expert ones. Despite this definition being accurate for particular AT users, it is too restrictive to be applied to a wider population.

3.3.6 Scherer's frameworks and the matching person and technology model

Over the years Scherer and colleagues have developed two frameworks and one model that attempt to explain the process of AT adoption and identify suitable outcomes for AT research. The framework for modelling the outcomes of assistive technology devices (ATDs) was first formulated by Fuhrer, Jutai, Scherer, & DeRuyter (2003). The framework represents the outcomes of AT intervention as the results of a complex interaction among the characteristics of the intervention itself, the users targeted by the intervention and the environment of the users. In a similar fashion to the career model proposed by Gitlin (1998) the relationship between the user and the AT is followed across 3 stages: procurement of the ATD, introductory use and longer-term use. Outcomes are assessed both in the short-term, after introductory use, and in the longer-term. The 6 outcomes measures recommended are based on the ICF (World Health Organization, 2001) and include both objective aspects such as AT effectiveness (e.g. is the AT appropriate for the task the user wishes to perform?) and efficiency (e.g. does the AT support the user correctly?) alongside subjective factors such as device satisfaction, psychological functioning and subjective wellbeing. However, the framework for modelling the outcomes of AT intervention offers no support for the development of specific models attempting to guide the process of AT selection which are at the base of any adoption process.

For this reason Scherer et al (2007) developed the framework for modelling the selection ATDs to complement the AT outcomes framework that was previously formulated. The framework for ATD selection provides a tool to conceptually organise the factors that can influence the process of AT selection with the aim of providing the best possible match between the person and the device within the selected environment. The AT selection process takes place in a specific environment which is defined by cultural and financial priorities, is regulated by a set of laws and policies and is heavily influenced by the attitudes and perception of key figures that interact with the user and the family. The AT selection is also shaped by personal factors such as social resources (support from family, friends and other caregivers), financial resources, individual expectations, pre-existing knowledge, access to relevant information, personal preferences and priorities. Interestingly, the framework highlights how the personal factors that will influence the selection process are not only the one of the user, but also the ones of the provider. For example, the technical knowledge of the provider and their ability to obtain support from other professionals for particular complex cases are considered important to find an AT that matches the needs of the user. During the assessment that guides the selection of the AT, the authors emphasize the importance of separating the objective functional need from the subjective predisposition of the user in order to be able to address them in a way that is both comprehensive and satisfactory.

Both the ATD selection and outcomes framework are formulated as general structures that can be used to gain a better understanding of AT selection and use. However, they lack the level of details necessary to identify the specific elements that determine the successful adoption, or rejection of newly prescribed ATs. To this end, building on both frameworks, Scherer (1998) used grounded theory to develop the Matching Person and Technology (MPT) model. Over the years the MPT model was revised and improved several times and its most recent version was published in 2017 (Scherer, 2017). According to Scherer (2017), the factors that will influence the process of AT adoption can be classified into three different categories: milieu, personality and technology. In many respects the MPT model shows similarities with the other models that were discussed previously. Some of the elements included in the *technology* domain such as relative advantage, ease of use and repair, adaptability, usability and financial cost can be easily compared with the perceived attributes of technology identified by Rogers (2010). Similarly, *personality* features such as cognitive and physical abilities, motivation, need for technology and lifestyle have already been described by both Cook & Polgar (2014) and Deibel (2013). Finally, Sherer's *milieu* encompass many of the social, physical, cultural and institutional context that were previously outlined in the HAAT (Cook & Polgar, 2014).

What makes the MPT unique in comparison with the other models and frameworks presented in this chapter is the fact that it has been provided with protocols, instruments and assessment tools in order to guide practitioners throughout the process of AT selection (Scherer & Craddock, 2002). Four different forms have been developed to help clinicians and providers to assess clients' needs in the most comprehensive way (Parette & Scherer, 2004). The *Initial Worksheet for the MPT process* is used to determine the user's goals and, according to the classification provided by the ICF, to establish the structures of the body that experience loss of function. Additionally, Parette & Scherer (2004) emphasizes how the worksheet should also be used to identify the person's strengths as they could greatly influence the selection of a particular technology. The second form, called *History of Support Use*, highlights the strategies and technologies that the individual uses or has used in the past to help determining strengths and weaknesses of new proposed solutions. The *Survey of Technology Use*, investigates the attitudes of the user towards technology, while the *Assistive Technology Device Predisposition Assessment* examines user satisfaction with different functional areas and ask them to prioritize various aspects of life in order to assess the pros and cons of potential ATs (Parette & Scherer, 2004).

The MPT model and its assessment instruments have been validated by several studies and it has shown both good validity and reliability (Parette & Scherer, 2004; Scherer, 2005; Scherer & Craddock, 2002; Scherer et al., 2005). Despite their usefulness, the various assessment tools that guide the MPT model have also had the effect of restricting its scope. Firstly, Scherer often seems to imply the existence of one perfect AT for the person, which in many situations can be either too optimistic or pessimistic. Secondly, Scherer's work is largely focused on severe mobility issues due to SCI and cerebral palsy and this reflects in the tools developed for the MPT model which tend to overemphasise the physical aspect of disability (Scherer, 1993).

3.3.7 Social cognitive model of AT use

The goal of social cognition models is to predict an individual's behaviour. At the core of social cognition theory is the belief that an individual will adopt the behaviour that maximises the expected personal benefit (Lenker & Paquet, 2003). Social cognitive models have been widely applied to the prediction of different health behaviours, and Roelands, Van Oost, Depoorter, & Buysse (2002) developed a specific model aimed at predicting the likelihood of AT adoption and use. According to Roelands et al. (2002), AT use can be predicted by combining the functional capabilities of the person with the person's intention to use the AT. Individuals with more severe disabilities are more likely to use AT as their functional need is greater. However, if the person is not sufficiently motivated, the AT will be discarded quickly. In turn, intention to use AT will be heavily influenced by three factors: general attitudes towards ATs, perceived assistive device self-efficacy and the expectations of significant others (e.g. family members, caregivers) towards the use of AT. Attitudes towards AT are the result of considerations regarding the relative advantages of AT use and the potential consequences of non-use. On the other hand, assistive device self-efficacy can be described as "the belief in one's ability to operate the AT easily to achieve the desired outcome". Finally, Roelands et al. (2002) emphasize the importance of AT awareness as people will be less keen to rely on ATs that they are not familiar with.

In many respects the social cognitive model formulated by Roelands et al. (2002) is too generic and lacks the level of detail provided by other frameworks. Environmental factors are completely overlooked and the model relies too heavily on the a priori user evaluation, rather than an objective assessment of real barriers and facilitators. However, the social cognitive model for AT use is the first to truly highlight how the adoption and use of ATs is ultimately the product of a personal decision of the user. Frameworks who rely on performance based outcomes such as the HAAT might often result in wrong predictions as the successful performance of the targeted activity might not be sufficient to motivate the user to adopt the selected AT.

3.4 Understanding the problem space for AT design

Many researchers have advocated the use of User Centred Design (UCD) methods in order to develop AT that are more acceptable to users, hence reducing chances of abandonment (Eisma et al., 2004; Poulson & Richardson, 1998). One of the core principles of UCD concerns the need to develop a comprehensive understanding of the problem space before engaging in the design of a potential solution (Maguire, 2001). Nevertheless, due to the complexity of their physical, functional, social and cultural requirements it can be extremely hard to organise the problem analysis phase for the design of ATs (Boger et al., 2017). What are the factors that need to be investigated in order to analyse the problem space? What questions should guide our investigation?

Models and frameworks for AT adoption could provide substantial help in this regard as they help to identify the factors that will determine the success or failure of new ATs. However, there is a considerable difference between understanding requirements for AT design compared to AT selection. In the latter the aim is to choose, among a group of known devices, one that will fit the needs of a specific person. On the other hand, when investigating a problem faced by many disabled users in order to design new ATs we have no idea what the specific characteristics of the new AT will be. If we remove the elements that are dependent on the characteristics of the AT, AT adoption models can be used to identify both the factors that need to be analysed in order to understand the design problem and the questions that should guide this investigation. For each AT adoption model/framework illustrated in the previous section, Table 3-1 provides a series of questions that should guide the problem analysis for design purposes.

Due to the overlapping focus of several models and frameworks, some questions were repeated multiple times. Overall, I identified 19 questions, highlighted in Table 3-1, which can be used to guide the problem framing for design purposes.

Table 3-1. Questions for framing the design problem identified from each AT adoption model

Model/Framework	Questions for Problem Analysis
Roger's Perceived Attributes (Riemer-Reiss, 1999; Rogers, 2010)	How does the person perform the activity? (1) What difficulties are encountered when performing the activity? (2) What are the values of the person? (3) What are the capabilities of the person? (4)
BBEE and successive evolutions (Baker, 1986; Deibel, 2013; King, 1999)	What difficulties are encountered when performing the activity? What are the capabilities of the person? How does the social context affect the person? (5) How does the physical context affect the person? (6)
HAAT (Cook & Polgar, 2014)	How does the person perform the activity? What are the risks associated with the activity? (7) How frequently is the activity performed? (8) What is the importance of the activity for the person? (9) What are the capabilities of the person? What are the goals of the person? (10) Where does the activity take place? (11) How does the social context affect the person? How does the physical context affect the person?
Kintsch and De Paula's Framework (Kintsch & DePaula, 2002)	How will the caregiver affect the user? (12)
Giltin's Career Model (Gitlin, 1998)	Are the needs and capabilities of the users going to fluctuate over time? (13) Is the physical context in which the activity is performed going to change overtime? (14) Is the social context of the user going to change? (15)
MPT (M. Scherer, 2017)	What is the lifestyle of the person? (16) What are the capabilities of the person? What are the goals of the person? What are the person's attitudes towards ATs? (17) How does the social context affect the person? How does the physical context affect the person?
Social Cognitive Model of AT adoption (Roelands et al., 2002)	What difficulties are encountered when performing the activity? What are the capabilities of the person? What is the importance of the activity for the person? How confident of his abilities is the user? (18) What are the expectations of the person? (19) How does the social context affect the person?

3.3 Chapter summary

As discussed in Chapter 2, wheelchair transfers are an important activity for the independence of wheelchair users. Unfortunately, transferring to and from the wheelchair can be extremely challenging and expose wheelchair users to the risk of falling or injuring their upper limbs. In this chapter I explained the importance of ATs and their potential in promoting independence for disabled people and facilitating activities that would otherwise be challenging or impossible.

New ATs could reduce the effort required to perform wheelchair transfers and decrease the risks associated with them, enabling more disabled people to preserve their independence and increase their opportunities for participation. However, the design of new ATs should always be carefully planned, as, if they do not match the user's needs, they are likely to be abandoned, leading to negative consequences (Bühler & Knops, 1999; Riemer-Reiss & Wacker, 2000). Some of the factors that have been identified to increase the likelihood of AT discontinuance are the scarce consideration of user's needs and the lack of user's involvement during the AT selection (Phillips & Zhao, 1993).

In order to understand what factors can promote the adoption and use of AT I reviewed models and frameworks that have been previously published in the literature to illustrate the AT adoption process. The aim of the AT selection process is to identify an existing device that can satisfy the needs of a specific user (Scherer & Craddock, 2002). For this reason, the main focus of many AT adoption models is the classification of relevant characteristics of the device itself. Nonetheless, they also highlight the importance of understanding factors related to the individual, the activity, and social and physical context in which the action takes place (Cook & Polgar, 2014; Deibel, 2013; Gitlin, 1998; Kintsch & DePaula, 2002; Roelands et al., 2002; Rogers, 2010; M. Scherer, 2017). Finally, from the analysis of the AT adoption models and frameworks I formulated 19 questions that can be used to guide the problem identification for design purposes.

Conducting a thorough analysis of user needs and including users during AT selection, could help design better technologies and reduce the chances of AT abandonment. However, only by actively involving disabled people in the creative stages of the design process we can hope to truly empower them to create and take ownership of new solutions that will truly promote their independence and wellbeing. In the following chapter, I will introduce the concept of PD, discuss the challenges associated with the involvement of disabled users in the co-design of new AT and outline the methodology used in this thesis to overcome these difficulties.

Chapter 4 Thesis approach and methodology

The previous chapters have provided the background on wheelchair users, wheelchair transfers and ATs. From the analysis of AT adoption models it emerged clearly that, in order to be successful, it is not sufficient for an AT to provide a significant advantage in respect to a specific activity. Regardless of its functional effectiveness an AT has to be compatible with the needs and values of the user and needs to comply with the requirements dictated by the social and physical context. Another crucial factor that determines the success of many AT interventions is the active involvement of the user during the selection process. Users should be allowed to voice their opinions, not only because they alone know the real extent of their needs and priorities, but also because they will be the one most affected by the introduction of the new AT. In the same way, the design of new ATs that target a specific disabled user group should be influenced by a subset of the user group.

In this chapter, I introduce the concept of participatory design and illustrate the strengths, limitations and challenges that emerge when involving users as co-designers. Based on these considerations, I present the main research question for this thesis and the sub questions that both stimulated the creation of the framework, which guides the organization of this work, and motivated the single studies carried out. Both qualitative and quantitative methods were used in this research depending on the aim of the individual study. Quantitative methods were used to identify the impairment characteristics and contextual factors that influence the performance of wheelchair transfers and to assess the effect of technique and physical environment. Qualitative methods were used to investigate the needs of wheelchair users in relation to transferring task and to explore the dynamics and experiences of wheelchair users and designers during a participatory design workshop.

4.1 Participatory design, principles, advantages and challenges

Participatory Design (PD) is a branch of both design research and practice, focusing on the process by which artefacts and services are generated and developed (Simonsen & Robertson, 2012). PD is derived from co-operative design methodologies for the informatisation of the workplace that were developed in Scandinavia in the 1970s and it is deeply rooted in the political workers movements of that time (Kanstrup, 2003). There are two core principles of PD. The first principle of PD, which is in many respects similar to the aim of design in general, is concerned with making a positive impact on the lives of users through the creation of more usable products and services (Sanders & Stappers, 2008). The second, and equally important, principle of PD lies in its democratic nature, which occurs through a blurring of the traditional roles of users and designers as both have equal power and share the responsibilities for the design outcomes (Bossen, Dindler, & Iversen, 2012; Kanstrup, 2003). This highlights one of the more controversial themes in PD research and practice: participation. At its roots PD advocates for active participation where users cease to be mere informants and become acknowledged creative partners in the design process (Bødker, Kensing, & Simonsen, 2009).

On the positive side, the active involvement of users, and other stakeholders, in the design process has multiple advantages. Firstly, users have direct experience in the challenges that they encounter in the performance of the target activity (Wilkinson & De Angeli, 2014). Their direct collaboration with designers ensures that their needs are not only considered, but lie at the core of technology design promoting the development of artefacts that are more useful and acceptable (Wilkinson & De Angeli, 2014). Secondly, having a direct influence on the development of a technology that might have an effect on one's own life empowers users and enables them to take a proactive approach to improving their lives (Ertner, Kragelund, & Malmborg, 2010).

On the other hand, implementing PD often comes with a cost for both researchers, or designers, and users. It is widely agreed that PD can only be successful when there is a mutual learning environment that allows for equal collaboration between all parties involved (Simonsen & Robertson, 2012). To this end, users and designers will often have to work together for significant amounts of time requiring prolonged and sustained participation (Kensing & Blomberg, 1998). From the point of view of the researchers, or designers, this often results in projects that require both time and money, resources which are usually in short supply in research as well as commercial settings (Shah & Robinson, 2007). For users the cost can be measured in terms of the time and effort they need to commit in order to participate in the design process without having any guarantees on the success of the project (Schuler, 2008).

4.2 Applying participatory design to the development of assistive technologies

When PD is applied to projects focussing on the design of new ATs the benefits of this approach, in terms of their outcomes, are often much greater but so are the associated challenges (Frauenberger, Good, & Alcorn, 2012). Particularly during the early stages of the design process (idea generation, prototype development and testing), disabled people bring to the team their unique knowledge and perspective. Their first-hand experience of difficulties associated with carrying out the activities of interest will, on one side, highlight users' needs that might otherwise go unnoticed. Additionally, their ability to constantly navigate a challenging environment makes disabled people skilled and creative problem solvers able to generate practical and innovative ideas for new ATs (Shah & Robinson, 2007). However, on the other side, the difference in perspectives between users and designers and the tendency of attributing a passive role to disabled people that originates from the medical model of disability can create even more difficulties when trying to establish clear communication and equal collaboration (Kujala, 2003). Many designers are unfamiliar with issues affecting disabled people and disabled users often struggle to express their needs in ways that can be easily translated into design requirements (Newell & Gregor, 2002; Newell, Dickinson, Smith, & Gregor, 2006). Creating a successful collaboration is possible, but it is likely to require more time and effort than is traditionally expected in PD and this can become a barrier to participation for disabled people (Petrie et al., 2006; Wu et al., 2004).

Recruiting disabled people for participation in research is always challenging (Dee & Hanson, 2016; Petrie et al., 2006; Sears & Hanson, 2012). However, when a group of disabled people is required for several workshops throughout an extended period of time the difficulty increases exponentially. Only users who have time at their disposal can take part. Further, participants must be able to get to and from the venue where the session(s) will be conducted and be able to tolerate the potential physical and mental burden that can arise from frequent and prolonged project work (Massimi, Baecker, & Wu, 2007; Robinson et al., 2009; Shah & Robinson, 2007). This usually results in the involvement of only very small groups which might not be fully representative of the whole population, featuring a wide range of abilities and needs (Sears & Hanson, 2012). Consequentially, the strong commitment expressed in the PD manifesto is often softened when applied to practice of PD for AT design. Users often become sources of information to help define the design requirements (Daveler et al., 2015; Robinson et al., 2009), or provide iterative feedback on progressively complex prototypes (McGee-Lennon, Smeaton, & Brewster, 2012; Sharma et al., 2008). Although these approaches might satisfy the first principle of PD (developing better products and services) they fail to satisfy the second (involving users on an equal collaboration with designers).

PD studies which focus on AT design with disabled people show varying levels of user involvement. These separate well into the three of the four categories used by Druin (2002) in her classification of children's level of involvement throughout the design process, namely informants, testers and design partners. Informants are usually consulted during the scoping phase to establish design requirements. Testers are involved once prototypes of low or high fidelity have been developed, often in an iterative process, to provide feedback on individual features and on the full design. Involving users as either testers or informants is valuable for many AT design projects. However, only when enabled to contribute creatively to the generation of new AT solutions users can be truly considered design partners (Druin, 2002).

When users are involved as informants the burden of participation, measured as the required time commitment is usually low. Projects might involve interviews (Azenkot, Feng, & Cakmak, 2016; Wu et al., 2004), focus groups (Kim, Smith-Jackson, Carroll, Suh, & Mi, 2009; Robinson et al., 2009; M. A. Williams, Buehler, Hurst, & Kane, 2015), questionnaires (Daveler et al., 2015), ethnographic observations (Slegers, Wilkinson, & Hendriks, 2013), brainstorming (Moffatt et al., 2004) and other techniques (Meiland et al., 2014). Regardless of the method chosen, the time commitment required from users is often manageable with sessions lasting only a few hours or a day at most.

For testers, feedback can be sought as early on as in the stage of developing design concepts and low fidelity prototypes (Daveler et al., 2015; Kim et al., 2009; Meiland et al., 2014), or later when functioning mid- and high-fidelity prototypes have been developed and can be tested in a field study (Moffatt et al., 2004; Sharma et al., 2008; Wu, Baecker, & Richards, 2005). However, an iterative evaluation that progressively shapes the final result is often recommended (Meiland et al., 2014; Robinson et al., 2009). An iterative approach offers definite advantages in terms of receiving accurate and comprehensive feedback on a device and its features as it progressively evolves throughout increasingly complex prototypes. Nevertheless it requires repeated sessions with each user, posing an increased burden on the person and resulting in difficulties from a project management point of view.

Involving users as co-designers is even more complex as it often requires continuous participation from several users. For example Wu et al. (2005) describes a 12-week long design process that was carried out with a group of 6 people with amnesia in order to develop a portable orientation aid called OrientiringTool. The project was successful at fulfilling both principles of PD. First, the OrientiringTool was positively evaluated after being tested in real-world settings. Second, the design team report highlighted how the open communication witnessed during the workshops led to mutual collaboration and empowerment of all participants (Wu et al., 2005, 2004). However, the level of participation required from users and the resources needed from the research group were very high and might be unmanageable for other groups who do not have access to such a large user populations.

Similarly, the case studies illustrated by Williams et al. (2015) and Moffatt et al. (2004) showed a design process spanning respectively across 6 and 7 weeks. Although in the project carried out by Williams et al. (2015) visually impaired users engaged in PD activities in only 2 of the 6 workshops, the remaining meetings were deemed necessary in order to give participants time to interact with each other, investigate the problem and shape their ideas before prototypes were built. On the other hand, researchers in the Widgets for Inclusive Distributed Environment (WIDE) project were able to engage disabled students as co-designers during individual PD workshops (Gkatzidou, Pearson, Green, & Perrin, 2011). However, the WIDE project had more specific constraints about its scope and the technology to be used and users "only" contributed in establishing design specifications and providing storyboards, narratives for a set sequence of events (Newman & Landay, 2000), to illustrate the general functioning of the widgets. Additionally, each group was composed of teachers, carers and practitioners, alongside disabled students. While, on one side, this probably facilitated the communication within the group, the presence of these proxies could have filtered the input from disabled students (Holone & Herstad, 2013).

To summarise, the graph in Figure 4-1 shows an overview of the studies discussed so far and illustrates the three-way relationship between the role of the users in the project, the required time commitment and the impact that the user has on the final design. As illustrated by the graph, involving users as informants requires limited time commitment but would also have a smaller impact on the final design (Azenkot et al., 2016; Daveler et al., 2015; Kim et al., 2009; Robinson et al., 2009; Slegers et al., 2013; Wu et al., 2004). The feedback provided during testing usually has a greater effect on the AT, particularly if evaluation is carried out in an iterative fashion, but will also be more burdensome for the users (Daveler et al., 2015; Kim et al., 2009; Meiland et al., 2014; Robinson et al., 2009; Sharma et al., 2008). Finally, when users become co-designers of the AT their contribution will significantly affect the final design. However, if their participation is limited to the initial design specification their impact will also be less than if they participated in the realization of the prototypes (Gkatzidou et al., 2011; Moffatt et al., 2004; M. A. Williams et al., 2015; Wu et al., 2004).

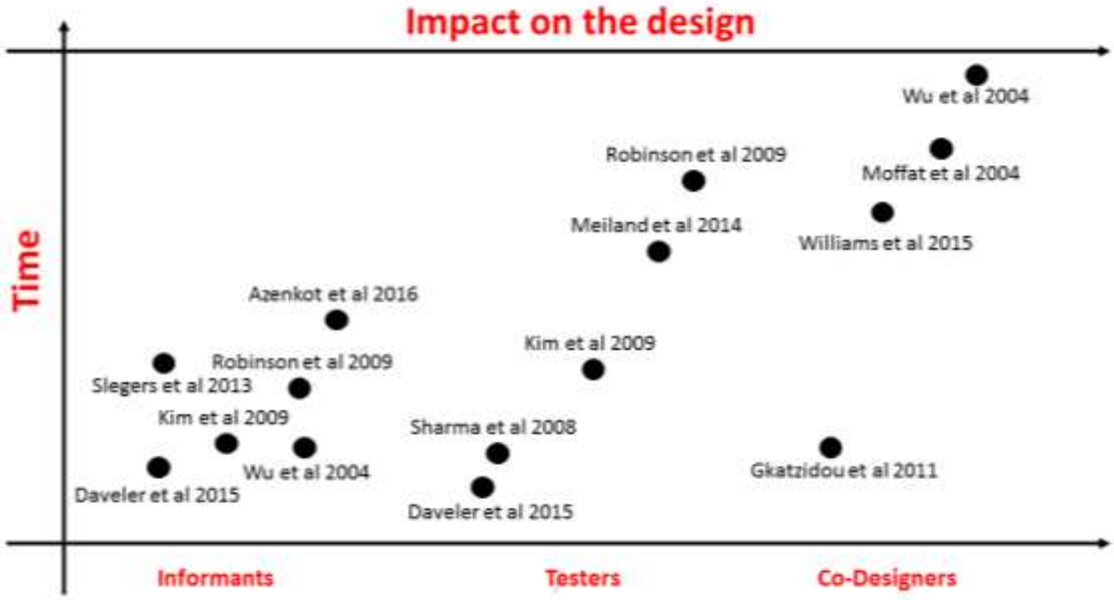

Figure 4-1 Scatter plot illustrating the relationship between time commitment, users' impact on design and role of participants across several PD projects involving disabled users

4.3 Research question

As illustrated in Chapter 1, the main research question that this thesis aims to address is:

How can wheelchair users be engaged and empowered to contribute to the design of new assistive technologies for independent wheelchair transfers that respond to their real needs?

The literature presented in this thesis so far shows how wheelchair transfers represent an under-researched area that is highly relevant to wheelchair users and would benefit from new AT and interventions aimed at facilitating performance and reducing associated risks (see Chapter 2). Design of new AT should aim to involve users in order to empower them and create better devices that are more likely to be successfully adopted (see Chapter 3). However, involving wheelchair users in PD is difficult as the time commitment usually required by PD can become a barrier to participation (see Section 4.2). To this end, the main research question was broken down into two incremental sub-questions, the answers of which build upon each other to address the main question:

RQ1: How can the impact of disabled users' participation in the PD of ATs be maximised?

RQ2: What are the factors that influence the performance of wheelchair transfers that need to be considered when designing new assistive technologies?

4.4 Developing the 2PAC framework

4.4.1 General characteristics

In order to answer RQ1, I developed a framework that aims to give focus and structure to PD projects on ATs to facilitate the quick formation of a positive collaboration between disabled people and designers, thus improving chances of participation for users. The first step in the development of the framework was to look at the difficulties which are commonly encountered in the early stages of PD projects. The inter-connected tensions are grouped under three different areas (*meaningful participation, decision making and prolonged engagement*) and hypothesis are formulated on how these difficulties could be addressed.

As illustrated by Kensing & Blomberg (1998), one of the most challenging aspects of PD relates to the need to maximise the impact of user participation. The unclear definition of the problem that PD is attempting to solve is one of the most important barriers to *meaningful participation*. As highlighted in Section 3.4, in UCD practice there is usually a clear distinction between the phases of problem analysis and design (Maguire, 2001). On the other hand, PD practice is often less structured. Although research on user needs and design requirements are generally carried out, this is usually done as a part of the whole design process that involves the users who are part of the PD team and, as mentioned previously, these users might not be fully representative of the whole population (Moffatt et al., 2004; M. A. Williams et al., 2015). Additional research on users' needs can sometimes be carried out with a larger number of participants, but there is no guidance for selecting the relevant aspects that should be investigated and shared with the PD team (Robinson et al., 2009; Wu et al., 2005). The lack of problem definition and comprehensive information on users' needs creates an incompatibility regarding the expected and effective role of the users within the design team. In less abstract terms, if the design team does not have access to sufficient information relating to the problem they are trying to solve, the users who are part of the team will have to become the source of that knowledge. Consequently, even though the users might have originally been involved as co-designers, they will likely end up acting as informants who are internal to the design team as the need for their knowledge and experience will become greater than the one for their creative input.

Dissatisfaction with the *decision making* process is another challenge of PD and creates, a real or perceived power imbalance between users, researchers and designers (Bratteteig & Wagner, 2012). The lack of clarity regarding how and why decisions are made in a certain way can lead to users feeling like their inputs are considered less seriously than the opinions of researchers and designers (Bossen et al., 2012). The issue often derives from three factors. Firstly, several PD projects lack both a clear structure and direction, creating misunderstandings between the different parties, which can result in tensions. Secondly, the researchers running the project are often part of the design team. This can lead to a power imbalance as the researchers are already the ones who initiate and direct participation and ultimately have control over the outcomes of the project (e.g. what gets published, shared and built) (Vines, Clarke, Wright, McCarthy, & Olivier, 2013). Thirdly, the experiences of each disabled person and the approach of each designer are usually unique. This can result in conflict between participants with different needs and viewpoints and pose challenges when decisions need to be made.

Several researchers claim that *prolonged engagement* among PD participants will help to build trust and improve communication resulting in equal cooperation towards shared goals (Ellis & Kurniawan, 2000). Familiarisation between members of the design team can help individuals feel more comfortable with each other. However, this thesis hypothesizes that similar results can be achieved more efficiently by promoting a more structured and better informed approach to PD; one that provides focus to the design team as a whole and allows all participants, regardless of their role and background to start from a shared ground of knowledge.

Based on these considerations, four requirements for the creation of the framework were established:

1. Create a general scaffolding structure that is clear to participants and can be used to guide the PD project
2. Maximise the possibility of participation while reducing the time commitment necessary for it
3. Create a common source of knowledge that can facilitate communication within the PD team
4. Equalise the power balance within the PD team

4.4.2 Building on AT adoption models

To create a shared source of knowledge to facilitate communication between participants, it is necessary to decide what information should be collected and how. In Chapter 3, AT adoption models were analysed in order to understand what factors influenced the success of AT. Based on the analysis, a series of 19 questions, listed below, that can be used to investigate the requirements for future AT was extracted.

1. How does the person perform the activity?

2. What difficulties are encountered when performing the activity?
3. What are the values of the person?
4. What are the capabilities of the person?
5. How does the social context affect the person?
6. How does the physical context affect the activity?
7. What are the risks associated with the activity?
8. How frequently is the activity performed?
9. What is the importance of the activity for the person?
10. What are the goals of the person?
11. Where does the activity take place?
12. How will the caregiver affect the user?
13. Are the needs and capabilities of the users going to fluctuate over time?
14. Is the physical context in which the activity is performed going to change overtime?
15. Is the social context of the user going to change?
16. What is the lifestyle of the person?
17. What are the person's attitudes towards ATs?
18. How confident of his abilities is the user?
19. What are the expectations of the person?

According to their focus and the means by which the questions can be addressed, these questions can be grouped under three different elements, which determine the need for AT and shape the adoption process: Person, Activity and Context. However, one fundamental difference between the AT selection and design is the fact that the AT selection is a highly personalized process that puts a specific person at the focus of the evaluation, while the latter is a more general process that targets a group of people rather than a single individual. In order to comprehensively frame the need for new ATs one additional element should be included: People. A description of each element is provided below and Figure 4-2 shows the distribution of the 19 questions across the four elements of the framework.

<u>Activity:</u> ATs are often designed to facilitate a specific task that should be thoroughly analysed. Risks and aspects of the activity that need to be simplified should be explored. Additionally, if the new AT has to interface with others ATs or devices this should be considered.

<u>People:</u> The aim of ATs is to help a group of people (with similar functional impairments) to complete a certain task. If the selection of the activity we wish to facilitate is the first

step of any AT design process, it is also crucial to identify the characteristics of the group of people that will be at the centre of our design effort. This step is particularly important as it can help direct the following phases and define broad aspects that need to be further explored.

Context: Activities take place in a specific environment. The physical context might affect how the person performs the activity and the difficulties encountered, hence influencing the functional design requirements of the AT.

Person: The user is not only the decision maker of the AT adoption process, but also the most important source of design requirements. For AT design and selection it is necessary to consider the capabilities of the individual and the characteristics of the disability to understand his/her specific difficulties. Furthermore, equal importance should be granted to less clinical aspects such as the person's needs, objectives and priorities. Although the social context is usually presented separately by most AT adoption models (Cook & Polgar, 2014; M. Scherer, 2017), its implication will have a direct effect on the user, making a separate analysis difficult and of little use. For this reason I propose to include questions relating to the analysis of the social context in the investigation of the personal factors.

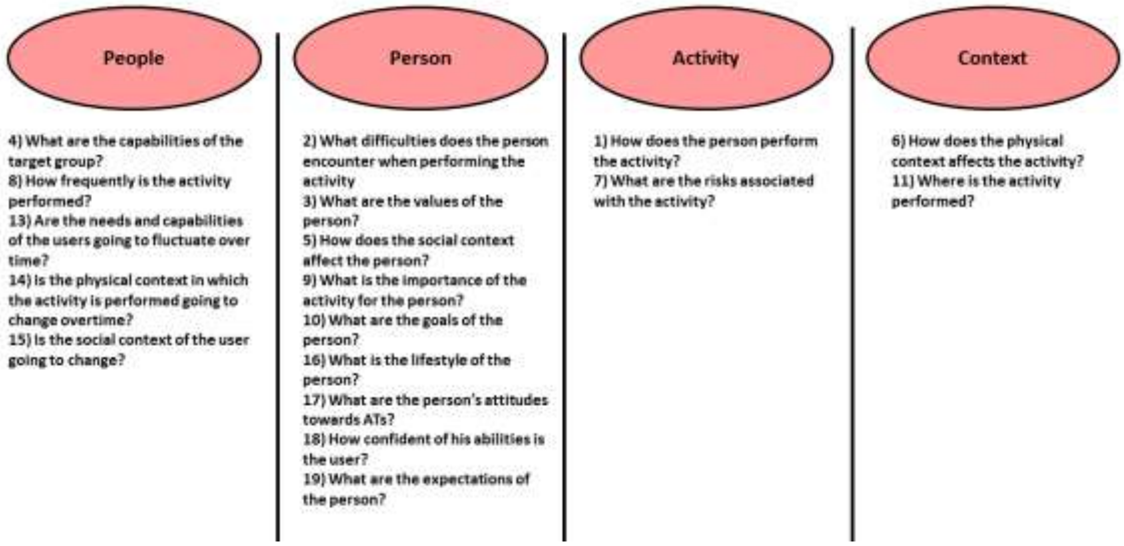

Figure 4-2 Questions framing the need for AT grouped under the 4 elements of the framework

4.4.3 The 2PAC framework

The four elements of the problem analysis process (People, Person, Activity, Context => 2PAC) form the core (and the name) of the proposed framework's structure. By introducing a clear separation between the problem analysis and design phases, the framework integrates aspects from UCD to improve the efficiency of PD without compromising its principles as information is shared with participants to facilitate focus and collaboration. Researchers who have a leading role in the initial stages, take a step back during design assuming the role of moderators and facilitators allowing for a more equalized power distribution between users and designers. The framework consists of 4 steps, respectively identify, analyse, share and design. The diagram of the model is shown in Figure 4-3 and the 4 steps are explained in more details below.

Identify

The first step involves the identification of specific issues that could be addressed through the design of new ATs and that are relevant to a particular disabled population. The identification process can be carried out through direct consultation with users or through a careful review of the literature. For wheelchair transfers, the issue was identified through the review of the literature presented in Chapter 2.

Analyse

As illustrated in the previous section, the second step focuses on understanding the problem space and frames it in the most comprehensive way possible in order to facilitate the generation of potential solutions that are rooted in the real needs of the users and to increase the chances of acceptability for ATs. This step is split in 4 different phases according to the areas of interest previously identified and, in this thesis, individual studies were carried out in the following order:

<u>Activity:</u> ATs are usually task-oriented devices and, for this reason, the analysis of the activity one wishes to facilitate should represent the first step in the information gathering process.

Observation of individual performance, alongside measurement of significant physical and cognitive parameters are often useful to capture strategies employed by disabled people and identify potential risks and pitfalls during the performance of an activity. This first stage will be covered in the study presented in Chapter 5 which looked at the effect of different transferring techniques on the risk factors identified for wheelchair transfers. The study was designed to address gaps identified in the literature while maintaining enough similarities so that our results could be compared with previous studies. For this reason, as recommended by Crytzer et al. (2015), participants' inclusion criteria were broadened to include people who performed independent wheelchair transfers regardless of their technique and medical condition. Additionally, GRF were recorded to measure the load of wheelchair transfer performance on the upper limbs (Gagnon, Nadeau, Noreau, Dehail, et al., 2008) and the TAI to evaluate the safety of the transfer (Tsai et al., 2013).

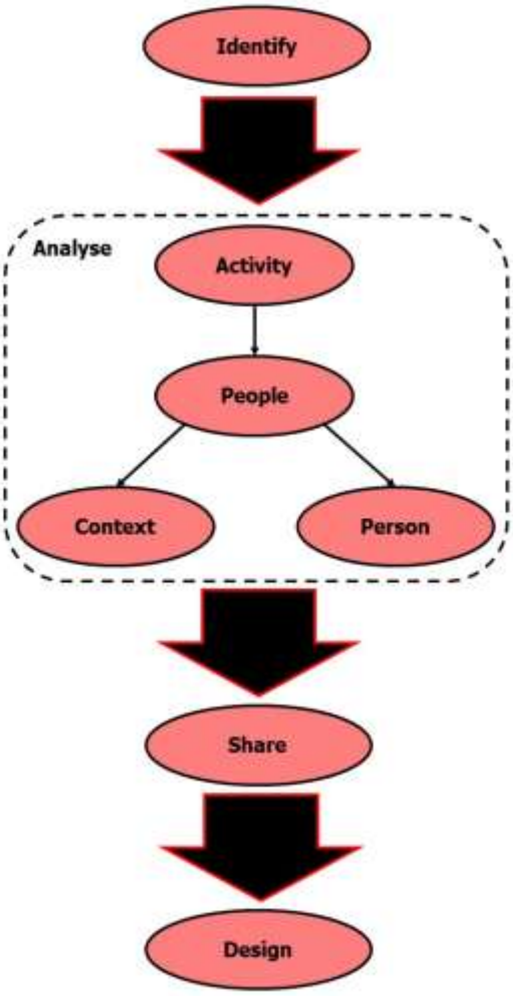

Figure 4-3 Diagram showing the sequence of steps in the 2PAC framework

People: Once the main aspects of the activity have been identified, the next step should focus on understanding the characteristics of the population that we seek to design for. Surveys can allow us to collect a large amount of information that can help define factors that affect users' performance in relation to a certain activity. Additionally, if design efforts are aimed towards a task that is common to disabled people with different impairments, the demographic section in the survey could help us identify the main characteristics of the target population including their medical conditions and specific issues they encounter. The survey carried out as a part of this thesis is presented in Chapter 6. The survey featured questions aimed at identifying selected factors that influence the performance of wheelchair transfers. In order to capture the differences between people performing independent and assisted transfers, responses were invited from all wheelchair users regardless of their medical condition or their need for assistance during transfers. Results from the survey helped to identify the different impairments of people who perform transfers with different techniques, choose the different types of transfers that had to be included in the context study and design the questions used for the final qualitative study.

<u>Context:</u> The impact of the physical context in which an activity takes place should be carefully considered. Environmental constraints should be evaluated using both objective and self-reported measures as it is important to assess how different settings affect individuals with different characteristics. For this stage quantitative approaches are recommended as they will produce results that can be used directly to inform design and test future prototypes. The study looking at the effect of the environment on the performance of wheelchair transfers is presented in Chapter 7. As for the Activity study, wheelchair users who performed transfers using either a standing or sitting technique with or without a transfer board, regardless of their medical condition, were included. Based on the results of the People study four types of wheelchair transfers that were described as common and with varying levels of difficulty were selected: bed, toilet, car and couch. As for the Activity study, the quality and safety of wheelchair transfers were evaluated using the TAI score (Tsai et al., 2013).

<u>Person:</u> Finally, the exploration of the personal experience of potential users, their needs and preferences should be carried out using qualitative methods. Focus groups or interviews should be semi structured with questions being based on the information collected during previous steps, however, semi structure provides enough room for exploring unexpected findings. Cultural probes, information gathering packages containing different artefacts such as diaries, cameras or postcards, could be used by participants as a self-reporting tools to gain further insights on specific needs in contexts where direct observation will be too unpractical or intrusive (Crabtree et al., 2003). Furthermore, design fiction could allow researchers and designers to explore imaginative scenarios and criticising potential solutions before they are designed (Blythe & Wright, 2006). The final step of the Analyse phase is described in Chapter 8. Due to the inherent difficulties encountered when recruiting wheelchair users, it was decided to carry out this qualitative study using a mixture of focus groups and semi structured interviews according to participant’s availability. The aim of this study was to explore the experiences of wheelchair users when transferring in their daily lives. In order to gain a more comprehensive understanding of the barriers and facilitators encountered by novice as well as more expert users, both wheelchair users and OTs who had experience teaching transferring skills were interviewed.

Share

Information collected across the four studies should be processed and synthesized in an organic and accessible medium (e.g. document, video). Information need to be presented in a clear and simple manner using language that is meaningful to a non-academic audience. The information should then be shared with the prospective participants of the following PD phase. All participants should be provided with the handout at least a few days before the workshop itself to have time to digest the information and ask questions when necessary. The choice of the presentation media (standard document, website, video…) should consider both the characteristics of the target audience and the resources available to the researchers. For the project illustrated in this thesis a short booklet was produced and distributed to all participants 1 week ahead of the PD workshop. The handout contained general information about the 2PAC framework and a summary of all the main findings from the studies illustrated in Chapter 5, 6, 7 and 8.

Design

The 4th phase of the framework revolves around the PD workshop featuring both users and designers. Depending on the area of interest and the disabled population involved, it could be beneficial to include caregivers in the design team. In order to avoid bias, members of the research team should undertake the role of moderators rather than actively participate in the design process. At the beginning of the PD workshop participants should be encouraged to interact with each other in order to identify specific area of interest. Participants should be given the opportunity to work as a larger team or split up into smaller teams according to their preferences. Once teams and area of interest(s) are defined, participants should be encouraged to follow a progressive structure, such as the tell-make-enact format proposed by Simonsen & Robertson (2012) as it would allow their design ideas to evolve from a general description to a physical prototype that can be envisioned in real world settings. Specific techniques can be used at the different stages if facilitation is needed. However, participants should be allowed to organize themselves as much as possible in order to reduce interference on the design process. The PD workshop that was carried out as a part of this thesis is presented and discussed in Chapter 9. The aim of the workshop was not just to generate ideas for useful and acceptable ATs that can facilitate wheelchair transfers, but also to test the efficacy of this framework. To this end, the interactions among wheelchair users and designers during the workshop were explored and the effect of the handout on communication and collaboration among participants was analysed. Finally, short interviews were carried out with all participants to better understand their experience throughout the PD workshop.

4.5 Wicked problems and mixed methods

The work in this thesis aims to develop a better understanding of the difficulties that wheelchair users encounter when transferring in their everyday lives and generate ideas for potential solutions. At the same time, the aim was to promote an approach that empowers wheelchair users, and disabled people in general, maximising their impact on the design of AT while reducing the burden of participation. Boger et al. (2017) highlights that, the development of useful and acceptable ATs (with or without a participatory approach) represents a wicked challenge requiring the holistic understanding of complex issues, which can only be achieved through a transdisciplinary approach. The 2PAC framework presented in the previous section, outlines the multi-step structure that I adopted in order to tackle this challenge. Due to the multifaceted nature of the main research question, the work carried out in this thesis could scarcely be constrained to the application of a singular qualitative or quantitative method. To this end, it was chosen to use a mixed methods pragmatic approach where the method for each study was selected according to its appropriateness in answering the research question (Scherer & Lane, 1997). Table 4-1 shows the research question, the chosen method of investigation and the type of participants who were recruited for each individual study presented in this thesis. Ethical approval was obtained for all studies from the UCL Ethics Committee. Study 3 (Analyse Context) was carried out in collaboration with the Georgia Institute of Technology and granted ethical approval from both UCL Ethics Committee and the Georgia Institute of Technology Institutional Review Board (IRB). Sample information sheets and consent forms for studies are presented in Appendix B.

4.6 Chapter summary

This chapter illustrates the overall methodology of this thesis. The concept of PD was introduced alongside the benefits and limitation of its application in the domain of AT design. Then, the research questions driving this thesis was presented and it was described how the 2PAC framework was formulated to address the challenges associated with the cooperative design of ATs to facilitate wheelchair transfers. Finally, based on the complexity of ATs design and the multi-step structure of the framework, I advocated for a pragmatic approach where, the most suitable method is selected based on the research question guiding each individual study.

Table 4-1 Research question, method and participant types for studies presented in this thesis

Study / 2PAC Phase	Research Question	Method	Participants
Study 1 / Analyse Activity	How does technique affect the performance of wheelchair transfers?	Quantitative: GRF and TAI	Wheelchair users
Study 2 / Analyse People	What are the factors that influence users when performing wheelchair transfers?	Quantitative: survey	Wheelchair users
Study 3 / Analyse Context	How does the environment affect the performance of wheelchair transfers?	Quantitative: descriptive movement analysis, TAI, perceived difficulty	Wheelchair users
Study 4 / Analyse Person	What are the needs of wheelchair users in relation to the performance of transfers in their everyday lives?	Qualitative: interviews, focus groups (thematic analysis)	Wheelchair users, OTs
Study 5 / Design	How does the availability of relevant information influence the co-design of ATs for wheelchair transfers?	Qualitative: ethnographic observation, interviews (thematic analysis)	Wheelchair users, designers

Now that the AT challenge that needs to be to tackled has been identified and the methodology guiding the research approach has been outlined, the next chapter describes the first study analysing the Activity domain of the AT need. The aim of the study is to understand how the use of different transferring techniques (unassisted sitting, unassisted standing and with transfer board) affects the performance of wheelchair transfers and the risks commonly associated with them.

Chapter 5 The effect of technique and transfer board use on wheelchair transfers

Transferring independently to and from the wheelchair is an important activity common to many wheelchair users regardless of their age, gender, lifestyle or impairment (Fliess-Douer et al., 2012; MacPhee et al., 2004). Despite this, as previously highlighted in Chapter 2, most available studies on wheelchair transfers focus on the analysis of independent sitting transfers (often called sitting-pivot transfers) performed by individuals with SCI (Gagnon, Nadeau, Noreau, Dehail, et al., 2008; Hogaboom, Worobey, et al., 2016; Kankipati et al., 2015; Kataoka et al., 2012). Although individuals with SCI constitute a significant group within the wheelchair user population, they are not representative of the full population. Sitting-pivot transfers are routinely performed by wheelchair users without a SCI and some authors suggest that inclusion criteria for studies on wheelchair transfers should be based on functional ability rather than medical condition in order to produce more generalizable results (Crytzer et al., 2015). Additionally, many wheelchair users are able to reach a standing position and perform a standing (pivot) transfer (Sanford, Echt, & Malassigné, 2000), whereas others might use a transfer board in one or more circumstances to reduce the effort required for transferring (Nas, Yazmalar, Şah, Aydın, & Öneş, 2015). Both these categories of wheelchair users should be involved in future studies if we wish to understand the implications of wheelchair transfers for the whole population.

The performance of independent sitting pivot transfers has been previously linked to both the risk of falls and the development of injuries affecting the shoulder and wrist (Forslund et al., 2017; Hogaboom, Diehl, et al., 2016; Hogaboom, Worobey, et al., 2016). Furthermore, independent sitting-pivot wheelchair transfers are among the activities which are most likely affected by the presence of pain in the upper limbs (Dalyan et al., 1999; Gellman, Sib, & Waters, 1988). This can be explained by the large forces transferred through the upper limbs during transferring; for example, whereas mean reaction forces during wheelchair propulsion conducted at a self-selected speed are approximately 10.6% of the individual's BW, the mean vertical reaction forces occurring at the hand during a transfer can be higher than 30% of the individual's BW (Michael L. Boninger et al., 2003; Gagnon, Nadeau, Noreau, Dehail, et al., 2008). The importance of reducing reaction forces during sitting-pivot transfers was further confirmed by the fact that both Hogaboom, Diehl, et al. (2016) and Hogaboom, Huang, et al. (2016) reported increased cross sectional area of the median nerve and biceps tendon after repeated sitting wheelchair transfers for individuals with grater body mass. The use of a correct transferring technique seems to mitigate the effect of elevated GRF on the median nerve (Hogaboom, Diehl, et al., 2016). However, the positive impact was limited to one of the two US parameters measured and technique did not seem to affect the appearance of shoulder tendons after repeated transfers (Hogaboom, Diehl, et al., 2016; Hogaboom, Huang, et al., 2016). Moreover, better transferring technique during unassisted sitting wheelchair transfers was only associated with reduced pain and signs of shoulder pathology among individuals with low and middle body weight (Hogaboom, Worobey, et al., 2016).

On the other hand, improving the technique might increase the safety of the wheelchair transfers, regardless of the person's body weight and the movement strategy adopted (Powell-Cope, Campbell, Hahm, Bulat, & Westphal, 2016). No clinical scale has been developed to specifically evaluate the risk of falling during the performance of standing and sitting transfers performed independently or with the aid of a transfer board. However, McClure et al. (2011) developed the TAI, a clinical assessment tool that can be used to evaluate the performance of independent or assisted wheelchair transfers performed with a sitting or standing movement strategy with or without the aid of a transfer board. The TAI provides a valid and reliable tool to assess aspects of transfer performance which includes the strategy for conservation of the upper limb and the safety of the transfer (McClure et al., 2011).

The present study aims to evaluate the effect of different movement strategies (sitting, standing) and transfer board use on the GRFs under the hands as measured during transfer performance and TAI score. These measures were chosen as they represent an indicator of the risk factors for falling and upper limb injury which are normally associated with wheelchair transfers. Additionally, the relationship between the TAI score and the GRFs measured during transfers was further explored in the attempt to better understand the potential of improving transfer technique to reduce the load on the upper limbs.

5.1 Method

5.1.1 Participants

One of the main aims of the present study was to broaden the scope of previous research by encouraging participation from a cohort of wheelchair users covering a greater spectrum of abilities, regardless of their medical condition or transferring technique.

Inclusion criteria were: aged between 18 and 85 years, use of a manual or powered wheelchair as a primary means of mobility, ability to perform independent transfer (sitting or standing) with or without the use of a transfer board. To reduce safety concerns, wheelchair users who complained of upper limb pain or injuries that could hinder their ability to transfer were excluded from the study. Potential participants were recruited from a laboratory database as well as from national and local charities. Six manual wheelchair users and one power wheelchair user (6 males, 1 female) participated in the study. Participants' characteristics are summarized in Table 5-1. Unfortunately, as seen in Table 5-1, it was not possible to recruit wheelchair users who transferred regularly with the aid of a transfer board.

Table 5-1 Demographic characteristics of participants

Participant	Medical Condition	Transferring Technique	Height (cm)	Weight (kg)	Gender	Age	Years of Use	Type of wheelchair
1	Double BKA	Standing	177.8	84.5	M	77	9	Manual
2	Multiple Sclerosis	Standing	188.9	95.4	M	58	5	Electric
3	SCI T9	Sitting (Transfer Board)	180.3	63.3	M	56	32	Manual
4	SCI T12	Sitting (Transfer Board)	195.6	92.7	M	28	7	Manual
5	EDS-Marfans	Sitting	182.9	75	M	26	1	Manual
6	SCI T4	Sitting	180.2	58.8	M	39	22	Manual
7	Endometriosis Stage IV	Sitting	170.2	70.4	F	25	3	Manual
Mean			182.3	77.2		44.1	11.3	
SD			8.1	14.2		20	11.4	

5.1.2 Experimental Protocol

After reading the information sheet and providing informed consent, all participants were asked to perform a transfer from their wheelchair to a bench, then transfer back into their own wheelchair, twice. We attempted to match the height of the bench onto which the wheelchair user would transfer to that of a rigid-frame wheelchair in a standard setup with a pressure relief cushion. Transfers were level for nearly all participants and only one person (Participant 2) had to perform a transfer with a height gap greater than 3cm (7 cm). Participants were instructed to freely approach the bench and position their wheelchair at a distance and angle that they were comfortable with. After each transfer, participants were also asked if they wished to reposition their wheelchair before transferring back onto it, including switching sides in order to maintain consistency between leading and trailing side. After a familiarization period, the four transfers were recorded. Between transfers, participants were invited to rest for as long as needed in order to avoid fatigue. With the aim of capturing the effect of transfer board use on the performance of wheelchair transfers, we asked all participants who performed sitting transfers if they were familiar with the use of a transfer board and if they felt comfortable using it. If the answer was positive, the person was asked to complete the third and fourth transfer using a standard wooden boomerang board (length 72cm, width 25cm). If the participant agreed to use the transfer board, additional practice time was granted before recording the third and fourth transfer. Only two participants (Participant 3 and 4) felt comfortable performing the last 2 transfers with the aid of the transfer board as they had received appropriate training for it during rehabilitation and were familiar with its use.

5.1.3 Evaluation of transfer quality (TAI)

Video recordings of participants' performance were collected using 2 USB Logitech C930e webcams (Logitech Europe S.A., CH) positioned at different angles in order to capture all details of the transfers. Videos were used to assess the quality of the transfers using the TAI. This evaluation was carried out independently by two trained physiotherapists using Part 1 of the TAI version 3.0 (Tsai et al., 2013). The TAI was chosen as an instrument for evaluating transfer quality as it is appropriate to the assessment of both sitting and standing wheelchair transfers performed independently, with human assistance or with the aid of ATs. This assessment tool has shown good test-retest reliability, interrater reliability and face validity among physiotherapists with different levels of expertise (McClure et al., 2011; Tsai et al., 2013). Furthermore, the resultant score is insensitive to an individual's characteristics, including the severity of impairment (McClure et al., 2011). The choice of applying only Part 1 of the TAI to the evaluation of transfers performed by participants had a twofold motivation. Firstly, each transfer is scored individually in Part 1, while Part 2 evaluates the summary of the performance of 4 transfers. Secondly, the final score of the TAI, which includes both Part 1 and Part 2, has been shown to be highly correlated ($R = .97$) to the score of Part 1 (Tsai, Hogaboom, Boninger, & Koontz, 2014). Part 1 is composed of 15 items with a dichotomous score concerning different aspects of transfer performance from the position of the wheelchair in respect to the target surface to the smoothness of movement during transfer execution. An answer of yes to an item corresponds to 1 point and no equals 0 points. Non applicable items are removed and the final score is calculated by multiplying the points obtained by 10 and divide it for the number of applicable items. The final score can range between 0 and 10, with higher scores indicating better transferring technique. Disagreements over scores were resolved through consensus meetings. Items 4, 5 and 15 of the TAI were removed from the evaluation as they were not applicable to any of the recruited participants. A copy of Part 1 of the TAI 3.0 is included in Appendix C of this thesis.

5.1.4 Measurement of GRFs

When quantifying vertical GRFs under both leading and trailing hands, it was important to avoid constraining the person's movement strategy during transfers. For this reason, rather than measuring GRFs using force platforms or other equipment with fixed placements as it is commonly done in biomechanics studies (Gagnon et al., 2012; A. M. Koontz, Kankipati, Lin, Cooper, & Boninger, 2011), we opted for asking all subjects to wear a pair of polyurethane gloves that had attached the Tekscan Grip System featuring a series of force sensitive resistors distributed across the palm (Tekscan South Boston, MA, USA) shown in Figure 5-1.

Figure 5-1 Position of the force sensitive resistors on the palm of the hand

The force sensitive resistors used in the Tekscan Grip System have previously shown decrease in accuracy when used to measure both static and dynamic loading against a soft and deformable surface (Parmar, Khodasevych, & Troynikov, 2017). To guarantee accurate force measurement we placed a wooden board of 0.5cm thickness on the surface of the transfer bench. The sampling frequency for the Tekscan system was set at 25Hz. The complete set-up for the experiment is shown in Figure 5-2.

Analysis of the Tekscan data was completed using a custom Matlab script (Matlab 2015b, Mathworks, Inc., Natwick, MA, USA). Reaction forces were normalized as a percentage of body weight as previously recommended by Gagnon, Nadeau, Noreau, Dehail, et al. (2008). Two-point calibration was carried out on both gloves according to the manufacturer instructions. For each transfer the peak and mean forces above a threshold of 20N were calculated for both leading and trailing hand. Force values below 20N were eliminated from the calculation of mean transfer force. This threshold was established after consulting the video and concluding that forces under 20N were often due to baseline noise of the sensors or to contact between the hands and other surfaces (hands resting on thighs).

Figure 5-2 Set-up for the study

5.1.5 Statistical analysis

The means and standard deviations of demographic characteristics were computed for all participants. According to the movement strategy used by the participant, individual transfers were assigned to one of three categories: sitting transfer, standing transfer and transfer board transfer (see Section 2.3 for detailed descriptions). TAI score, mean and peak vertical GRFs for both leading and trailing hands were calculated for each transfer.

GRFs values and TAI scores were tested for normality using the Shapiro-Wilk test. Due to the continuous nature of the variables and the normal distribution of the data, a one-way analysis of variance (ANOVA) was used to assess the effect of technique and transfer board use on TAI scores, mean and peak GRFs under leading and trailing hands. Tukey tests were used for post-hoc analysis when significant differences were found. The Pearson correlation coefficient was calculated between TAI score, mean and peak GRFs under both hands for all three categories. Finally, a paired two tailed t-test was used to evaluate the effect of transfer board use for transfers performed by the same individual. The level of significance for all tests was set as 0.05. The statistical analysis was performed using SPSS 24 statistical software (SPSS Inc., Chicago, IL, USA).

5.2 Results

5.2.1 Effect of technique and transfer board use on quality of transfers and GRFs

Maximum, minimum, mean and standard deviation for TAI score, peak and mean reaction forces for each group are displayed in Table 5-2 (GRFs values are reported in %BW).

Table 5-2 Descriptive statistics of TAI scores and vertical GRFs for different transferring techniques

Technique	Value	Minimum	Maximum	Mean	Standard Deviation	95% Confidence Interval
Standing	Peak Leading (%BW)	11.7	18.0	14.8	4.5	5.5 - 25.1
	Peak Trailing (%BW)	14.3	22.2	18.2	5.6	3.9 – 36.4
	Mean Leading (%BW)	4.6	6.0	5.3	1.0	3.6 – 14.2
	Mean Trailing (%BW)	8.2	8.8	8.5	0.4	4.6 – 12.3
	TAI Score	4.9	4.9	4.9	0.3	4.6 – 5.2
Sitting	Peak Leading (%BW)	24.4	35.9	32.4	4.7	26.6 – 38.2
	Peak Trailing (%BW)	28.3	41.3	36.8	5.2	30.3 – 43.3
	Mean Leading (%BW)	9.7	14.4	11.4	2.2	8.7 – 14.2
	Mean Trailing (%BW)	11.1	16.5	13.8	2.0	11.4 – 16.2
	TAI Score	6.1	8.2	7.2	0.8	6.2 – 8.2
Transfer Board3	Peak Leading (%BW)	29.3	30.7	30.0	1.0	21.1 – 38.9

Peak Trailing (%BW)	35.5	35.7	35.6	0.1	34.3 – 36.8
Mean Leading (%BW)	11.4	12.2	11.8	0.6	6.7 – 16.9
Mean Trailing (%BW)	11.7	12.3	12.0	0.4	8.2 – 15.8
TAI Score	4.6	6.3	5.5	1.2	4.4 – 6.8

As expected, sitting transfers displayed higher peak and mean reaction forces under both hands. At first glance, standing transfers exhibited notably reduced mean and peak GRFs under the leading and trailing hands compared to both sitting and transfer board technique. A statistically significant difference between all groups was confirmed by one-way ANOVA ($F(2,6) = 12.547$ (peak leading), 11.071 (peak trailing), 8.568 (mean leading), 7.677 (mean trailing); $p = .007$ (peak leading), .01 (peak trailing) .017 (mean leading), .022 (mean trailing); $\eta^2 = .807$ (peak leading), .787 (peak trailing), .741 (mean leading), .719(mean trailing)). However, post hoc analysis showed that the difference was significant only when comparing standing transfers and sitting transfers for peak leading (14.8 ± 17.6 min, $p = .006$,), peak trailing (18.2 ± 18.5 min, $p = .009$), mean leading (5.3 ± 6.14 min, $p = .019$) and mean trailing GRFs (8.5 ± 5.2 min, $p = .018$). Differences between standing and transfer board transfers were significant for peak leading (14.8 ± 15.2 min, $p = .027$), peak trailing (18.2 ± 17.4 min, $p = .027$) and mean leading (5.3 ± 6.5 min, $p = .031$) GRFs, while differences between mean trailing GRFs were not significant between standing and transfer board transfers ($p = .16$). All GRFs' differences between transfers performed with a sitting technique or with a transfer board were instead non-significant (lowest $p= .436$).

From descriptive statistics it appeared that the TAI score was negatively affected by the performance of transfers with a standing technique and with a transfer board. The significance of this difference was further confirmed by the one-way ANOVA ($F (2, 6) = 6.901$; $p = .028$, $\eta^{2 =}$ .697). However, results of the post hoc analysis showed that the difference was only significant between sitting and standing transfers (7.2 ± 2.3, $p = .036$). No significant difference was found for mean TAI score between standing transfers and transfer board transfers ($p = .77$) or sitting transfers and transfer board transfers ($p = .102$). It is worth noting that the two participants who performed transfers with the aid of the transfer board in our study were not regular users of the AT. To this end, in addition to the one-way ANOVA comparing the GRFs and TAI score against the other technique groups, we also carried out a two tailed paired t-test to verify the improvements, or declines associated with transfer board use for the 2 subjects. There was a non-significant decrease in peak leading GRFs between sitting transfers (33.275 ± 1.026) and transfer board transfers (30 ± .99); t (1) = 2.298, p = .261, d = 5.886 peak trailing GRFs between sitting transfers (38.85 ± 2.899) and transfer board transfers (35.6 ± .141); t (1) = 1.512, p = .372, d = 1.069. Almost no difference was observed for mean trailing GRFs between sitting (12.1 ± 1.414) and transfer board transfers (12 ± .424); t (1) = .77, p = .951, d = 0.054. On the other hand, a non-significant increase was observed for mean leading GRFs between sitting (9.8 ± .141) and transfer board transfers (11.8 ± .566); t (1) = -4, p = .156 d = 2.828 and for TAI score between sitting (7.1 ± .566) and transfer board transfers (5.45 ± 1.202); t (1) = 3.667, p = .170 d = 2.593.

5.2.2 Relationship between TAI score and GRFs

When analysed across all techniques, no significant correlation was found between TAI score and peak leading GRF (r = .601, n = 9, p = .087), peak trailing GRF (r = .595, n = 9, p = .091), mean leading GRF (r = .485, n = 9, p = .185) and mean trailing GRF (r = 557, n = 9, p = .119). We were initially surprised to notice that there was a positive trend between higher TAI scores and greater reaction forces underneath both leading and trailing hands as it is shown in Figure 5-3.

When sitting transfers were examined separately, they generally exhibited an inverse trend, as shown in Figure 5-4. However negative correlations between mean TAI scores and peak leading GRF (r = -.167, n = 5, p = .788), mean leading GRF (r = -.182, n = 5, p = .769) and mean trailing (r = -.498, n = 5, p = .394) where all non-significant. Similarly, the slightly positive correlation observed between TAI score and peak trailing GRF (r = .096, n = 5, p = .878) was also non-significant. Due to the low number of samples, correlation between reaction forces and the TAI score during standing and transfer board wheelchair transfers were not calculated.

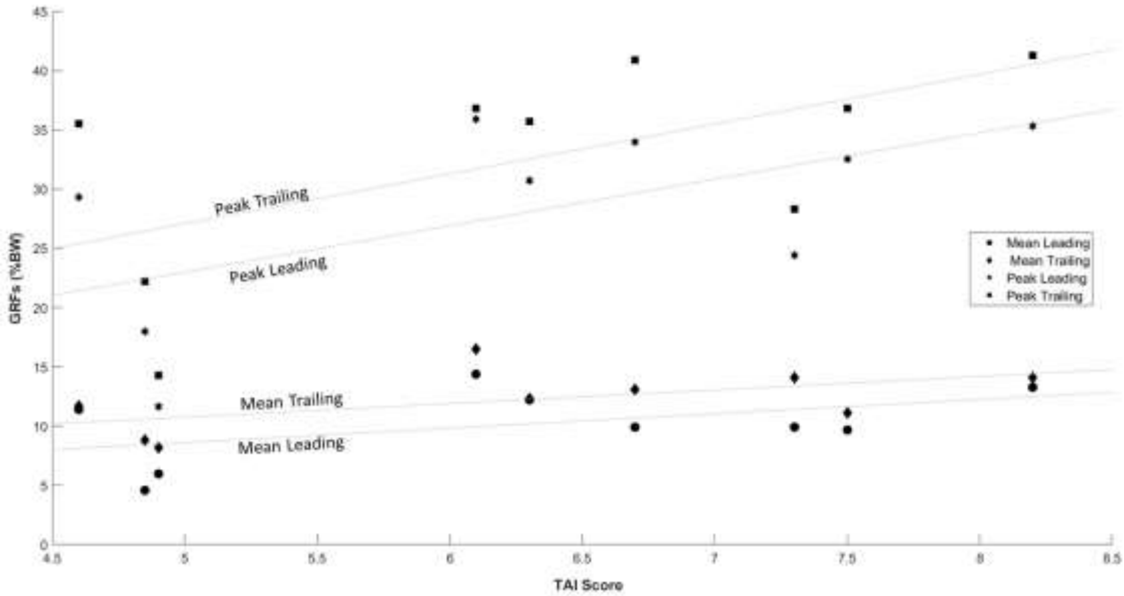

Figure 5-3 Scatter plot showing the relationship between mean and peak GRFs underneath both hands and TAI score across all groups

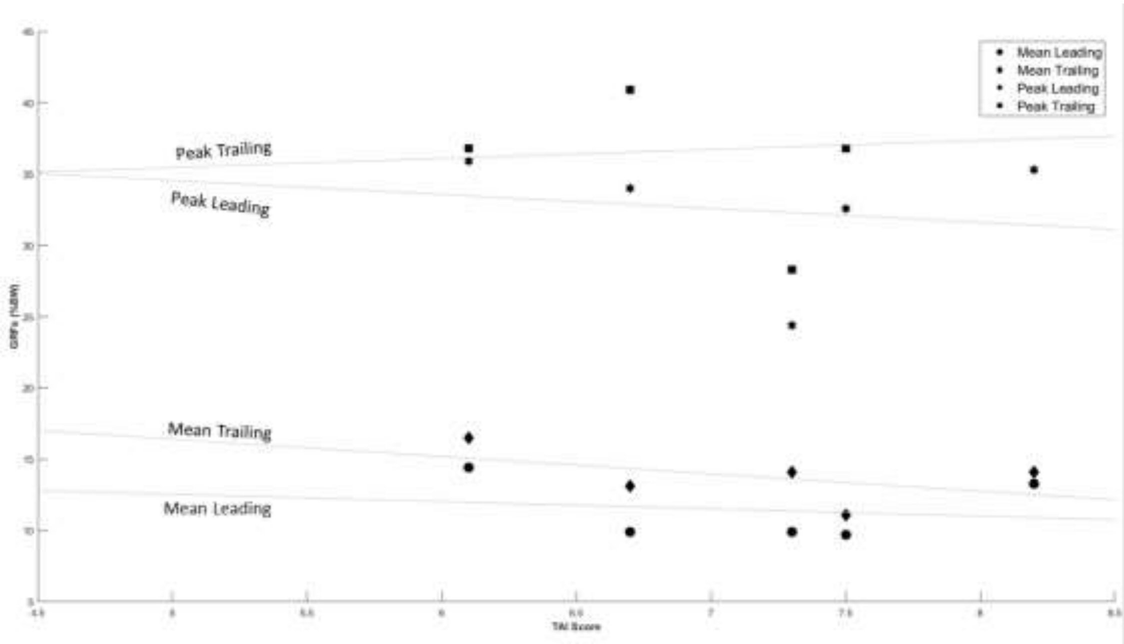

Figure 5-4 Scatter plot showing the relationship between mean and peak GRFs underneath both hands and TAI score for sitting transfers

5.3 Discussion

Previous studies have identified strong links between the performance of wheelchair transfers, the risk of falling and the development of upper limbs injuries (Alm et al., 2008; Hogaboom12 et al., 2013; Opalek et al., 2009). The present study is the first to investigate the impact of technique and transfer board use on the overall quality of wheelchair transfers and the vertical GRFs measured underneath leading and trailing hands.

Results from this study confirm the expectation that standing and transfer board transfers exhibit lower reaction forces under both hands when compared to sitting transfers. However, this difference is only significant between sitting and standing transfers. Transfer boards were found to be only partially effective in reducing the weight born by the upper limbs. This was further confirmed when paired t-tests were used to evaluate the impact of transfer board use on repeated transfers performed by the same individuals. Results show that transfer boards were slightly effective in reducing peak GRFs, but their use can lead to a small increase in mean GRFs and reduce the overall quality of the transfer. Overall, although the risk of developing upper limb injuries might be lower for individuals performing standing and transfer board transfers – resulting in the lower peak forces we observed – their transfer quality scored poorly, which might put individuals who use these techniques at a higher risk of falling. Although this could be partially due to the individual characteristics of the study's participants or to a lower accuracy of the TAI to assess standing and transfer board transfers compared to sitting transfers, it potentially represents an important clinical indicator of the increased safety of sitting wheelchair transfers. This was also corroborated by the positive correlation found between TAI score and reaction forces across different techniques as sitting transfers had higher reaction forces compared to the other groups, but they were also judged to have been performed better.

From a clinical perspective, these results could have important implications. Firstly, people who perform standing transfers could greatly benefit from receiving additional transfer training in order to improve their technique and perform safer transfers. For example, among our participants, safe positioning of both leading and trailing hand was more likely to be observed for sitting compared to standing transfers. Correct hand placement is often highlighted during training for sitting transfers as it is crucial to reduce joint forces (Tsai et al., 2014). However, it can also considerably increase the safety of standing wheelchair transfers (O'Meara & Smith, 2006). Secondly, further studies involving a larger cohort of participants should be carried out in order to verify the effectiveness of transfer boards in reducing the load on the upper limbs during wheelchair transfers' performance. Current clinical recommendations (Boninger et al., 2005) are based on the reduction of joint forces measured during a series of studies focusing on dependent transfers performed by healthcare professionals featuring able-bodied participants acting as patients (Grevelding & Bohannon, 2001). For individuals with reduced upper limbs' strength the use of a transfer board might represent the only viable alternative when transferring to and from their wheelchair (A. Koontz et al., 2012). However, their effectiveness in preventing the onset of upper limbs' pain and injuries should be carefully evaluated and eventual trade-offs between reduction of mechanical load and increased risk of falling should also be considered.

When comparing results from this study to previous studies which measured GRFs during sitting pivot transfers it was observed that the mean and peak values were lower than the ones described by both Gagnon, Nadeau, Noreau, Dehail, et al. (2008) and Forslund et al. (2007). There are two possible reasons for these discrepancies. First, the difference in mean GRFs can be explained by the fact that both Gagnon, Nadeau, Noreau, Dehail, et al. (2008) and Forslund et al. (2007) monitored GRFs only during the lift phase of the transfer, while in this study the preparation phase was included in order to capture the occurrence of scooting motions. This resulted in a considerably larger window of time, lowering the mean value of GRFs for both leading and trailing hand. Peak reaction forces reported in Gagnon, Nadeau, Noreau, Dehail, et al. (2008) were also higher, respectively 44.5 BW% under the trailing hand and 39.6 BW% under the leading hand; compared to 36.8 BW% and 32.4BW% measured during this study. However, all participants in Gagnon, Nadeau, Noreau, Dehail, et al. (2008) were individuals with SCI, whereas participants in this study had different medical conditions that might have allowed them to bear more weight on their legs, hence reducing the load underneath their hands.

When looking at the correlation between the GRFs generated during sitting transfer performance and the total score of the TAI Part 1, the overall trend of the study's findings confirms the results presented by Tsai et al. (2014). However, the negative correlation between quality of transfers measured by the TAI and GRFs measured underneath the hands was found to be non-significant. Reasons are likely to be related to the fact that both the set-up of the experiment and the number of TAI's items included in the analysis were different between the two studies. Additionally, Tsai et al. (2014) evaluated the TAI score against kinetics variables such as specific joint reaction forces and moments rather than vertical reaction forces. The position of each joint and the presence of shear forces could easily be responsible of the discrepancy between the results.

Results presented in the present study highlight some important differences between transfers performed with sitting, standing technique or with the aid of a transfer board and the effect that these differences might have on common risk factors associated with wheelchair transfers. Nonetheless, inherent limitations of the study, in particular the small sample size, suggest caution in the interpretation of the results. Secondly, it is important to highlight how the participants who performed transfers with the aid of a transfer board in the current study were not regular users of transfer boards. Individuals who use transfer boards in their everyday lives might exhibit better technique compared with study's participants and gain a greater benefit from their use. Additionally, only the transfer between the wheelchair and a bench of similar height was examined in this study and generalization to different real life situations such as transfers performed between the wheelchair and a car seat or a bathtub cannot be assumed. Chapter 7 will explore how the changing environment, encountered when performing various types of transfers, affects people who perform wheelchair transfers using different techniques.

5.4 Chapter summary

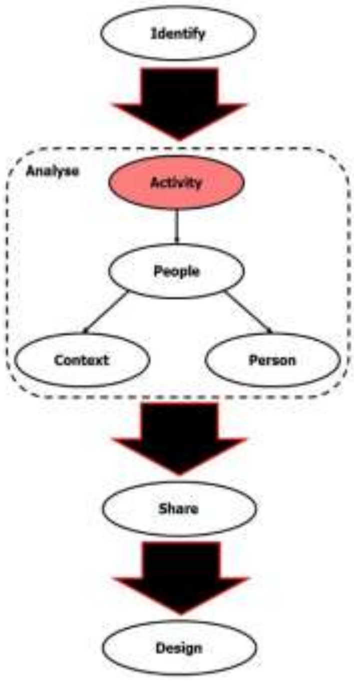

Figure 5-5 Diagram illustrating how the current study corresponds to the Analyse (Activity) phase of the 2PAC framework

This chapter presents the first study, focusing on the investigation of the Activity, from Analyse phase of the 2PAC framework (see Figure 5-5). Wheelchair transfers are a fundamental activity that is important to all wheelchair users, regardless of their impairment and the type of wheelchair they use. Some of the most important issues that are commonly associated with the performance of wheelchair transfers are the excessive load applied to the upper limbs which can lead to the development of shoulder and wrist injuries, and the risk of falls that can occur while transferring. One of the biggest gaps identified in the literature on wheelchair transfers reviewed in Chapter 2, was the lack of information concerning how transfers performed with different movement strategies are affected by these two risks factors. To this end, in the current study I extended the investigation to explore the relationship between GRF measured underneath the hands and transfer quality among individuals with different disabilities performing transfers with standing, sitting technique and using transfer boards.

Results show how the use of different transferring techniques has an important effect on the challenges associated with the performance of wheelchair transfers. Although sitting transfers generated higher reaction forces which might lead to a greater risk of developing upper limb injuries they also seem to be of better quality, potentially resulting in a decreased risk of falling, particularly when compared with standing transfers. Transfer board transfers sits somewhere in between these two extremes as they exhibit slightly lower GRFs than sitting transfers and better transfer quality than standing wheelchair transfers. The text box below shows the design implications that have been extracted from the results of the study presented in this chapter.

Design Implications:

1. New ATs for wheelchair transfers should be designed differently according to the transferring technique of their users
2. ATs that improve technique and reduce the risk of falling are more likely to be beneficial to people who perform unassisted standing transfers
3. ATs that help to reduce the mechanical load withstood by the upper limbs are more likely to be beneficial to people who perform unassisted sitting transfers
4. ATs for people who perform transfers with the aid of a transfer board should combine the technique improvement with the reduction of the mechanical load withstood by the upper limbs

Chapter 6 Personal, technique related or general? Analysis of factors affecting the performance of wheelchair transfers

Regardless of the characteristics of the individual, transfers are one of the most important activities in the lives of all wheelchair users (Fliess-Douer et al., 2012; Mills et al., 2002). As highlighted in Chapter 2, wheelchair users represent an extremely broad and diverse group that includes people with different medical conditions, demographic characteristics, lifestyles, needs, difficulties and goals (LaPlante & Kaye, 2010). Depending on their individual characteristics, some people will be able to perform wheelchair transfers independently, while others might need partial or complete assistance. Furthermore, some people who transfer independently might adopt a standing or sitting technique while others might rely on ATs to facilitate their performance (Hoeman, 2008). Due to their diversity, wheelchair users will have different needs and strategies when transferring to and from their wheelchair.

In the previous chapter objective quantitative measures were used to evaluate how different independent transferring techniques can affect the issues that are commonly associated with the performance of wheelchair transfers such as risk of falling and developing upper limb injuries due to the high mechanical load (Forslund et al., 2017; Hogaboom, Diehl, et al., 2016; Hogaboom, Worobey, et al., 2016). The study proved to be useful in helping to understand how the risks correlated to transfer performance might be different for people who use different movement strategies. Nonetheless, it does not provide us with any information about the characteristics of the wheelchair users who perform transfers with different strategies and how their characteristics might impact various aspects of their performance in real life. For example, previous studies have estimated that a person with SCI transfers to and from their wheelchair approximately 15 times a day (Curtis & Black, 1999; Finley et al., 2005; Sonenblum & Sprigle, 2016). However, the number of transfers reported by each individual can vary from 0 to 45 transfers per day (Curtis & Black, 1999). What is the cause of such a large variation? Are transfers performed more or less frequently depending on the level of independence of the individuals and the movement strategy they adopt when transferring?

Several factors have been shown to affect the individual's ability to perform wheelchair transfers. Studies by Dalyan et al. (1999) and Samuelsson et al. (2004) reported respectively that presence and the intensity of upper limb pain interfered with the performance of wheelchair transfers for 74% and 62% of wheelchair users with SCI. Furthermore, results presented by Alm et al. (2008) have also classified wheelchair transfers, particularly transferring into and out of a car, as one of the items on the Wheelchair Users Shoulder Pain Index (WUSPI) where people reported the highest intensity of pain. However, these studies give us no indication of how pain impacts the performance of wheelchair transfers; nor if and how people with different impairments are affected by the presence of pain during transfers.

Several studies have identified how different types of wheelchair transfers (wheelchair-toilet, wheelchair-car, wheelchair-bed) can be more or less difficult for the individual and potentially lead to increased physical effort (Bode, Heinemann, Kozlowski, & Pretz, 2014; Janssen et al., 1994). Additionally, Toro et al. (2012) measured the influence of different environmental factors such as height difference, gap dimensions, the presence of an obstacle, the presence and height of a frontal or lateral grab bar on the performance of wheelchair transfers. Results indicated how height difference between wheelchair and target seat and the presence of an obstacle had the greatest impact on the participant's ability to transfer. Placing a grab bar in front of the target seat helped approximately 20% of the individuals during several of the transfers performed. Although results from these studies might be helpful to understand objective difficulties that wheelchair users in general encounter when transferring in the built environment, they fail to consider how these difficulties might vary across subjects using different transferring techniques.

Few studies have taken into account the use of ATs in the evaluation of wheelchair transfers (Koontz et al., 2012), and none has investigated the likelihood of transfer's ATs use among people with various levels of independence nor how the use of ATs impacts the perceived difficulties of wheelchair transfers. Finally, psychological factors such as confidence and self-efficacy have also been demonstrated to have an important effect on performance level during wheelchair sports (Martin, 2002). Furthermore, studies from Best et al. (2016) and Sakakibara et al. (2013) have shown how increased confidence and self-efficacy of manual wheelchair skills results in improved performance that positively affects participation. Wheelchair transfers are described as an important and challenging activity for many wheelchair users (Bode et al., 2014; Fliess-Douer et al., 2012), but how does the level of independence and the technique used by the individual affects self-confidence and satisfaction?

Most studies on wheelchair transfers have focussed on one aspect related to the performance of wheelchair transfers such as evaluating the impact of upper limb pain (Alm et al., 2008) or transfer set-up and environmental constraints (Toro et al., 2012). Moreover, the majority of available studies either focuses on the performance of independent sitting transfers performed by people with SCI (Gagnon, Koontz, et al., 2009) or generalises findings across many wheelchair users regardless of their level of independence and the technique used when transferring.

The present study has a twofold aim. The first one is to identify general characteristics of wheelchair users who perform wheelchair transfers with various levels of independence and using different transferring techniques. The second aim is to explore how the need for assistance and the use of different transferring techniques affects the performance of transfers in wheelchair users' everyday lives.

6.1 Method

6.1.1 Materials and procedure

A five section cross-sectional self-administered survey was designed for the study. The questionnaire was developed based on a literature review concerning factors that can potentially influence the performance of wheelchair transfers.

The survey was distributed in electronic form and potential participants were recruited by advertising the survey on UK based charity newsletters, websites and social media. Additional participant calls were made by posting on forums for wheelchair users, flyers placed in rehabilitation centres and word of mouth. Inclusion criteria for the study were: aged over 18 years and use of a wheelchair as a primary mean of mobility (both self-reported). The landing page included an informed consent form and participants were able to access the survey agreeing to participate.

The questionnaire was pilot tested with a small group of both manual and powered wheelchair users (n = 10) that had different medical conditions and performed different types of wheelchair transfers with various degrees of assistance. Based on their feedback, two additional items were introduced and some minor changes in the wording of three questions were implemented to improve clarity (see Appendix D). The final survey contained 23 items divided into five sections:

1. Demographic Information (8 Questions): General characteristics of the respondent were collected in this section including the subject's gender, age, weight, height, and experience as a wheelchair user, primary medical

condition, primary type of wheelchair used and any additional wheelchairs used.

2. Wheelchair Transfer Characteristics (5 Questions): Questions in this section explored general characteristics of wheelchair transfers normally performed by the respondent such as the need for assistance during transfers, use of a sitting vs standing technique, the number of transfers performed on a daily basis, the type of transfers normally performed (bed, bathroom, or other transfers in the house, in/ out of the car and also transfers between wheelchairs) and perceived difficulty of each type of transfers performed.
3. Use of Assistive Technologies (6 Questions): Items in this section were divided into two parts. The first part was aimed at assessing the use of various assistive technologies categorized for the type of wheelchair transfer performed. The second part was intended to capture an overview of the main advantages and difficulties of using assistive technologies, the self-reported ease of use and motivations for non-use.
4. Presence and Intensity of Pain (3 Questions): This section consisted of two items aimed at assessing the presence and intensity of upper limb recurring pain within the last six months. Additionally, a third question was added to explore the frequency of pain exacerbated by wheelchair transfers.
5. Wheelchair Transfer Motivation (1 Question): This section contained four rating activities, grouped into a single item, for statements developed based on the Intrinsic Motivation Inventory (Deci & Ryan, 2003). The aim was to evaluate the value attributed to the skill, the effort invested in the performance, the perceived competence of the respondent and the pressure related to the activity execution.

A multiple choice response format was preferred for the majority of questions as it reduces the time and burden of participation (Kelley, Clark, Brown, & Sitzia, 2003). To maintain consistency, as the Intrinsic Motivation Inventory features rating questions using a 7 point Likert scale, all rating question throughout the survey used the same format. At the end of the questionnaire an open ended question was added, asking for additional comments, insights or feedback from respondents.

6.1.2 Statistical analysis

Data from completed surveys were analysed using SPSS 24 statistical software (SPSS Inc., Chicago, IL, USA). Twenty-six (62%) respondents were male and 16 (38%) female. Descriptive statistics were calculated in order to illustrate demographic and general characteristics of the respondents, types of transfers performed, advantages and disadvantages of ATs. Respondents were divided into 3 primary groups according to the level of assistance needed when transferring and their transferring technique. Associations between wheelchair users' demographic characteristics and transferring technique and level of assistance were explored using cross tabulation and Chi-squared testing. Data related to the daily frequency of transfers were checked for normality using the Shapiro-Wilk test. Due to the non-normality of the data across different groups, a Kruskal-Walllis test was used to determine the impact of assistance and technique on the frequency of wheelchair transfers performed on a daily basis. Chi-squared testing was employed to investigate the association between participants' technique, presence of pain and AT use, while Kruskal-Walllis was used to analyse the impact of transfer technique and independence on intensity of pain, reported difficulty, individual's motivation and self-satisfaction. Where significant differences were found, a Dunn's test with Bonferroni correction was used for post hoc analysis of Kruskal-Wallis pairwise comparison, and standardised residuals were examined for Chi-squared tests. Spearman's correlation was used to assess the relationship between satisfaction with transfer performance and reported difficulty across different transferring techniques. Lastly, a two tailed independent t-test was employed to assess the impact of participant's weight on the likelihood of AT use during transfers. Level of significance for all statistical tests was set at .05.

6.2 Results

6.2.1 Participants

A total of 42 fully completed surveys were returned. Demographic characteristics are presented in Table 6-1. The median age of the respondents was 46.5 years, ranging from 19 to 67 (IQR = 22). Median self-reported weight and height were, respectively 72.3 kg and 172.7 cm, ranges spanned between 30.4 kg to 120 kg (IQR = 33.3) and 122 cm to 195.6 cm (IQR = 21). Respondents were on average very experienced wheelchair users, nearly 55% had more than 10 years of experience. Median number of years of experience as a wheelchair user was 13.25. Primary medical conditions varied greatly across subjects. The most common reported diagnosis was SCI, followed by MS and cerebral palsy (CP). However, over 35% of the respondents had other medical conditions which affected their mobility including Ehlers-Danlos Syndrome, muscular dystrophy and post-polio paralysis. Respondents were mainly manual wheelchair users, with only 31% reporting powered or pushrim activated power assisted wheelchairs (PAPAW) as a primary means of mobility. Twenty-seven subjects also reported the ownership and use of other wheelchairs and mobility devices, including scooters, sport wheelchairs and add-on hand bikes.

Table 6-1 Demographic characteristics of participants

Characteristic	**Frequency**	**Percentage**
Gender		
Male	26	62%
Female	16	38%
Age (Years)		
18-25	6	14.3%
26-35	4	9.5%
36-45	6	14.3%
46-55	17	40.5%
56-65	8	19.0%
65+	1	2.4%
Weight (Kg)		
Less Than 50 Kg	3	7.1%
50-70 Kg	17	40.5%
70-90 Kg	12	28.6%
90 + Kg	10	23.8%
Height (Cm)		
Less Than 165 Cm	13	31%
165-180 Cm	16	38.1%
180-195 Cm	12	28.6%
195+ Cm	1	2.4%
Experience As A Wheelchair User		
Less Than 1 Year	2	4.8%
1-5	10	23.8%
6-10	7	16.7%
10+	23	54.8%
Type Of Primary Wheelchair		
Mw Rigid Frame	19	45.2%
Mw Foldable Frame	10	23.8%
Powered Wheelchair	11	26.2%
Papaw	2	4.8%
Medical Condition		
Sci (Paraplegia)	15	35.7%
Sci (Quadriplegia)	7	16.7%
Ms	2	4.8%
Cp	3	7.1%
Other	15	35.7%

From cross tabulation of demographic factors the sample appears very homogeneous, with even distribution of age groups and physical characteristics across different medical conditions and primary wheelchair type. More clear relationships were instead found between medical condition and type of primary wheelchair used, with the totality of respondents' who reported a low level SCI using rigid and foldable frame manual wheelchairs as a primary mean of mobility.

6.2.2 Wheelchair users' characteristics according to level of independence and transfer strategies

Thirty-one (73.8%) of the respondents reported being able to transfer without any assistance. Of these 23 (74.2%) performed sitting transfers while eight transferred using a standing technique. Seven participants (16.7%) stated that they usually need some assistance in order to safely transfer in and out of their wheelchair and six (85.7%) used a sitting technique. Only four participants, accounting for the 9.5% of the total population, defined themselves as completely dependent when performing wheelchair transfers. Due to the low number of participants performing assisted and dependent transfers, their responses were combined, whereas independent wheelchair transfers were categorised according to the technique (sitting or standing) used by the individual. A significant relationship was found between an individual's medical condition and transferring strategy $\chi^2 = 32.43$, and $p < 0.001$. Over 60% of the respondents performing independent sitting wheelchair transfers reported having a SCI that only affected their lower limbs, while 74.1% of the tetraplegic participants stated that they needed partial or complete assistance when performing transfers. All participants with CP performed independent standing transfers while respondents with other various medical conditions were more evenly spread across the 3 transferring techniques. No other significant association was found between participants' transferring technique, primary type of wheelchair used ($p = .07$) and individuals' body weight ($p = .316$). Figures 6-1, 6-2 and 6-3 show the distribution of participants' characteristics across the 3 transferring techniques.

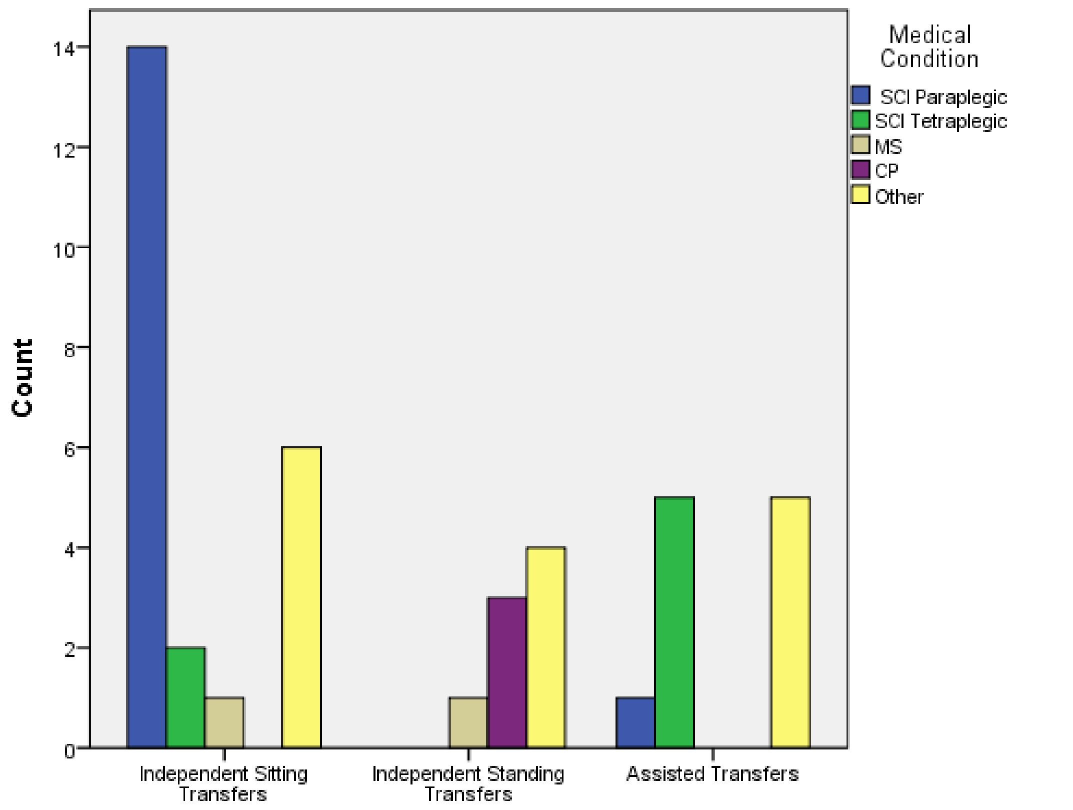

Figure 6-1 Bar chart showing distribution of participants' medical condition according to transferring technique

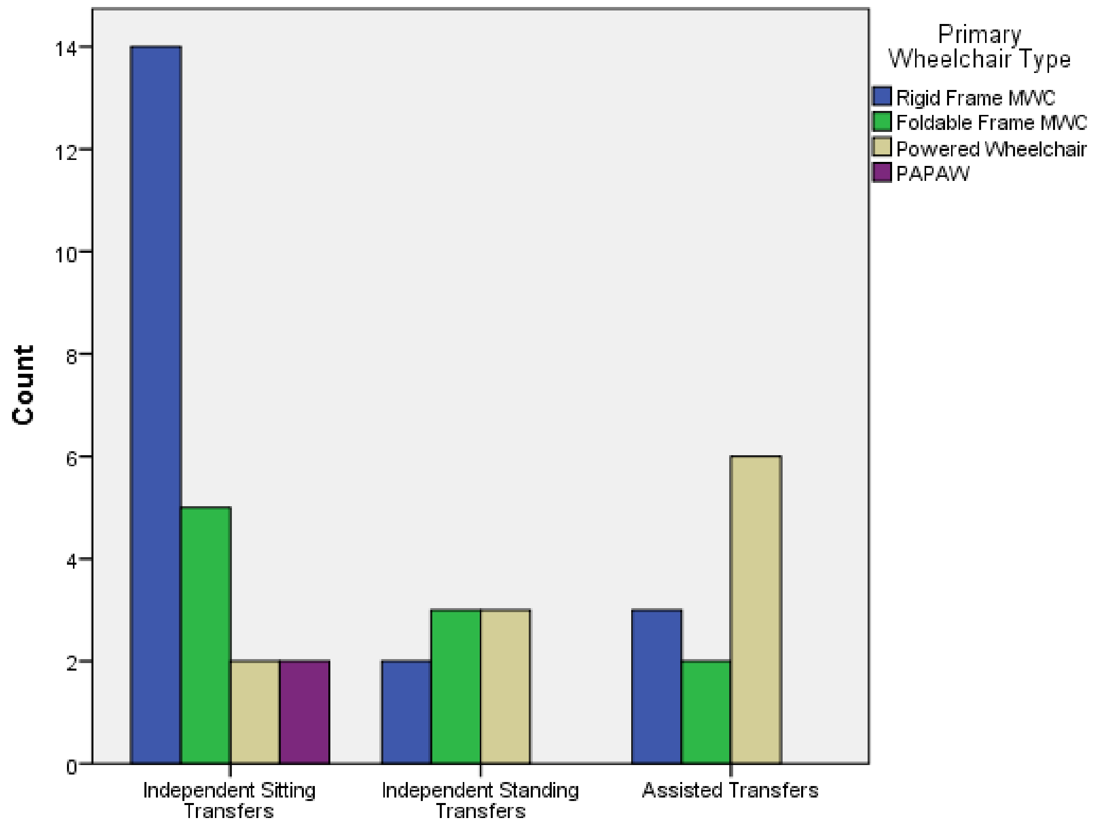

Figure 6-2 Bar chart showing distribution of participants' primary wheelchair type according to transferring technique

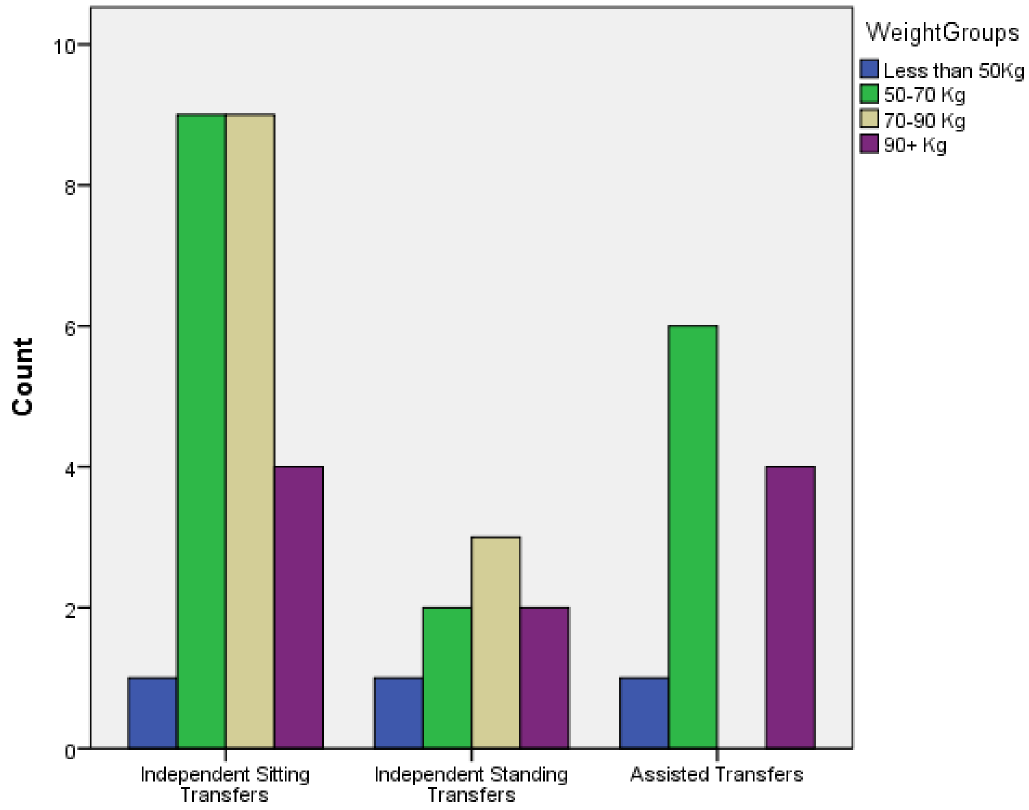

Figure 6-3 Bar chart showing distribution of participants' weight according to transferring technique

6.2.3 Frequency of transfers, types of transfers and reported difficulty

The median number of transfers performed daily by respondents was 8 (IQR = 5.3). There was a statistically significant difference between transferring technique groups as determined by the Kruskal Wallis Test ($\chi^2(2) = 8.128$, p = .017). A Dunn's post-hoc test with Bonferroni correction revealed that the daily frequency of transfers was significantly lower for participants who needed assistance (median = 4, IQR = 5, *p* = .016) compared to participants who performed independent sitting transfers (median = 8, IQR = 9). The median number of daily transfers reported by participants performing independent standing transfers was 7.5 (IQR = 3.5) but the difference was not significant when compared to the other 2 groups (lowest p = .37).

When asked about the different types of transfers routinely performed, all participants reported performing bed to wheelchair transfers and various transfers from and to the wheelchair when in the bathroom (e.g. toilet, shower, commode chair) on an everyday bases. Car transfers were also very common, with 76.2% of the respondents performing them daily, other house transfers (e.g.: couch, dining table) were slightly less common 64.3%, whereas transfers between different wheelchairs were a regular occurrence for 69% of respondents. Additionally, thirteen respondents reported frequent transfers onto office chairs, restaurants and/or cinema seats, plane seats and various exercise or rehabilitative devices such as hand bikes and standing frames. When looking at the types of transfers performed by individuals using different transferring technique and with or without assistance, it was found that car transfers were performed by 91.3% of the participants using an independent sitting transferring technique. Respectively, only 62.5% and 54.5% of wheelchair users performing standing and assisted transfers reported regular transfers to and from car seats. Similarly, people using an independent sitting technique were more likely to perform house transfers (69.6%) compared to individuals performing independent standing transfers (62.5%) or assisted transfers (54.5%). Transfers between wheelchairs were common practice for all respondents who used an independent standing technique while they were performed by only 65.2% of individuals using independent sitting technique and 54.5% of people performing assisted transfers.

Participants were also asked to rank the level of difficulty of each transfer they routinely perform on a Likert scale from 1 (Very Easy) to 7 (Very Hard). When considering all participants within a single group, bed transfers were considered the easiest among the more frequent transfers (Mean 2.74, STD ± 1.71). House transfers (e.g.: couch, dining table) are also performed with moderate ease (Mean 3.00, STD ± 1.47), while bathroom transfers, transfers between wheelchairs and car transfers appear as a more challenging scenarios (Means 3.76, 3.79, 3.94, STDs ± 1.88, 1.92, 1.95). People who reported additional routine execution of other transfer types, in addition to the five basic scenarios we proposed (bed, bathroom, car, house and between wheelchairs), rated them as generally easy (Mean 2.62, STD ± 1.39). When responses were examined separately according to participants' transferring technique, it was observed that reported average difficulties were lower for individuals performing independent sitting transfers across all conditions. The Kruskal Wallis Test shows a statistically significant difference between groups for bed ($\chi^2(2) = 10.317$, $p = .006$), car ($\chi^2(2) = 2.564$, $p = .020$), house ($\chi^2(2) = 12.03$, $p = .002$) and other transfers ($\chi^2(2) = 7.5$, $p = .024$). Post-hoc analysis revealed that all transfers were considered to be significantly easier by participants using an independent sitting technique compared to individuals who required assistance (bed transfers $p = .009$, car transfers $p = .016$, house transfers $p = .002$, other transfers $p = .041$). Figure 6-4 shows the mean difficulty reported for different types of transfers by respondents using different transferring techniques.

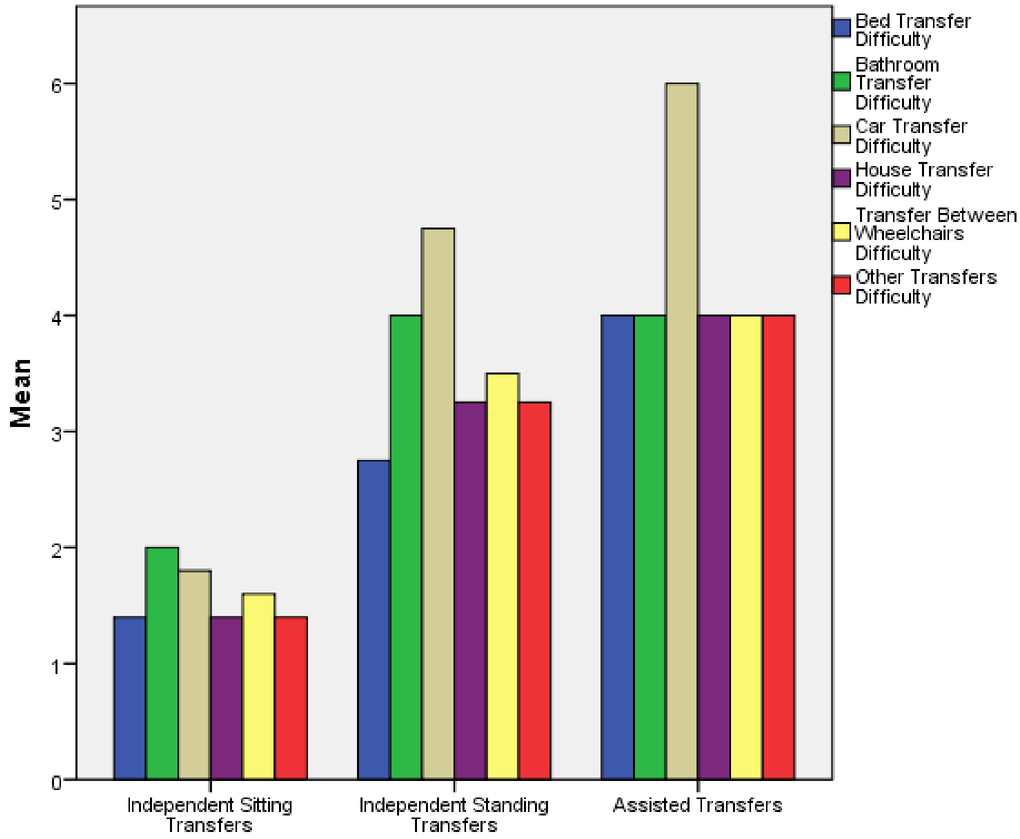

Figure 6-4 Bar chart showing mean reported difficulty for different types of transfers according to individuals' transferring technique

6.2.4 Presence and influence of pain on transfer performance

As expected, painful symptomatology in one or more areas of the upper limbs was reported by the majority of participants. Complaints of shoulder and wrist pain in the previous six months were the most common, affecting respectively 69% and 52.4% of the respondents. Frequencies of hand and elbow discomfort were only slightly lower, respectively 50% and 42.9%. Additionally, 52.4% of participants reported recurring pain in other body locations such as the neck, back and buttocks. The relationship between upper limb pain and wheelchair transfer was confirmed by the fact that 66.6% of the subjects complained that their pain was exacerbated by wheelchair transfers at least occasionally. Average intensity of pain, was moderately high for all upper limb areas with values ranging from 4 at the elbow to 4.45 at the wrist. The Chi-squared test revealed no significant association between presence of pain during transfers, and the technique used for transferring ($p = .236$). Furthermore, the Kruskal Wallis Test confirmed that there was no significant relationship between the wheelchair users' transferring technique and the intensity of shoulder ($p = .311$), elbow ($p = .680$), wrist ($p = .550$) and hand ($p = .974$) pain. The presence of upper limb pain during transfers did not significantly affect the number of daily transfers for individuals performing independent sitting ($p = .765$), independent standing (p = .656) or assisted transfers (p = .082). Overall, participants who complained of frequent upper limb pain during transfer performance generally reported higher level of difficulty for all transfer types. However, this difference was deemed significant only for bed ($\chi^2(3) = 8.417$, p = .038) and house transfers ($\chi^2(3) = 9.023$, p = .029). Post-hoc analysis showed that in both cases the differences were only significant when comparing subjects whose pain is always exacerbated by transfers and the other three groups (highest significant p = .043).

6.2.5 Motivation and satisfaction with transfer performance

Over 88% of subjects considered transferring skills extremely important, giving the maximum score of 7 on the provided Likert scale. This importance was further confirmed by the fact that, when asked about the effort invested in the task, 85.7% of the subjects stated that they invested great effort in performing wheelchair transfers safely and effectively (Score 6 and 7 on Likert scale). Participants were generally, satisfied with the way they transferred in and out of their wheelchair and they felt reasonably secure during the performance. However, 16.7% of respondents were unsatisfied with their skills (1-3 points on Likert scale) and 28.6% felt extremely tense during wheelchair transfers (Score 6 and 7 on Likert scale). Transferring technique and need for assistance did not seem to impact on the importance people attributed to wheelchair transfers (p = .137), the satisfaction with their ability (p = .17) or the perceived stress during wheelchair transfers (p = .119). However, a significant relationship was found between the transferring technique used by the participant and the effort invested in performing safe transfers ($\chi^2(2) = 7.575$, p = .023). Dunn's test showed that participants performing independent sitting transfers tried harder to perform safe transfers (6.65 ± 1.08) compared to participants using an independent standing technique (5.75 ± 1.39 min, p = .019) and participants performing assisted transfers (5.73 ± 1.95 min, p =.039). Regardless of their transferring technique, participants who reported increased difficulties for various types of transfers were less likely to be satisfied with their transferring skills ($r = -.505$, $p < .001$). Furthermore, pain during transfer also had an effect on how nervous subjects felt during transfer performance ($\chi^2(3) = 9.788$, p = .020). Post-hoc analysis revealed how differences in the level of perceived insecurity were significant only between subjects complaining of occasional pain during transfers (2.95 ± 2.16 min, p =.012) and subjects reporting constant pain during transfers (5.88 ± 1.25).

6.2.6 Use and needs for ATs

The vast majority of respondents, 73.8%, declared to benefit, in one or more situation, from the use of an assistive technology or from the presence of environmental modifications such as swivel seats or adapted vehicles. Overall, grab bars were the most commonly adopted, used by 42.9% of participants, followed by transfer boards (31%), hoists (16%), environmental modifications (11.9%) and other less common devices (7.2%). However, the type of transfer for which each assistive technology is usually employed differs from one device to the other. Grab bars were found almost exclusively within the house, particularly in the bathroom. Only four individuals declared having special handles mounted in their car in order to ease their transfers. On the other hand, the use of transfer boards was slightly more common for car transfers (33.3%), compared to bed (23.3%) or other house transfers (20%). As expected, hoists were found only within the house and used mainly for bathroom, bed, house or transfers between different wheelchairs. Reported environmental modifications concerned adapted vehicles in 66.7% of cases and hospital beds in the remaining 33.3%. No significant relationship was found between the likelihood of AT use and the transferring technique adopted by the subject ($p = .28$). Surprisingly, the choice of AT was only mildly affected by the individual's transferring technique. Transfer boards were more common among participants performing independent sitting transfers, while grab bars were used more by participants who transferred while standing up. However, the difference in AT distribution was only significant for hoists which were used almost exclusively by people needing assistance for transferring ($p = .025$). Regardless of participant's transferring technique, no association was found between the presence of pain during transfers and the use of ATs. However, as shown in Figure 6-5, participants who reported the use of various ATs during transfers were found to be significantly heavier (78.603 kg ± 22.186) than participants who transferred without using any AT (63.764 kg ± 16.256) $t(40) = -2.027$, $p = .049$.

Respondents reporting frequent use of one or more ATs were prompted to rate the usability of the assistive technologies they were familiar with. Not surprisingly, environmental modifications and grab bars were generally considered easier to use, with a mean score of 2.0 ± 1.56 and 2.56 ± 1.65 on a 7 point difficulty scale. Transfer boards closely followed with a mean score of 2.62 ± 1.56, while hoists were rated as most difficult with a mean score of 3.14 ± 2.27. Participants who declared no use of assistive devices on a regular basis were invited to provide one or more reasons for their choice. The majority of subjects simply stated that they had no need for any assistive devices (28.12%), while the remaining subjects provided reasons such as high cost (21.88%), low portability (21.88%) and external space constraints (15.62%). When participants were asked to describe one or more positive aspects of assistive technologies for wheelchair transfers, ease of use and increased confidence during transfer execution accounted for over 50% of responses. Portability and ability to partially relieve the load on the upper limbs were also included among the advantages of assistive devices by respectively 16.4% and 11% of the subjects. On the other hand, space constraints, unstable positioning, excessive weight and uncertainty about the correct way to use them were listed among the factors that can create difficulties when using assistive devices.

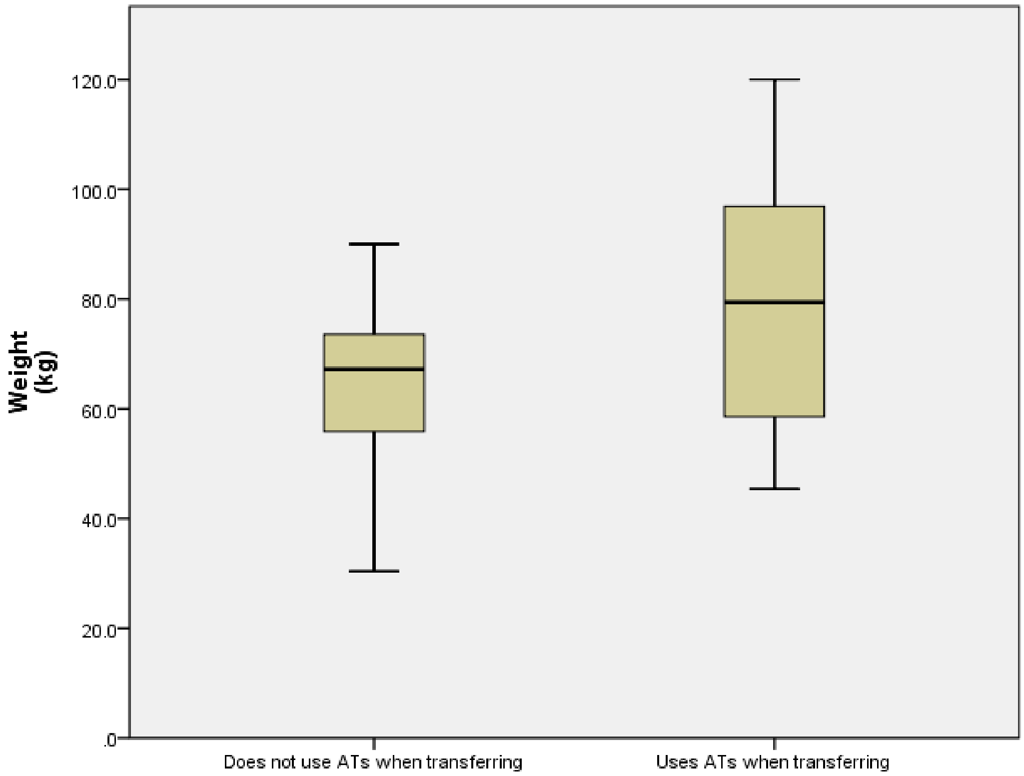

Figure 6-5 Boxplot showing weight differences between participants who use (or do not use) ATs when transferring

6.3 Discussion

Most studies on wheelchair transfers have focused their efforts towards attempting to isolate and explain individual variables that affect the performance of wheelchair transfers such as the presence of upper limb pain (Alm et al., 2008), the configuration of the transfer set-up (Toro et al., 2012) or the impact of specific aspects of the physical impairment affecting the individual (Desroches, Gagnon, Nadeau, & Popovic, 2013). As noted by Crytzer et al. (2015) this approach is not sufficient to capture the complexity of aspects that can affect the ability of an individual to perform wheelchair transfers. This is the first study that attempts to take a more comprehensive look at the various factors that can affect the performance of wheelchair transfers and explore the potential relationships among them.

Chapter 5 presented a study highlighting how the use of different transferring techniques can have a great impact on the safety of the transfer and the mechanical load withstood by the upper limbs. As transferring technique plays such an important role in the performance of wheelchair transfers, the first aim of this study was to analyse the individual characteristics that are associated with the performance of sitting, standing and assisted transfers. Results from the survey presented in this chapter show that primary medical condition is the main factor that determines the movement strategy adopted by the person when transferring. As weight has been shown to significantly decrease the functional abilities of many wheelchair users (Nyland et al., 2000), it was expected that individuals with higher bodyweight would be more likely to require assistance during transfers. However, findings show that, while greater bodyweight increased the likelihood of ATs use, it had no impact on the transferring technique used by participants nor did it affect their need for assistance. Results from the survey confirmed that transferring technique had an important impact on the performance of wheelchair transfers in real life. However, several other factors were found to have an impact on the performance of wheelchair transfers, regardless of the technique used by the subject when transferring (See Figure 6-6).

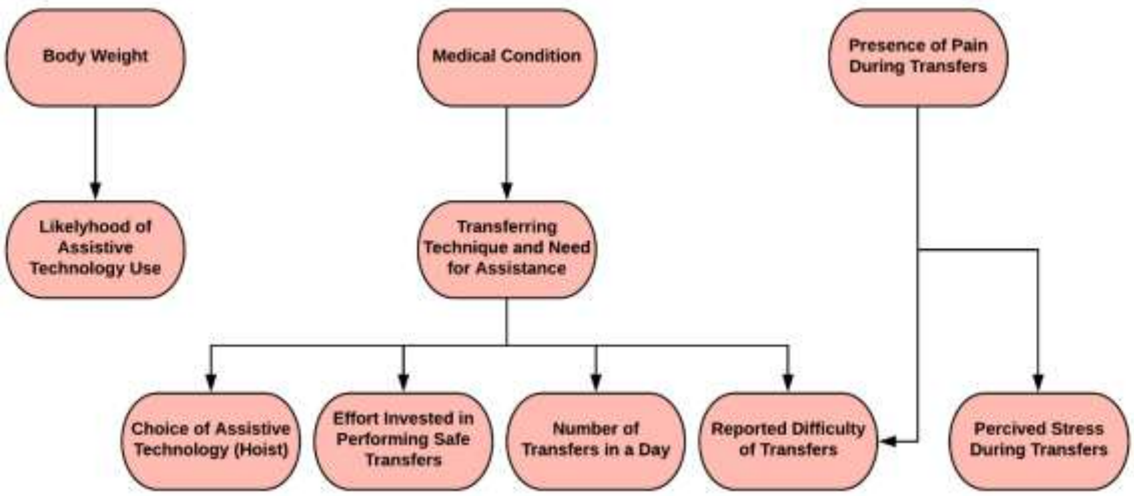

Figure 6-6 The diagram presented in the picture illustrates all the significant relationships, identified in the current survey, between the various factors related to the performance of wheelchair transfers.

In the survey carried out by Fliess-Douer et al. (2012), wheelchair users with different impairments, lifestyles and abilities agreed in rating transfers as the most essential skills in everyday life. The current study shows similar results, with 88% of respondents attributing crucial importance to their ability to transfer. Despite the fact that the importance attributed to the task was consistent across all wheelchair users, we found that individuals performing independent sitting wheelchair transfers reported investing more effort in ensuring the safety of their transfers. Wheelchair users who need assistance during transfers might be more likely to rely on their caregivers to make sure that transfers are performed in a safe and efficient manner. On the other hand, the scarcer safety consideration by wheelchair users performing standing transfers might be related to their lack of awareness. Most wheelchair users are likely to learn about the importance of using efficient and safe technique when transferring during rehabilitative training. Wheelchair skills, and transfers, training are considered an important part of rehabilitation for individuals with SCI (Taylor-Schroeder et al., 2011), who represented a substantial portion of the survey participants who performed independent sitting transfers. Respondents performing independent standing transfers were individuals with CP, MS and EDS which potentially makes them less likely to have received comprehensive wheelchair transfers training (Fliess-Douer et al., 2012; Worobey, Rigot, Hogaboom, Venus, & Boninger, 2017). Without proper training they might have limited knowledge of how to best perform safe and efficient transfers and be less aware of the potential risks associated with transferring.

Reported perceived difficulty of different transfer type was mostly in line with results presented by Janssen et al. (1994) who measured physical strain, based on the individual’s heart rate, of several standardised ADLs (transfers, negotiation obstacles, household tasks, washing hands) including various wheelchair transfers. Transfers to the car seat and to a shower wheelchair were identified as more strenuous activities, while toilet and bed transfers appeared to be less demanding. In the current study, participants identified car transfers and transfers between wheelchairs as more difficult to perform, however bed transfers were considered significantly easier than bathroom transfers. Differences could be due to different experimental set ups, as Janssen et al. (1994) asked participants to perform transfers in a series of standardized environments, whereas survey’s participants were asked to evaluate the transfers they perform in their own home. Additionally, Janssen et al. (1994) evaluated three bathroom transfers (toilet, shower bench and shower wheelchair) separately, while in the current study they were grouped together as bathroom transfers which might have confounded results. Transferring technique was found to have an important impact on the perceived difficulty of wheelchair transfers. Unsurprisingly, participants who needed assistance for transferring reported consistently higher scores for transfer difficulty across different transfer types. On the other hand, it was expected that participants who were able to perform independent standing transfers to report lower difficulties than participants who relied on their upper limbs for transferring. However, even if able to reach a standing position, many wheelchair users will lack both lower limb strength and balance. This is likely to make their transfers more challenging, despite the fact that their physical impairment appears to be less severe compared to people who need to fully rely on their upper limbs for transferring.

Overall, the average number of transfers performed daily by the survey's respondents was lower than reported in literature. However, in the study carried out by Curtis & Black (1999) participants were all athletes and Finley et al. (2005) included only paraplegic subjects able to perform independent wheelchair transfers. Unsurprisingly, participants who required assistance reported the lowest number of transfers per day. The combination of increased difficulty and the need to rely, at least partially, on caregivers' help, made participants more likely to only perform transfers that were strictly essential. Similarly, it is reasonable to assume that the higher difficulty reported by individuals performing standing transfers is at least partially responsible for the reduced number of transfers carried out in a day.

The incidence of upper limb pain among survey's respondents was consistent with findings from the literature and appeared unaffected by participants' transferring technique (Ballinger et al., 2000; McCasland et al., 2006). The interference of upper limb pain during transfer performance reported by Samuelsson et al. (2004) was confirmed by the fact that over 66% of participants reported that pain was often exacerbated by the performance of wheelchair transfers. On the other hand, as noted by Finley et al. (2005), the presence of upper limb pain did not have significant effect on the number of wheelchair transfers performed in a day. As previously highlighted, the ability to transfer in and out of their wheelchair is crucial for the individual's independence. For this reason, wheelchair users might chose to endure the pain caused by the task in order to ensure their independence. The presence of upper limb pain was also shown to affect the perceived difficulty of transfer performance and increased the sense of anxiety people might experience during the performance of wheelchair transfers. This is particularly important considering that transfers have a great influence on the overall fear of falling that wheelchairs users might experience (Butler Forslund, Roaldsen, Hultling, Wahman, & Franzén, 2016). Anxiety might also negatively affect performance and increase the risk of falls, as it has been documented for walking, particularly among elderly subjects (Jørstad et al., 2005).

Surprisingly, the choice of using ATs was mostly not affected by the transferring technique of the individual. Additionally, despite the fact that medical guidelines recommend the use of assistive technologies for wheelchair transfers for all subjects experiencing upper limb pain and/or at risk for upper limb injury (Gagnon, Koontz, et al., 2009), no relationship was found between the likelihood of AT use and the presence of upper limb pain during transfers. Participants reporting use of ATs were found to weigh more which suggest that ATs are considered a valuable tool when the task becomes physically strenuous. Several people used more than one assistive technology and the choice can be affected by environmental conditions and the type of transfer to perform. Although this was expected for fitted modifications and non-portable devices, such as wheelchair hoists, the use of transfer boards was also found to be subjected to this variability. As illustrated in the study conducted by Haubert et al. (2015) the environmental conditions in which a wheelchair transfer is performed will have an important effect on the movement strategy of the individual and these changes appear to be relevant regardless of the technique or AT used.

Participants generally found their assistive technologies easy to use and reported an increased level of confidence when performing transfers. Over 83% of the respondents reported encountering at least one difficulty when using assistive technologies. Frustrations were mainly related to physical limitations of various devices, including excessive weight, bulky profile and instability during transfer performance. Inability to deal with space constraints, low portability and excessive cost were also among the most common reasons participants provided to explain why they chose not to use any assistive technology. These findings suggest that the different types of transfers the individuals perform and the environmental constraints associated with each type of transfer might affect, beside the transferring technique, also the ability to use assistive technologies when needed.

Finally, despite the effort to include participants with a diversity of impairments, over half of the survey respondents reported SCI as a primary medical conditions and paraplegic participants made for over 60% of the respondents included in the group performing independent sitting transfers. However, the remaining participants were more evenly spread across other medical conditions such as MS, CP and EDS. The overrepresentation of people with SCI in research targeting wheelchair users as a whole might be the result of the selective targeting perpetrated by many researchers over the years. Trauth et al. (2000) reported that people who were more aware of research and had previous experiences of participation were more likely to take part in further research studies. The more frequent involvement of people with SCI might have created a community of individuals who are more likely to be active on forums and websites where calls for participants are disseminated and are also more willing to participate. Overtime, consistent efforts to include people with a larger spectrum of impairments could help facilitate the involvement of participants who are currently hard to reach.

6.4 Chapter summary

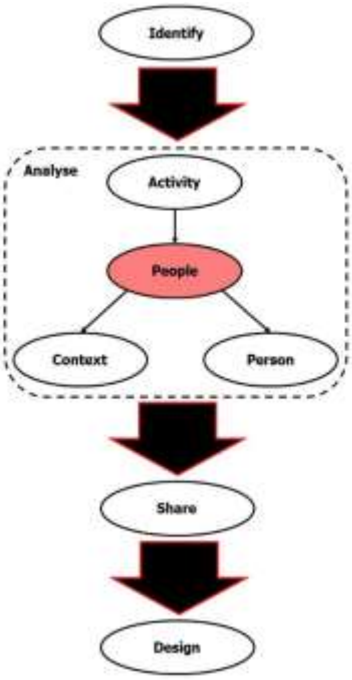

Figure 6-7 Diagram illustrating how the current study corresponds to the Analyse (People) phase of the 2PAC framework

This chapter presents the second study which focuses on the People's investigation from the Analyse phase of the 2PAC framework (see Figure 6-7). There are several factors that can affect the performance of transfers in the real world and it is the combination of these individual factors that makes transfers a challenging activity for many wheelchair users. In both Chapter 2 and Chapter 5 it was highlighted how different transferring technique can radically change not only the sequence of movements that the person carries out when transferring, but also the risks and potential difficulties associated with the performance of wheelchair transfers. To this end, this survey was designed to investigate both the individual's characteristics associated with the use of different transferring techniques and the interplay between wheelchair users' transferring technique and the other factors that can affect the performance of wheelchair transfers in their everyday lives.

Findings from the current study show how transferring technique is usually determined by the individual's impairment. In turn, the choice of transferring technique will greatly affect the perceived difficulty of different types of wheelchair transfers and, consequentially the number of transfers that people will perform in a day. On the other hand, the relevance of other factors seems to be unaffected by the transferring technique used by the person. Concerns about the impact of transfers on the development of upper limbs injuries and pain are usually only mentioned in relation to people performing independent sitting wheelchair transfers. However, the presence of pain during transfers is a problem concerning all wheelchair users. Furthermore, the presence of pain was also related to increased stress during transfers which, in turn, might lead to a greater risk of falling. Currently, AT use was found to be unrelated to both transferring technique and presence of pain during transfers and only linked to increased body weight. Overall, available ATs are only moderately effective in enabling people to perform wheelchair transfers and they can cause frustration for the users due to their high cost and limited functionality. The text box below shows the design implications that have been extracted from the results of the study presented in this chapter.

Design Implications:

1. New ATs for wheelchair transfers should target people performing unassisted standing and assisted transfers perform less transfers and experience greater difficulties than people performing unassisted sitting transfers
2. People with higher body weight are more likely to use ATs during transfers which can indicate that over a certain body weight threshold a good technique is not sufficient to reduce the effort require for transferring
3. People performing independent standing transfers and assisted transfers are less aware of the need to adopt a safe transferring technique and new ATs should help them to develop safer strategies for transferring
4. People who experience upper limb pain are more likely to feel stressed and experience difficulties during transfers, which can make them more likely to benefit from ATs that improve safety
5. Cost, portability and stability are important attributes of ATs for wheelchair transfers

Chapter 7 Does the setting matter? Analysis of wheelchair transfers across different environmental conditions

Many ADLs such as getting up from bed, taking a shower or having dinner with one's family take place in specific environments that often shape the way in which the person carries out the activity. The performance of general skills like wheelchair pushing or transferring is usually aimed at the completion of various ADLs. The specific ADL will determine the physical context in which these skills are performed. In turn, the physical environment will affect the way in which the person pushes (Hurd, Morrow, Kaufman, & An, 2008) or transfers to and from the wheelchair (Toro et al., 2012). Respondents of the survey presented in Chapter 6 stated that they often perform different types of wheelchair transfers and reported varying levels of difficulty depending on the type of transfer performed. The greater challenge presented by certain types of transfers can become a barrier for some wheelchair users and causes them to be unable to complete the transfer independently. Other wheelchair users might still be able to carry out transfers without assistance. However, the constraints imposed by the physical environment might cause them to modify their technique in a way that is unsafe and/or less physically efficient.

Among studies looking at the characteristics of wheelchair propulsion, several authors have attempted to evaluate the effect of different types of environmental conditions, in the form of indoor and outdoor terrains, on wheelchair pushing. For example, Hurd, Morrow, Kaufman, & An (2008) measured temporal spatial parameters and upper limbs kinetics during wheelchair propulsion across four different level terrains: tile, carpet, smooth and aggregate concrete. Their results show how outdoor terrain, particularly aggregate concrete, often presents a more difficult challenge for wheelchair users requiring greater pushrim forces and increased pushing frequency. Similarly, Koontz et al. (2005) observed that start-up pushing on surfaces that offer greater resistance such as ramps, grass and outdoor interlocking pavers required considerably greater forces compared lower friction surfaces such as tiles, hardwood flooring and low pile carpet. Changes in environment are not only associated with differences in the forces required to push the wheelchair, but can cause important variations in the propulsion pattern exhibited by the individual. Richter, Rodriguez, Woods, & Axelson (2007) observed that, when pushing uphill, participants were more likely to use an arc pattern (hands sliding up along the push rim during the recovery phase) as they felt they needed more control over their wheelchair. Furthermore, small irregularities (e.g. bump in the road) often present in outdoor terrains appear to increase the asymmetry between the two upper limbs during wheelchair propulsion (Hurd et al., 2008b). Overtime, this may cause uneven loading of the upper limbs that can lead to the development of injuries (Hurd et al., 2008b).

From a biomechanical point of view, wheelchair transfers are less constrained activities than wheelchair propulsion. For this reason, it is reasonable to expect that environmental conditions will play an even bigger role in determining the movement strategy adopted by the individual and the potential risks associated with transfer performance. Despite this, studies on wheelchair transfers have mainly been carried out within laboratory settings, often using sophisticated and expensive equipment and standardized protocols (Gagnon, Nadeau, Desjardins, & Noreau, 2008; Kankipati et al., 2015; A. M. Koontz, Gagnon, Brindle, & Cooper, 2010; A. M. Koontz et al., 2011). These studies focus on specific aspects of the independent sitting transferring technique and the effect of vertical and horizontal gaps between transfer surfaces. They conclude transfers using a head-hips technique (the person leans forward and pivots by turning the shoulder in the direction opposite to the direction of the transfer) compared with upright trunk technique (the person does not lean forward and keeps the shoulders in line with the buttocks when moving towards the target surface) (Kankipati et al., 2015; A. M. Koontz et al., 2011); and transfers between surfaces with minimal height difference and small horizontal gaps (Gagnon, Nadeau, Desjardins, & Noreau, 2008; Kankipati et al., 2015; A. M. Koontz et al., 2010) will help to reduce mechanical load and preserve upper limb function. Each of these studies comment on the importance of placing the leading hand close to the initial position of the body in order to ensure optimal technique. These laboratory-based studies offer great advantages in terms of accuracy of measurements, reproducibility and possibility of comparing results across different studies, however, these settings are often not representative of real life conditions (Crytzer et al., 2015). This is important as the positioning of the leading hand is itself determined by the environment in which the transfer is taking place and can influence the strategy adopted by individuals. Only a few researchers have explored the characteristics of wheelchair transfers across different real life conditions.

Transferring into and out of a car has been determined as one of the most important life skills for manual wheelchair users regardless of their medical condition or level of ability (Fliess-Douer et al., 2012). Additionally, compared to other everyday transfers, car transfers are more likely to be associated with shoulder pain (Alm et al., 2008) and increased physical strain (Janssen et al., 1994). Despite this, only two studies have looked at the movement strategies adopted by wheelchair users when performing car transfers (Haubert et al., 2015; Kataoka et al., 2012).The study by Haubert et al. (2015) provides a descriptive analysis of the technique used by 29 paraplegic participants when performing transfers into and out of their car and loading their wheelchair into and out of their vehicle. A great variability of leg and hand positioning was reported, which would be likely to result in significant changes in the overall movement strategy adopted by the individual. Moreover, the position of the leading hand was found to be associated with the intensity of shoulder pain. Participants who placed the leading hand on the steering wheel were more likely to exhibit higher WUSPI scores compared with participants who placed their hand on the driver seat or used the overhead grab bar (or door frame) (Haubert et al., 2015). The study carried out by Kataoka et al. (2012) focus on the kinematic analysis of the movement strategies used during car transfers by 4 individuals with C6 tetraplegia using a transfer board. All participants demonstrated a rotatory head-hip relationship (head moves in the opposite direction of the buttocks) to facilitate the transfer. However, possibly due to their different balance capacity, they showed various degrees and combination of trunk and neck flexion during the dynamic phases of the transfer. Unfortunately the study did not report any detail concerning the positioning of hands and feet during car transfers (Kataoka et al., 2012). Both studies provided descriptions of the movement strategies employed by participants. However, neither included an objective evaluation concerning how these changes affected the risk of falling and upper limb injury which are commonly associated with transfer performance (Forslund et al., 2017; Hogaboom, Worobey, et al., 2016).

Although important, car transfers represent only one of the types of transfers that wheelchair users normally perform daily. For example, in the study carried out by Bode et al. (2014) bath tub and shower transfers were found to be amongst the most difficult tasks to perform for among SCI patients within a year after hospital discharge. The only study which included a full ergonomic assessment of different transferring conditions was the one carried out by Toro et al. (2012). This study investigated how factors such as horizontal and vertical gaps, obstacles and grab bars presented alone, or in combination, affected the ability of 120 individuals, with different medical conditions and various levels of abilities, to perform wheelchair transfers (Toro et al., 2012). Results from this study show that, when an obstacle is present, 42% of participants were unable to complete a wheelchair transfer. However, when a frontal grab bar was present, the number decreased to 33%. The aim of the study was to understand how standards for the design of the built environment, developed to ensure the delivery of the Americans with

Disabilities Act Accessibility Guidelines worked in practice. However, the setting of the study included a custom-built, modular transfer station used to simulate the different transfer set ups rather than observing the performance of wheelchair transfers in real world environments. Additionally, the results were aimed at the creation of more accessible environments and the authors do not provide any information as to how different conditions affected the technique or the perceived difficulty of wheelchair transfers.

One of the main challenges associated with the evaluation of transfer performance across different scenarios is represented by the need to employ an assessment instrument that is representative and objective yet portable enough to ensure feasibility. Most studies focussing on evaluating the risk of falls or upper limb injuries during the performance of wheelchair transfers focus their analysis on the quantification of kinematics, kinetics of trunk and upper limbs (Finley et al., 2005; Gagnon et al., 2012; Gagnon, Nadeau, Noreau, Eng, et al., 2008; Kankipati et al., 2015). Despite its accuracy and objectiveness, traditional biomechanics analysis relies on the use of force platforms and motion capture systems. These systems are both complex to set up and difficult to move across different transfer scenarios making them unsuitable for studies featuring multiple set ups in different locations. Instrumented pressure sensing gloves, such as the ones used in the study presented in Chapter 5, could provide inaccurate data for scenarios featuring transfers onto beds, couches and car seats as they require the contact with rigid surfaces in order to provide correct measurements (Parmar et al., 2017).

Wearable devices such as tri-axial accelerometers have been used to measure temporal-spatial parameters of gait, classify type and intensity of physical activity and even monitor the occurrence of wheelchair transfers (Bonomi, Goris, Yin, & Westerterp, 2009; García-Massó et al., 2015; J. A. Lee, Cho, Lee, Lee, & Yang, 2007). However, no existing was found study where wearable sensors had been used to evaluate the quality of wheelchair transfer performance. Although EMG can be used to monitor the muscular activity and can provide an indication for the risk of upper limb overuse, they give no indication of the safety of the transfer (Gagnon, Nadeau, et al., 2009; Wang et al., 1994). Alternatively, the TAI developed by McClure et al. (2011) provides an objective tool to evaluate all aspects of wheelchair transfer performance including safety and upper limb conservation strategies. As highlighted in both Chapter 2 and Chapter 5, the TAI is a suitable instrument to evaluate the quality of wheelchair transfers performed with different techniques (sitting, standing) and for transfers performed with the aid of transfer boards or human assistance (Tsai et al., 2013). Furthermore, the TAI is not sensitive to the set-up of wheelchair transfers making it an ideal instrument to evaluate wheelchair transfers across a variety of real world scenarios.

The study presented in this chapter aims to explore how wheelchair transfer technique changes across different real-world transfer scenarios. The impact that different environmental conditions have on objectively measured transfer quality, subjective perception of difficulty, and the relationship between these two assessment tools were also explored.

7.1 Method

7.1.1 Participants

This study was carried out in collaboration with the Rehabilitation Engineering and Applied Research (REAR) Lab at the Georgia Institute of Technology and has obtained ethics approval from both the UCL Ethics Committee and the Institutional Review Board at Georgia Tech. Information sheets and consent forms distributed among participants are included in Appendix B of this thesis. As for the study illustrated in Chapter 5, one important aim was to recruit a cohort of wheelchair users with various medical conditions and who exhibited different independent transferring techniques. Participants were included in the study if they met the following inclusion criteria: (1) aged between 18 and 65 years, (2) use a manual or power wheelchair as their primary means of mobility and have at least 6 months of experience as a wheelchair user, (3) perform wheelchair transfers independently using a sitting or standing technique with or without the use of a transfer board. Participants were excluded if they (1) were currently admitted in a hospital or a rehabilitation facility, (2) reported having upper extremity pain that was exacerbated by transfers, or whose ability to transfer was limited by the pain, (3) reported any medical condition that was likely to be exacerbated through the study protocol such as angina, exercise induced asthma, uncontrolled hypertension etc.

Thirteen participants, ten males and three females volunteered to take part in this study. A summary of demographic characteristics is provided in Table 7-1. Ten participants had a SCI, nine reported a complete SCI and only one an incomplete SCI (Participant 2). Four of the participants with SCI had tetraplegia (C6-C7) and six had paraplegia (T1-T12). Of the remaining three participants, one had a below the knee amputation (BKA) on the left leg, one had neuromyelitis optica (NMO) and one had transverse myelitis (TM). All participants were residents in the local community. Eight participants reported using rigid frame manual wheelchairs as a primary means of mobility, three participants reported using foldable manual wheelchairs and two participants used electric wheelchairs.

Table 7-1 Demographic characteristics of participants

Participant	Gender	Age	Height (cm)	Weight (kg)	Medical Condition	Years of Use	N of transfers per day
1	F	49	165	62	SCI T4	1.3	13
2	M	26	185	90	SCI C6	2.1	10
3	M	26	178	64	SCI C7	0.8	12
4	M	47	183	82	SCI T4	8.5	8
5	M	25	191	70	SCI T5	2.8	8
6	M	39	165	107	BKA (left)	6.1	18
7	F	51	173	118	NMO	5	8
8	M	30	196	80	SCI C6	12	16
9	M	35	170	73	SCI T12	3.3	10
10	M	35	191	107	SCI T1	7.8	10
11	M	47	175	89	SCI C7	9	8
12	M	46	188	104	SCI T5	10.9	10
13	F	58	152	54	TM	9.5	17
Mean		39.5	178.9	84.6		6.1	11.4
SD		10.9	12.7	20.0		3.8	3.6

7.1.2 Experimental Protocol

After signing the informed consent, all participants filled in a short questionnaire with questions concerning their demographic information, type of transfers usually performed, presence, location, and intensity of upper limb pain, use of assistive technologies during wheelchair transfers, perceived difficulty for different transfer types, overall satisfaction with transfer technique and specific difficulties encountered when performing wheelchair transfers. All ratings for pain and transfer difficulty were provided on a 10-point scale. Based on the results of the survey presented in Chapter 6, four types of wheelchair transfers that were found to be common among wheelchair users with varying levels of ability were identified: Wheelchair-Car Transfers, Wheelchair-Toilet Transfers, Wheelchair-Bed Transfer and Wheelchair-Couch Transfer. After completing the initial questionnaire, participants were then asked to perform a series of transfers for three of the four selected scenarios. All participants had to perform four Wheelchair-Bed transfers and the height of the bed was always set to match the height of the individual's wheelchair. Participants where then able to choose two out of the other three scenarios proposed (toilet, couch or car), according to the types of transfers they performed more frequently. The order of the three selected scenarios was randomised for each participant. Figure 7-1 shows the setting for bed, toilet and couch scenarios.

Figure 7-1 Set ups for the bed (left), couch (centre) and toilet (right) transfer scenarios

When a participant chose to perform a wheelchair to car transfer, the participant's own vehicle was used for the study. Four participants drove a Jeep where the height of the driver seat was over 1.5 meters from the ground. Two (Participant 8 and 12) transferred directly onto the driver's seat while two (Participant 2 and 3) transferred onto a car lift as shown in Figure 7-2. Four participants drove sedan cars, and two owned an adapted minivan fitted with a swivel seat and performed the transfers with the wheelchair inside the car as shown in Figure 7-3.

Figure 7-2 Participant transferring to and from a standard Jeep (left) and participant transferring to and from a Jeep equipped with a car lift (right)

Figure 7-3 Participant transferring to and from the driver seat of an adapted minivan (left) and participant transferring to and from a the driver seat of a sedan car (right)

Each participant was asked to perform up to four transfers (two from the wheelchair onto the target surface and two from the target surface onto the wheelchair seat) for each of the chosen scenarios with a minimum rest of one minute after each transfer. Adequate resting periods were guaranteed across all transfers performed in order to avoid fatigue.

7.1.3 Descriptive analysis, height difference and perceived difficulty

As all participants used their own wheelchairs throughout the experiment, this resulted in different height gaps between the wheelchair seat and the other transfer surface (except for the Bed-Wheelchair transfer which was always level). Therefore, height differences between wheelchair and target seat was measured and assigned to one of three categories: gap less than 5 cm, gap between 5 and 15 cm and gap greater than 15cm. Video recordings of participants' performance were collected using 2 USB Logitech C930e webcams (Logitech Europe S.A., CH) positioned at different angles in order to capture all details of the transfers. Video recordings were used to analyse the transfer strategy adopted by the subject, including documentation of hand and feet positioning, the number of scoots before body lifting, false starts, and total transfer time. As movement strategies adopted during transfers are highly dependent on the technique used by the individual, differences across transfers performed in various scenarios were compared only among individuals using the same transferring technique (independent sitting, independent standing, transfer board). To simplify this analysis and allow comparison across different transfers and individuals, a standardized transfer description sheet was created for the study. At the end of each transfer, participants were also asked to rate its difficulty using a modified CR 10 Borg Scale (Capodaglio, 2002). Both instruments are available for revision in Appendix C of this thesis.

7.1.4 Evaluation of transfer quality (TAI)

The video recordings of the transfers performed by participants were used to rate transfer quality using part 1 of the TAI 3.0 (Tsai et al., 2013). Transfer performance was assessed independently by two trained physiotherapists and any disagreement over different scores was resolved through consensus meetings. Items 4, 5 and 15 of the TAI were removed from the evaluation as they were not applicable to more than 80% of the transfers performed by participants. This instrument has already been applied to the evaluation of wheelchair transfers' quality for the study illustrated in Chapter 5 (see Section 5.1.3), its features would not be described again here. Details concerning the appropriateness and reliability of the TAI alongside an overview of its overall structure can be found in Section 5.1.3. A copy of Part 1 of the TAI 3.0 is also included in Appendix C of this thesis.

7.1.5 Statistical analysis

Descriptive statistics including mean and standard deviation, were calculated for demographic data and to summarise participants' answers to the initial questionnaire. As seen in Chapter 2 and 5, the sequence of movements performed by the individual when transferring is dependent on the technique used (i.e. independent seated transfer, independent standing transfer, seated transfer with transfer board). For this reason, transfers were assigned to three different categories according to the technique used by the individual. TAI scores attributed to participants' transfers and total transfer time were checked for normality using the Shapiro Wilk test. Due to the non-normality of the data the Kruskal-Walllis test was first used to assess the impact of different transfer scenarios and height gaps on total transfer time and TAI score. Furthermore, the Kruskal-Walllis test was also used to assess the impact of different transfer scenarios, and height gaps on the perceived difficulty reported by the individual. Where significant differences were found a Dunn's test with Bonferroni correction was used for Kruskal-Wallis post-hoc pairwise comparison. Spearman's correlations were used to investigate the presence of a linear relationship between the total TAI score, total transfer time and the perceived difficulty reported by the individual. The level of significance for all tests was set at 0.05. The statistical analysis was performed using SPSS 24 statistical software (SPSS Inc., Chicago, IL, USA).

7.2 Results

7.2.1 Initial questionnaire

None of the participants complained of upper limb pain on the day of the study. However, four participants reported having had pain in the last six months that affected one or more areas of their upper limbs. Two reported association between pain and transfer activities in the past. All participants reported regular performance of independent transfers at home, one participant (Participant 10) mentioned the need for assistance when transferring in and out of the bathtub at home. Only two participants performed transfers with the aid of a transfer board during this study, however, three additional participants declared regular use of a transfer board transfers onto shower wheelchiars. Most participants were satisfied with their transfer skills and felt safe during wheelchair transfer performance. However, two individuals (Participants 1 and 10) identified the need to improve some aspects of their technique, particularly the need to strengthen the upper limbs or find better strategies to relieve weight from them. All participants stated that they routinely performed bed to wheelchair transfers, transfers in the bathroom and car transfers. Other wheelchair transfers around the house were a common occurrence for eleven participants, while transfers between wheelchairs were performed frequently by only six participants. Other common transfers described by participants were: transfers onto stair lifts, mobility scooters and standing frames.

Average difficulties reported on the 10-point scale for the different types of routinely performed transfers were as follows: wheelchair-bed transfers 1.38 ± .65, wheelchair-toilet transfers 1.92 ± 1.03, wheelchair-car transfers 1.85 ± 1.34, other wheelchair transfers inside the house 2.0 ± 1.10 and transfers between wheelchairs 2.3 ± 1.51. (See figure 7-4). When asked what elements might cause them additional difficulties when performing wheelchair transfers, most participants identified environmental factors such as the presence of large height difference or horizontal gaps, lack of space that prevents the correct positioning of the wheelchair, unfamiliar setup or the potential instability of one of the transfer surfaces. Other concerns expressed by participants were related to personal factors such as spasticity, fatigue and tiredness.

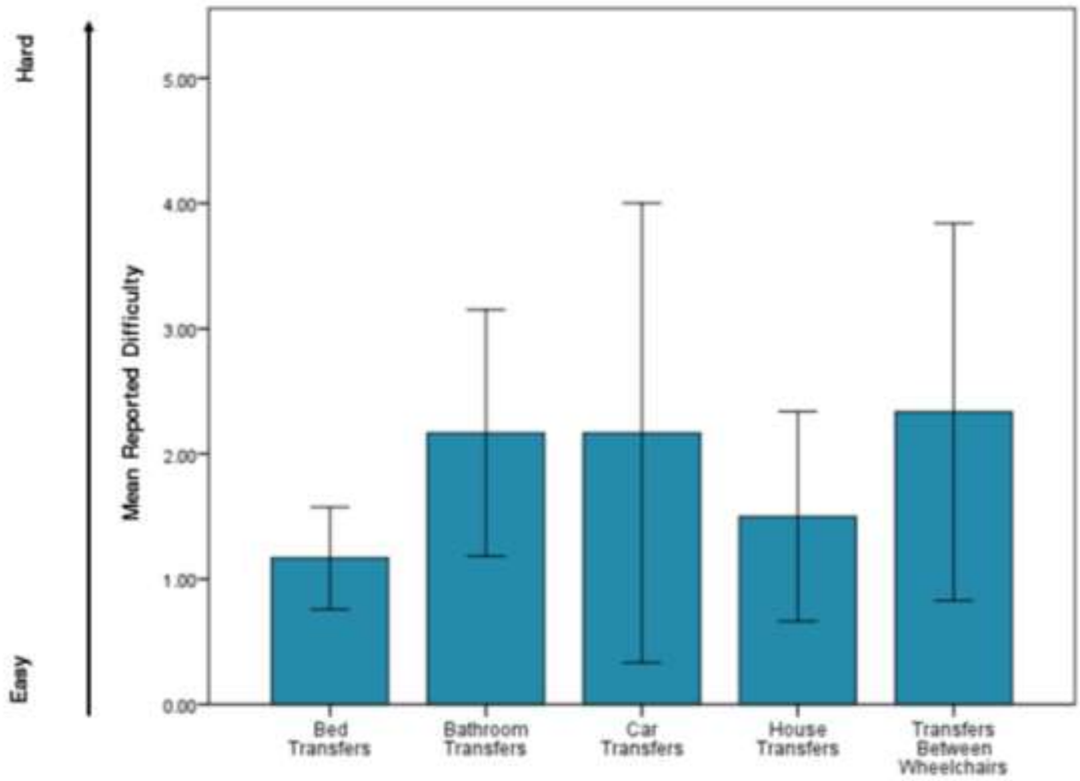

Figure 7-4 Bar chart showing mean reported difficulty, and SD, for different types of transfers usually performed by participants.

7.2.2 Transfers characteristics

Data from 153 transfers were collected from the 13 participants. Only one participant (Participant 1) was unable to complete the whole protocol as she was only able to complete one of the four couch transfers, resulting in a total of nine transfers. One hundred and twelve transfers were performed using an independent sitting technique, 26 with a standing technique and 15 with the assistance of a transfer board. An overview of the transfers performed by participants during the study, the technique used, the scenarios in which they were performed alongside mean TAI score and perceived difficulty is illustrated in Table 7-2.

Table 7-2 Technique, number and scenarios of wheelchair transfers performed by participants during the study

Participant	Technique	N of transfers performed	Scenarios	TAI Score	Percived difficulty	Transfer Time (s)
1	Transfer Board	9	Bed, Car, Couch	7.1±1.33	2.1±.6	5.93±2.81
2	Sitting (10), Standing (2)	12	Bed, Car Toilet	7.2±.74	1.8±.96	2.88±2.89
3	Sitting	12	Bed, Car Toilet	9.4±.63	2.7±.49	1.31±.38
4	Sitting	12	Bed, Car Toilet	6.6±.77	2.5±.52	1.48±.46
5	Sitting	12	Bed, Car Toilet	8.2±1.1	1.6±.9	1.63±.38
6	Standing	12	Bed, Couch, Toilet	6.1±.97	1.0±0	4.21±1.3
7	Standing	12	Bed, Couch, Toilet	5.7±.79	1.7±1.56	12.01±4.08
8	Sitting	12	Bed, Car Toilet	7.4±1.1	1.0±0	1.57±.3
9	Sitting	12	Bed, Car Toilet	8.5±.71	1.0±0	1.63±.43
10	Sitting	12	Bed, Car Toilet	6.2±.68	1.9±.51	1.35±.39
11	Transfer Board (6), Sitting (6)	12	Bed, Car Couch	4.7±1.11	1.3±.89	4.04±3.99
12	Sitting	12	Bed, Car Toilet	7.4±1.35	1.9±.67	1.91±.56
13	Sitting	12	Bed, Car Toilet	6.7±1.48	2.1±1.16	1.11±.18

Transfer technique was constant among all scenarios for eleven participants. However, Participant 2 used an independent sitting technique for ten transfers and a standing technique for two transfers. Participant 11 transferred using an independent sitting technique six times and with the assistance of a transfer board for the remaining transfers. Eighty-four of the transfers performed (52 bed, 12 toilet, 20 car) had a height difference between start and target surface of less than 5cm. For 61 of the transfers performed (32 toilet, 16 car, 13 couch), the height difference was between 5 and 15 cm. The remaining eight transfers (car) featured a height gap greater than 15 cm.

7.2.3 Effect of height gap and scenario on transfer quality, time and difficulty

Height gaps were only found to have a significant effect on TAI score ($\chi^2(1) = 6.56$, $p = .01$, $\eta^2 = .61$) for transfers performed with the aid of a transfer board. TAI score was significantly lower for transfers performed between surfaces featuring gaps of 5-15 cm (4.3 ± .88, $p = .01$) compared to level transfers (7.01 ± 1.23). No other significant difference of height gaps on TAI score was observed for transfers performed with an independent sitting ($p = .61$, $\eta^2 = .01$) or standing technique ($p = .71$, $\eta^2 = .03$). Regardless of the transferring technique used, height gaps did not appear to have any significant effect on either total transfer time or reported difficulty (lowest $p = .1$).

A significant difference in the reported difficulties among transfers performed in different scenarios was found for both independent sitting ($\chi^2(2) = 7.84$, $p = .001$, $\eta^2 = .126$) and standing transfers ($\chi^2(3) = 4.19$, $p = .017$, $\eta^2 = .489$). Among participants who transferred with an independent sitting technique, toilet transfers were judged to be significantly more difficult (2.17 ± .88) than bed (1.47 ± .65, $p = .001$) and car transfers (1.63 ± .82, $p = .012$). On the other hand, when transfers were performed with a standing technique, car transfers were found to be significantly more difficult (3.5 ± .71) than bed (1 ± 0, $p = .03$), and toilet transfers (1 ± 0, $p = .03$). Among transfers completed with the aid of a transfer board, no significant differences were found in the reported difficulties across the different scenarios ($p = .32$, $\eta^2 = .184$). However, the different scenarios had a significant effect on the TAI score attributed to transfers performed with a transfer board ($\chi^2(2) = 6.629$, $p = .036$, $\eta^2 = .612$). Post hoc analysis showed that couch transfers received significantly lower TAI scores (4.3 ± .88), compared to both bed (6.93 ± 1.29, $p = .022$) and car transfers (7.13 ± 1.32, $p = .018$). Regardless of the transferring technique used, transfer scenarios did not appear to have any significant effect on the total transfer time or reported difficulty (lowest $p = .42$).

No significant correlation was found between TAI score and reported difficulty for independent sitting transfers ($p = .3$), independent standing transfers ($p = .72$) and transfer board transfers ($p = .45$). Similarly, we found no significant correlation between TAI and total transfer time for independent sitting transfers ($p = .23$), independent standing transfers ($p = .17$) and transfer board transfers ($p = .25$).

7.2.4 Descriptive Analysis

When transfers were performed by individuals using an independent sitting technique, the overall strategy was similar for both bed and toilet transfers, and car transfers where the vehicle was fitted with either a lift or a swivel seat. Across these scenarios, both leading and trailing hands were often positioned on the transfer surface, flat or in a fist. Even in the toilet scenario where two handrails were available, participants utilized them for only 25% of transfers on the leading side and for 33.3% of transfers on the trailing side. Both feet were kept on the footrest for only 10.8% of transfers, for 48.65% of transfers they were both placed on the ground and in the remaining cases one was placed on the ground while the other one was positioned on the footrest of the wheelchair.

Movement strategies were different for transfers performed between the wheelchair and the driver seat of a sedan car or a jeep. For these particular car transfers participants positioned one foot inside the car and one either on the ground or on the wheelchair footrest for 56.3% of the transfers, both feet inside the car for 25% of the transfers and both feet on the ground in the remaining cases. The leading hand was placed on the wheelchair cushion or the car seat for 75% of the transfers. Remaining car transfer cases were equally split between transfers where the participant placed the leading hand on the wheelchair frame or wheel when transferring out of the car and transfers onto the car seat where the participant placed the leading hand on the steering wheel. The trailing hand was positioned flat on the starting surface for 62.5% of the transfers, on the roof of the car for 10.5% of the transfers from the wheelchair, on the steering wheel for 10.5% of the transfers from the wheelchair and on the top of the car door for 10.5% of the transfers from the car seat. Participants performed a single scoot to position themselves towards the front of the seat for 60.7% of the transfers with consistent occurrences across different scenarios. False starts were rare, 3.6%, and only observed during bed transfers.

The movement strategies adopted by participants performing standing transfers did not appear to vary greatly across different scenarios. Both feet were stably placed on the ground regardless of the context of the transfer. On the other hand, the position of the hands varied more often across the different scenarios. During car transfers, participants were more likely to use their leading hand to reach for an overhead support when standing up, whereas during couch transfers and bed transfers the leading hand was often kept straight in front of the body during the initial transfer. When available, on both leading (62.8%) and trailing side (71.4%) participants preferred to place their hands on structures that could be easily grabbed in order to increase stability and facilitate lift and descent as shown in Figure 7-5. Additionally, the position of both hands was often changed within the same transfer, following the body movement from the start to the target surface, in order to guarantee maximum support. In contrast with what was seen for individuals performing independent sitting transfers, scoots were observed for only for 23.1% of the transfers and false starts were recorded for 11.1% of the transfers. Both scoots and false starts were considerably more common when the participant was transferring in a scenario were the starting surface offered low resistance such as a bed or a couch.

Figure 7-5 Participants performing standing transfers using their hands for additional support during car (left), bed (centre) and toilet transfers (right).

Among transfers performed with a transfer board, feet position was not affected by the scenario and instead depended on the direction of the transfer (to/from the wheelchair). When transferring out of the wheelchair, participants maintained their feet on the footrest, whereas one foot was positioned on the footrest and the other on the ground when the participant was transferring back onto the wheelchair. The trailing hand was usually placed flat on the starting surface across all scenarios and, similarly to what observed among participants who transferred using a standing technique, progressively slid across the transfer board as the subject moves towards the target surface. In contrast, the position of the leading hand was greatly affected by the transferring scenario. During bed and couch transfers the leading hand was always placed flat on the transfer board, somehow mirroring the trailing side, during car transfers participants used the leading hand to grab the steering wheel or the head support of the driver seat in other to pull themselves towards the target surface. Scoots were observed for 26.6% of transfer board transfers, and false starts for 33.3% of transfer board transfers. All occurrences of scoots and false starts were detected during couch and bed transfers.

7.3 Discussion

This is the first study to analyse quality and perceived difficulty of wheelchair transfers in various real-world scenarios for participants using different transfer techniques.

Transferring techniques observed across the participants were: independent seated transfer, transfer board seated transfer and standing transfer, eleven participants exhibited only one technique while two participants demonstrated two different techniques across the 12 transfers performed. This is particularly interesting as these changes in technique were highly dependent on the settings in which the transfers were performed. Participant 2 was only able to perform standing transfers when moving from his wheelchair to the car seat as he grabbed the top of the car door and used a custom mounted grab bar to gather the support necessary to reach a standing position. Similarly, Participant 11 was able to perform transfers using an independent sitting technique only for car transfers and transfers from the wheelchair to the bed. Both the presence of a height gap between the two surfaces and the lower resistance provided by soft starting surfaces such as bed's mattresses or couch's cushions represented environmental barriers that significantly affected the ability of the person to perform a transfer without the need for ATs.

In Chapter 6 it was highlighted how the transferring technique used by the individual was primarily dictated by the medical condition of the person, and that the use of ATs was linked to greater body weight. However, results from this study suggest that the environmental conditions can represent either a barrier or a facilitator of transfer performance with important effects on the individual's transferring technique. As reported by Koontz et al. (2012), the large majority of studies focusing on the analysis of wheelchair transfers involve primarily participants with SCI or unimpaired participants performing independent sitting transfers which prevents us from generalisation of the results. Although the majority of participants in the current study had a SCI, they exhibited a variety of transferring techniques that can be more easily generalised to the wider population.

The presence of height gaps between transferring surfaces increases the upper limb mechanical load associated with the performance of wheelchair transfers (Gagnon, Koontz, et al., 2009; Toro et al., 2012). Nevertheless, among transfers performed by participants of the current study, the presence of a greater height gap was only found to have a negative effect on the TAI score attributed to transfers performed with the aid of a transfer board. Height gaps are likely to present a greater challenge when participants have limited transferring ability. Due to the design of the study which featured the performance of repeated transfers, wheelchair users who participated in the study potentially had above average transferring ability. This could potentially explain the fact that the reported difficulty for all transfer scenarios were lower than the ones observed in the previous study and TAI scores attributed to transfers performed with independent sitting and standing techniques were not affected by the presence of different height gaps.

The transferring scenario was found to significantly affect either the perceived difficulty reported by the participant or the TAI score attributed to the transfer, depending on the transferring technique used by the person. In accordance with the findings illustrated in Chapter 6, participants performing independent standing transfers rated car transfers as more difficult compared to both bed and toilet transfers. In contrast, when participants transferred using an independent sitting technique bathroom transfers were found to be more challenging than car or bed transfers. This was particularly interesting as the accessible toilet used for the scenario of the study was fitted with grab bars that are supposed to facilitate the performance of wheelchair transfers. However, as noted by Toro et al. (2012), grab bars commonly fitted in accessible toilets are often placed too high to be useful for many independent sitting wheelchair transfers and were scarcely used by participants. When analysing movement strategies for transfers performed with different techniques, we found that, despite their differences, indoor scenarios often presented similar characteristics between them. In contrast, car transfers presented strategies that where considerably different, not only to other scenarios, but also across different participants due to the uniqueness of the set up. This reinforces the findings from previous research that highlights the importance of investigating car transfers separately from other scenarios (Haubert et al., 2015; Kataoka et al., 2012; Schaupp et al., 2016).

Several wheelchair skills tests use the time needed to complete a task as an outcome measure for the evaluation of successful performance (Fliess-Douer et al., 2010). However, in the current study study no significant relationship was found between the TAI score attributed to the transfer and total transfer time. This is easily understandable as wheelchair transfers are complex activities that are associated with various difficulties and risks depending on several individual’s and environmental factors (Koontz et al., 2012; Opalek et al., 2009). An evaluation solely based on the time required to complete the task is likely to be too simplistic and highly inaccurate. Interestingly, no significant relationship was found between the TAI score attributed by clinicians and the perceived difficulty reported by the participant. This was surprising as previous studies by Newton, Kirby, MacPhee, et al. (2002) and Rushton, Kirby, & Miller (2012) confirmed the presence of a strong correlation between the subjective estimation and objective evaluation of individual’s capacity across several wheelchair skills. However, Rushton et al. (2012), in agreement with the results presented here, found that self-assessment of safety in relation to wheelchair skills did not correspond to objective evaluation by trained professionals. As transfers and other wheelchair skills become an integral part of the daily routine of wheelchair users who live in the community, individuals will often become used to performing these tasks with strategies that are non-efficient or potentially dangerous. Overall, results from the current study support the assumption that in order to gather accurate and relevant insights from studies looking at the performance of wheelchair transfers in real world environments, specific objective tools should be used to assess the quality of transfers.

Although this study illustrates novel and relevant insights concerning the performance of wheelchair transfers across different scenarios, it has limitations that need to be considered when interpreting the results. The small number of participants, although not uncommon among studies focusing on wheelchair users, suggest caution in the generalization of the results. Furthermore, despite the attempt to recruit wheelchair users with different impairments, the majority of participants had a SCI potentially creating additional challenges for generalization. Finally, although four scenarios which can be commonly found in the real world were investigated, the current study was a semi controlled trial and the indoor scenarios in which participants performed the various transfers might be different from the one found in participants' houses.

7.4 Chapter summary

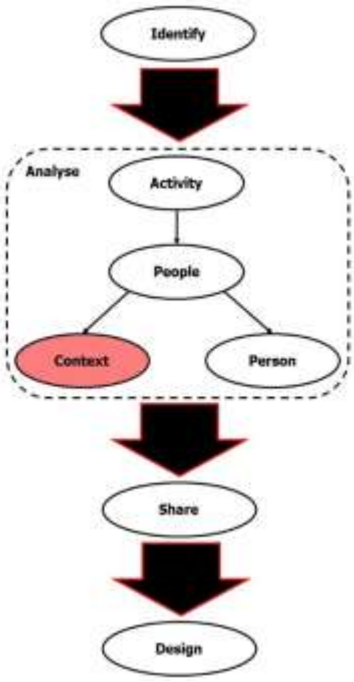

Figure 7-6 Diagram illustrating how the current study corresponds to the Analyse (Context) phase of the 2PAC framework

This chapter presents the third study which focuses on the Context investigation from the Analyse phase of the 2PAC framework (see Figure 7-6). The survey results illustrated in Chapter 6, highlighted how wheelchair users perform various types of transfers in their everyday lives and transfers performed in different contexts are often associated with particular challenges and varying degrees of difficulty. To this end, a semi controlled observational study was designed with the aim of investigating how the context in which wheelchair transfers are performed can affect their performance. As the results presented in both Chapter 5 and 6 emphasised the importance of transferring technique on risks and difficulties encountered when performing wheelchair transfers, all the transfers performed by participants were stratified into three different categories according to their technique: independent sitting transfers, independent standing transfers and transfers performed with the aid of a transfer board.

Interestingly, no significant relationships was found between the perceived difficulty of the transfer or the time required to complete the transfer and the quality of the transfer measured using the TAI score. The lack of a significant relationship between time needed and quality of the transfer is likely due to the complexity of the task which makes it unsuitable for an evaluation based on a single measure. This is especially true for a time based evaluation as attempting to transfer too quickly can lead the person to adopt unsafe strategies (e.g. leaving the feet on the footplate when transferring rather than place them safely on the ground). On the other hand, discrepancies between the subjectively reported difficulty and objectively assessed quality could be due to the unreliability of participants' opinion in the sense that "wrong movement strategies" become part of the individual technique among wheelchair users living in the community.

The descriptive analysis shows how, across all categories, different environmental constraints associated with various scenarios can lead to considerable changes in the movement strategy, and consequently, the biomechanics of the transfer, potentially increasing or reducing the risks of falls and upper limb injuries. This was particularly true for car transfers, as the configuration of different vehicles can create unique set ups that will determine how individuals perform transfers to and from the wheelchair. Furthermore, the context of the transfer can significantly affect both the quality of the movement and the difficulties encountered by the person when transferring.

When designing new ATs to facilitate the performance of wheelchair transfers in multiple environmental contexts, these differences should be carefully considered. ATs will need to be adaptable to various types of transfers and be able to accommodate the different movement strategies used by the individuals in response to the environmental constraints. The text box below shows the design implications that have been extracted from the results of the study presented in this chapter.

Design Implications:

1. New ATs which are designed to facilitate transfers performed in different scenarios (especially car transfers) need to be able to accommodate the different movement strategies used by the person
2. Car and toilet transfers are considered more difficult than bed and couch transfers and might benefit more from new ATs
3. The presence of a height gap (possibly combined with a soft surface) can decrease the safety of transfers performed with a transfer board and new ATs could address this gap
4. Wheelchair users transferring with an unassisted standing technique are more likely to use grab bars (or similar ATs) than wheelchair users using and unassisted sitting or a transfer board transferring technique
5. Ubiquitous systems which monitors the performance of wheelchair transfers could allow users themselves and clinicians to identify potential risks associated with transfers performance, as relying on self-reporting is not a reliable solution.

Chapter 8 Understanding independent wheelchair transfers. Perspectives from stakeholders

Transfers are one of the most common and important activities in the everyday lives of many wheelchair users (Fliess-Douer et al., 2012; K. A. Morgan, Engsberg, & Gray, 2017). As seen in the previous chapters, the number of times a person transfers to and from the wheelchair in a single day, the type of transfers performed and the movement strategies adopted to carry out the transfer vary greatly across different individuals. These differences depend not only on the impairment and the environmental conditions, but also on habits, lifestyle and personal preferences. As seen in Chapter 2, several studies have focused on quantifying kinematics and kinetics aspects of wheelchair transfers (Gagnon, Nadeau, Noreau, Eng, et al., 2008; Kankipati et al., 2015), while others have assessed safety and quality of wheelchair transfers using the TAI (Tsai et al., 2013). Although most studies were focused on analysis performed in biomechanical laboratories, others were carried out in real world settings in order to provide a more accurate representation of everyday transfers (Haubert et al., 2015; Kataoka et al., 2012). The only study attempting to gain a more comprehensive understanding of the issues surrounding wheelchair transfers and suggesting potentially new directions for future research was carried out by Crytzer et al. (2015) who conducted a series of focus groups with a cohort of 31 experts. Results highlighted the need for further investigation into the relationship between internal (pain, fear, spasticity, confidence) and external (gaps, poor wheelchair design, barriers) factors affecting the performance of wheelchair transfers, and the unique dimension of these relationships for different individuals (Crytzer et al., 2015). Although all participants had considerable experience in wheelchair related fields, most were professionals rather than wheelchair users. Clinicians, researchers or designers with sufficient expertise might be able to sympathise and even understand the experiences of many wheelchair users, but they lack their personal perspectives (Sears & Hanson, 2012).

In many respects wheelchair transfers represent a gateway for independence for wheelchair users. Transfers not only have a huge impact on the functional life of a wheelchair user but they can also shape internal and external perception of the individual and their perceived disability (Iezzoni Li, McCarthy Ep, Davis Rb, & Siebens H, 2000;

Super & Block, 1992). Despite this, the personal dimension of wheelchair users in relation to transferring tasks has never been explored.

The qualitative exploration of disability related issues and the implications of their findings for AT design represents a growing area of interest. The interview study carried out by Bennett et al. (2016) highlights how the value amputees attributed to upper limb prosthetics goes far beyond their functional impact. Prosthetic devices become an integral part of people's identity and their impact on the presentation of self is equally, if not more, important than their "assistive" function. Similarly, participants in the study carried out by Carrington, Hurst, & Kane (2014) preferred unobtrusive inputs and outputs in the interfaces for mobile computing devices as they did not wish to add devices that will change the form factor of their power wheelchairs. This is not surprising, as many wheelchair users "wear their wheels" in the same way that amputees wear their prosthesis (Holloway & Dawes, 2016). Insights gained from interviews are not only useful for discovering hidden interactions of users performing specific activities (with or without the use of ATs), but can be used to formulate design recommendations for devices that are better able to address the needs of people with disabilities. For example, Carrington, Chang, Mentis, & Hurst (2015) carried out a series of semi-structured interviews to identify problems related to the inaccessibility of fitness tracking devices for wheelchair athletes. Based on their findings they developed suggestions on aesthetics, hardware, ergonomics and type of feedback that could make existing devices more useful and accessible for wheelchair users. Similarly, Zuleima Morgado Ramirez & Holloway (2017) interviewed a group of 12 manual wheelchair users to understand needs and requirements concerning power assist devices that can be attached to manual wheelchair in order to reduce the efforts required for propulsion. Users' insights were gathered with the aim to identify the ideal form factor of power assist devices and make concrete design recommendations for features ranging from regenerative breaking to a network of sensors that can monitor the state of the environment to provide adequate power output.

The studies presented in Chapters 5, 6 and 7 helped to recognise the objective difficulties and risks that are related to the performance of independent transfers in the everyday lives of wheelchair users. However, to gain a comprehensive understanding of the personal perspectives, needs and concerns of wheelchair users in relation to everyday transferring activities a direct consultation is essential. Furthermore, the insights captured from this investigation could, in addition to the objective data collected from previous studies, provide more concrete design implications that could guide the final stage of this project. Based on these considerations, the aim of this study was to collect direct testimony, from both wheelchair users and OTs, of the most important and difficult aspects of independent wheelchair transfers. In comparison to the studies illustrated in previous chapters, the investigation moves beyond the evaluation of objective factors such as the impact of impairment, technique and environmental barriers or facilitators, and encompasses the personal elements that shape the individual experiences of wheelchair users.

8.1 Method

8.1.1 Participants

In order to get a more comprehensive and objective overview of difficulties encountered during wheelchair transfer performance participants were recruited among both OTs and wheelchair users. Participants were recruited from a laboratory database and through Disabled People Organizations. Inclusion criteria for the study were: age over 18 years, and having at least six months of experience as a wheelchair user or as an occupational therapist with specific competencies in wheelchair skills training. Additionally, users had to be able to perform independent transfers using a standing or sitting technique, with or without a transfer board. A total of 15 people, four OTs and eleven wheelchair users who satisfied the inclusion criteria were recruited for this study. The four OTs had been working in a SCI rehabilitation centre for a period ranging from 9 months to 16 years. All wheelchair users had at least one year of experience using their wheelchair as a primary means of mobility. Five wheelchair users reported using a standing technique for most of their transfers, four used an unassisted sitting technique and two benefitted from the use of a transfer board for most of their transfers.

8.1.2 Materials and procedure

Due to the inherent difficulties encountered when recruiting wheelchair users, the qualitative study was carried out using a mixture of focus groups and semi structured interviews. Distribution of participants between focus groups and semi-structured interviews alongside participants' gender and the transferring technique reported by the wheelchair users are shown in Table 8-1. According to their availability, nine participants were enrolled in the focus groups (5 wheelchair users and 4 OTs). Wheelchair users and OTs were assigned to different focus groups. This separation was planned in order to create more homogeneous groups to facilitate sharing of opinions, without the presence of unbalanced power dynamics due to professional roles. The remaining six participants took part in semi structured interviews featuring the same questions that were asked during the focus groups.

Table 8-1 Summary of participants' characteristics and their allocation between focus groups and interviews

Participant	Gender	Medical condition	Transferring technique	Data collection method
OT1	F	NA	NA	Focus group
OT2	F	NA	NA	Focus group
OT3	F	NA	NA	Focus group
OT4	F	NA	NA	Focus group
WU1	F	Complex Regional Pain Syndrome	Sitting	Focus group
WU2	F	Spina Bifida	Sitting	Focus group
WU3	M	Spina Bifida	Standing	Focus group
WU4	F	SCI	Transfer board	Focus group
WU5	M	SCI	Sitting	Interview
WU6	M	MS	Standing	Interview
WU7	M	CP	Sitting	Interview
WU8	F	EDS	Standing	Interview
WU9	M	SCI	Transfer board	Interview
WU10	M	SCI	Sitting	Interview
WU11	F	MS	Standing	Interview

For consistency reasons, the questioning route was the same for both focus groups and interviews. Questions asked in both focus groups and interviews were aimed at exploring various aspects of wheelchair transfers and ranged from questions concerning transfer technique, the difficulties encountered when learning transferring skills and when transferring on a daily basis, how wheelchair users dealt with pain, fear of falling and their thoughts on current and potential ATs for transfers. Introduction scripts and the list of questions for focus groups and interviews are included in Appendix E. In order to capture additional details concerning the personal dimension of transfers a simple cultural probing technique was used (Crabtree et al., 2003). All wheelchair users were asked to write down and read a description or present a video of a transfer they thought was particularly important to them.

Thematic analysis was chosen as the analysis method for this study due to its rigour, flexibility and usefulness in summarising relevant features of complex datasets (Braun & Clarke, 2006). Focus groups and interviews were audio recorded and transcribed. To familiarize myself with the data before the analysis, I transcribed all focus groups and interviews. Transcription was non-verbatim (sounds such as “hem”, “mmm”, “um”, filler words and false starts were removed) with the aim to improve readability without summarising or paraphrasing participant’s words. Transcripts were then analysed and coded using a hybrid deductive and inductive approach as suggested by Fereday & Muir-Cochrane (2006) in an iterative fashion until saturation was reached (Weed, 2017). Four key themes were established a priori based on the aim of the study and the questions asked in the interviews were: “Important elements of wheelchair transfers' performance”, “Difficulties when transferring”, “Transfers and pain”, “Transfers and ATs”. Transcripts were initially revised individually and significant parts relevant to these four themes were highlighted and annotated to create content labels and descriptive codes. As the analysis progressed, codes were compared, renamed, split and combined to create the most comprehensive and coherent description of the data. Similarly, codes were grouped into relevant themes in an iterative fashion were themes first defined as they emerged and subsequently reviewed, refined and renamed in a iterative fashion to ensure the correct interpretation of the data (Braun & Clarke, 2006). A second inductive analysis was conducted to identify other relevant codes that emerged from the data collected. After comparative examination and triangulation with pre-identified codes and themes (Silverman, 2006), three additional themes were extracted from the data.

8.2 Results

Seven main themes were identified from the analysis of all transcripts. Six themes were considered highly relevant to the scope of the current study. Although the seventh theme might appear not directly in line with the aim of this study, it was decided to include it in the report as several wheelchair users highlighted the issue as being extremely important to them and having a direct influence of the difficulties they encountered when transferring. Despite the different backgrounds and experiences of various participants, all themes were found to be recurring across focus groups and interviews. A summary of the identified themes alongside some significant quotes is presented in Figure 8-1.

Figure 8-1 Summary of the seven themes identified from interviews and focus groups

8.2.1 The value of wheelchair transfers (1)

Both OTs and wheelchair users clearly attributed extreme importance to the ability to transfer in and out of the wheelchair. OTs underlined how transfers represent a gateway to independence from the beginning of the rehabilitative process for people with SCI. Newly injured people would find themselves in a bed, and being able to independently transfer from the bed to the wheelchair allows them to reach the first level of independent mobility. Successive transfers to and from toilets, car seats or couches open up new possibilities for mobility, self-care, entertainment and interaction with others. Similarly, the videos and comments shared by WUs, regardless of impairment, years of wheelchair use and transferring technique, showed how the ability to transfer in and out of the chair was crucial to them.

Emphasis was put on the value of transfers in the context of their family life (WU5 "*I get on the couch in the play room to read and play with my little boy*") work, (WU11 "*I transfer on a perching stool when I teach to my student because when I was teaching from my wheelchair my students couldn't see me or hear me and this was starting to affect my work*"), their ability to travel (WU4 "*I drive everywhere, I am in and out of the car constantly so car transfers are very important to me*") and their mobility in general (WU7 "*With muscles, if you snooze you lose. If I didn't transfer it would be far too easy for me not to exercise*"). WU7 also pointed out how transfers have an intrinsic value in their ability to challenge stereotypes associated with WUs, by presenting a separate image of the WU and the chair ("*When I transfer onto a chair in a restaurant I can see the shock on the waiters face and I can understand them. If you ask anybody to picture a wheelchair user they will picture him on a chair, and I think there is something quite disruptive about moving away from the chair. It can help change people's perception*").

8.2.2 The four pillars of wheelchair transfers (2)

When describing important factors in the performance of wheelchair transfers, four elements were repeatedly emphasised by both wheelchair users and OTs: technique, confidence balance and strength. Having sufficient strength, in upper or, lower limbs, or both, is a necessary requirement for both sitting and standing transfers. Depending on the environmental conditions, certain types of transfers, such as car transfers, might require a greater amount of strength. This results in individuals needing to practice more before being able to safely attempt them (WU9 "*I was told from the beginning that I would have been able to do a car transfer, but they needed me to get stronger first. I had to wait five months before they let me try*"). Insufficient strength can also affect the transferring technique and motivate the decision of a person to use a transfer board. Additionally, strength affects the individual's ability to cope with both horizontal and vertical gaps. As expected, upper limb strength was described as a necessary requirement for sitting transfers, however it was also reported to be a great asset for individuals who usually perform standing transfers, particularly in difficult situations (WU1"*When my legs are not really behaving I have to hold on to something and pull myself up. Otherwise I can't do it*").

Although strength is important, another element playing a determinant role is the use of a correct transferring technique. Both wheelchair users and OTs agreed that the most crucial element of a good transferring technique is a sufficient forward lean of the trunk, which creates momentum to relieve weight from the buttocks and helps to guide the body in the correct direction (OT1 *"For most people the core it's really the technique, and if you do the technique properly most of the times you won't have any problem"*). The degree of forward lean was also described as being correlated with the gaps separating the starting and target surfaces. However, achieving a sufficient forward lean was considered the most difficult skill to achieve, particularly for people with SCI due to their lack of trunk control (WU4 "*The lean is very important. The bigger the gap you have to cross the more you have to lean. The less control of your muscles you have the harder it gets because you just end up on your face*"). On the other hand, the concept of correct technique seemed both less defined and less important for individuals performing standing transfers. In this population, the description of transfers' strategy was notably less standardized. Furthermore, maintaining correct balance was given higher priority compared to implementing strategies to reduce the load on upper and lower limbs. For this reason, several WUs preferred to reduce how much they leaned forward, and instead relied on their arms to push themselves up. Additionally, they often use external supports, such as handles, rails, walls or furniture to maintain their balance once they reach a standing position (WU6 "*When I transfer I need to have armrests on the wheelchair to rise from and then I often need something to grab onto when I stand up"*).

Regardless of their impairment and transferring strategy, one element that affected how people transfer in and out of the wheelchair is confidence. Lack of confidence in their technique, strength or balance can lead people to perform transfers incorrectly. When feeling insecure some people tend to transfer too fast to "*get over and done with it"* (OT3), which can lead to falls or injuries. Others might have hesitations that limit their movements and make the transfer more difficult due to a more backward position of the centre of mass and subsequent lack of momentum. The individual's level of confidence can be affected by several factors from a reduction of their physical capabilities due to fatigue to a challenging environment. Additional training, practice and the presence of a spotter to supervise the transfer were suggested as potentially helpful measures.

8.2.3 Internal and external difficulties (3)

There are several elements that can make transferring harder for wheelchair users; these can be divided into internal and external difficulties. Internal difficulties are often specific to the individual and can be related to the impairment itself or to transitory circumstances such as tiredness. Spasticity (abnormal and uncontrolled movement of a body part) was reported to be the main internal difficulty for many wheelchair users performing sitting transfers (WU1 "*It's hard enough to transfer if your legs aren't working, it's harder if they are kicking*"). On the other hand, people performing standing transfers often have balance issues, which are particularly severe when getting up for a transfer due to the change of position. Several wheelchair users also pointed out how fluctuations in their impairment, due to tiredness or their medical condition, can pose extreme challenges, which force them to constantly evaluate and change their strategies based on the available capabilities (WU8 "*The symptoms I have change a lot, it's the nature of my condition. Some days I can walk a bit, while if I am having a really bad day, I am just crawling and I struggle to even get up… It's just hard to know it before you try something stupid….*")

External difficulties were more various and often described in association with a particular type of transfer. Large gaps in height and width were one of the most commonly reported difficulties alongside lack of space to correctly position the wheelchair, inefficiency of wheelchair brakes, instability of transferring surfaces and the degree of bucket of the seat (created when the seat is higher towards the knee compared to the hips). Several WUs who regularly performed transfers to and from sport wheelchairs complained about the absence of breaks which poses significant challenges and increases the danger of these transfers. On the other hand, several participants who performed standing transfers complained about the current design of wheelchair footplates as they can be difficult to move and can prevent the individuals from placing their feet appropriately when transferring (WU11 "*Because my balance is poor I can't bend forward to flip the footplates up, but then they are in my way. I can't step over them because they are too far away and I can't step to the side of them*". Participants also mentioned the importance of several circumstantial factors. Rain, sweat or being wet after a shower can make sliding along a transfer board considerably more difficult. One difficulty that was specifically associated with car transfers was the potential presence of uneven or sloped terrain where the car is parked. Individuals performing standing transfers were particularly concerned about the potential negative effect this has on their balance; whereas people performing seated transfers described the difficulty of transferring while having to make sure that their wheelchair didn't accidentally move. Lastly, one difficulty reported often by both groups was related to the challenge of dealing with unfamiliar situations and generally awkward transfer set ups. These challenges are common when travelling on planes, staying in hotel rooms or visiting friend's houses as people need to adapt their technique and develop workarounds with little or no possibility to prepare in advance.

8.2.4 Learning how to transfer (4)

Although most participants highlighted the importance of using a safe and efficient transferring technique, we discovered that only a few wheelchair users had received appropriate training to learn how to transfer. Individuals with SCI were the only ones who received formal training and guidance from medical professionals on how to develop safe transferring skills. Among other participants, some reported having learned mainly from peer observation (WU2 "*Everything I have learned, I have learned from watching other people around me, modify it and then do it myself*"). When direct observation was not possible, virtual resources were used in the attempt to fill the gap (WU3"*I ended up googling and going to YouTube to watch videos of transfers*"). Other participants relied solely on their own experience and learned through a long trial and error process (WU1 "*Everything I have learned, I have learned from falling and not doing it again*"). Participants did not seem to think that their lack of training had affected their capabilities. However, some people, such as WU8, expressed concerns about the potential damage that could result from their absence of training ("*If you don't learn to do stuff properly the chances are that before or after I am going to do myself an injury because of bad technique in my own wheelchair…*").

Even when transfer training was provided, it was often in controlled clinical settings where barriers were reduced to a minimum, and assistance could be provided upon request. Some people declared that they learned all the skills they needed during rehabilitation. Other participants noted how, despite judging the training they received in the hospital extremely useful, their transfer strategy needed to be modified in order to be independent and safe once they went back home (WU4 "*After discharge, you can't stick to 'by the book' transfers that you were taught. You have to try and see what is going to work for you*").

8.2.5 Fear the falls but bear the pain (5)

Avoiding falls when performing wheelchair transfers was found to be one of the primary concerns for the majority of participants. The specific reasons varied across the different individuals. Some were apprehensive about the potential injuries that a fall could result in, while others were more worried about the potential reaction of people who witnessed the event (WU8 "*For me a lot of the stress around falling is about how people are going to respond. A lot of time people try to help you, but they only pull you around and make everything harder and it's hard for you to direct them properly*"). Fear of falling wasn't necessarily seen as a negative thing as it prompts wheelchair users to take care of their technique and avoid unnecessary risks. On the other hand, excessive fear was reported to have a negative effect on both confidence and transfer technique. Notably, two participants seemed to have little or no concern about the possibility of incurring a fall when transferring. For WU1 falls were reported so frequently that they were considered a common occurrence. While WU7 simply stated that fear was pointless as transfers were an integral part of his daily routine ("*I don't have a choice about transferring because of the impact it has on my quality of life. And, if I fell, I would have to get back on the bike anyway… So I am not scared*").

Pain in the upper or lower limbs was also commonly associated with wheelchair transfer performance. Some participants described how pain caused them to change the way in which they perform certain transfers (WU2 "*When my carpal tunnel is very bad I need to push on my forearms rather than my hands to get out of the bath*") or found a way to facilitate them (WU 10 "*When I get out of the bath I usually take the plug away and push myself up. When my shoulder was very sore I started to leave the plug in so I could get the maximum assistance for my lift*"). Other wheelchair users reported attempting to reduce the frequency of transfers whenever possible. However, when transfers were considered important for their daily routine they were performed regardless of the pain (WU4 "*If I can I just try to do less, don't hop on the couch or in and out of the car too much. I try to limit but I still have to do those transfers*"). For some participants, pain was simply part of their transfers and, when bearing the pain was the only alternative to risking a fall, it was considered a preferable alternative (WU3 "*My shoulder just screams at me every time I load too much and this happens with every transfer. But if I try to do it in another way I will just fall over so I have to deal with it*").

8.2.6 Perspectives on current and new ATs (6)

The only ATs to facilitate wheelchair transfers that all participants were familiar with were transfer boards. The majority of participants reported using a bath board to transfer into the bath and two participants (WU4 and WU9) used transfer boards for all their transfers. Opinions on transfer boards were generally positive as they were considered functional objects which were fit for purpose. However, transfer boards were commonly described as helpful only for level transfers or transfers were the height gap was moderately low. Transfers with considerable height gaps between the two surfaces resulted in the board having an excessive slope causing the person to slide down in the middle of the transfer. Additionally, several participants complained about their weight, the difficulty of carrying them around and the fact that they can be easily damaged. OTs also noted how, for some WUs, particularly those with reduced upper limb function, picking up and positioning the transfer board correctly could represent a challenge in itself. WU10 expressed concerns about using ATs unless they were absolutely necessary as he felt they could, over time, decrease his ability ("*The available equipment is good, but you don't want to start to use assistive technologies too soon because you need to keep your strength and ability as high as possible. Once you start using a transfer board you are not going back because you are not doing any training or exercise that will help you do a clean transfer*").

Most participants expressed their desire for improved transfer boards or other new ATs that could support them when transferring in and out of their wheelchair. Some suggestions concerned wheelchair modifications such as retractable footplates that would not get in the way, or extendable armrests that could offer support when the person is standing up to transfer. Others focused more on improved versions of transfer boards. Improvements varied from low tech solutions such as telescopic or collapsible transfer boards that could be easily carried around and function as a portable tray when needed. Alternative ideas involved a more complex board that could deal with greater height gaps, such as transfer board with steps or transfer boards with an embedded sliding seat that could lock in place allowing the user to break the transfer into smaller motions. One participant advocated for a motorized transfer board featuring a conveyor belt mechanism that could safely carry wheelchair users with more limited mobility. However, ideas were not only related to transfer boards. Other suggestions included a device that could be used to level all transfers by raising the height of the lower surface, a system that could keep the shoulders in a stable and safe position during transfers or a glove that could be used to increase the grip when relying on slippery supports during transfers.

Finally, several participants mentioned the need for resources, not necessarily ATs, which could help people learn how to transfer by providing suggestions, guidelines and tips for safe and efficient technique regardless of the medical condition of the individual. Suggested solutions varied from digital repository of information to chest placed sensors able to provide real-time bio-feedback on the optimal trunk forward lean for wheelchair users with SCI. Regardless of their format, instructions and guidance would need to be flexible enough to be adaptable to different individuals, and span across various situations. It was also underlined that information concerning correct transferring technique should always include visual material as a simple verbal explanation was considered insufficient (WU9 "*You have to be able to show it, not just explaining it. If I don't see it I am never going to get it*").

8.2.7 Wheelchair users not wheelchair bound (7)

The last theme that emerged from the analysis was not directly in line with the aim of the current study. However, it brings to attention an important issue that impacts most wheelchair users and can also directly affect wheelchair transfers. All participants, whose primary medical condition was not SCI, described episodes highlighting how both the public perception and the net of services related to wheelchair provision, training and assistance are shaped around the stereotype that sees all wheelchair users as individual with a SCI. An example of this discrepancy was given by the fact that, among participants of the current study, no individual with an impairment different from SCI had received any training on transferring technique. Even when people researched for information on their own, they were unable to find guidelines or advice from health professionals that could guide their learning (WU3 "*I didn't really get any wheelchair skills training or transfer training… I remember I tried to look online as well ages ago but I couldn't find anything useful for me"*).

Several wheelchair users also mentioned how they often feel the pressure of this stereotype when in public settings. They explained how this can directly affect their behaviour as they seek to avoid potential judgement from strangers (WU11 "*My condition is not constant. The thing that annoys me is that a lot of the times I could get up and take a few steps, but often I don't do it. It's like I always have to behave as if it was a bad day for me. Which is actually the worst thing I can do for my own health. But people don't react well if they see you on the chair one day and walking the next day*").

8.3 Discussion

The main goal of the current study was to gain a deeper understanding of the experiences of wheelchair users in relation to transferring tasks. The diversity of impairments, transferring techniques and lifestyles among wheelchair users and OTs allows to capture a variety of viewpoints and ensured variability among individuals' opinions. Surprisingly, regardless of the participants' diversity, the seven themes identified were present in all focus groups and interviews. However, the relevance of different elements varied depending on the individual's characteristics. For example, the importance of training and technique was highlighted several times by OTs, individuals with SCI and subjects who acquired a disability in their adulthood. On the other hand, participants who were born with a medical condition which required them to use a wheelchair for mobility, attributed considerably less importance to the concept of proper technique and standardized training. Throughout their development, they have learned transferring skills in the same way that an able bodied child might learn to stand up and walk. Similar differences were also found between participants of different age. Older wheelchair users were more concerned about the possibility of falling while performing a transfers, while younger participants were less worried about their safety.

Interestingly, all wheelchair users who participated in the study made a point of highlighting, not only how important their transferring skills are for their independence, but also how overlooked they usually are by clinicians, other professionals and often themselves. Several people reported how it was difficult for them to describe their transfer technique in detail or the difficulties they might encounter when transferring as they were never asked similar questions before. The focus group gave participants an opportunity to learn from each other and share the personal strategies they use to facilitate transfers. A potential explanation for this lack of information exchange among peers might be related to the fact that transfers belong to the personal sphere of the individual. Challenging wheelchair propulsion, such as propulsion on steep slopes or rough terrain usually takes place outside the house. This might make it easier to observe strategies that other users employ or ask for suggestions on how to deal with specific difficulties. On the other hand, transfers often take place within the house or when the person is alone, which might reduce opportunities for observation or exchange of information. Additionally, the importance of transferring skills and the potential loss of independence that can arise from the inability to transfer without assistance can lead some users to become overly sensitive of others people's feelings and consequentially transfer less often around other wheelchair users (WU7 "*Sometimes we don't want to boast about it because some people can't do it. It's like an unspoken politeness…*").

Overall, the seven themes identified in this study emphasise the complexity of wheelchair transfers. Transferring skills are difficult to acquire and the concept of correct technique, although extremely important, is often poorly defined. As reported by Crytzer et al. (2015) wheelchair transfers can be further complicated by the built environment or the design of the wheelchair. Additionally, internal factors such as pain, spasticity, tiredness and fluctuations of the individual impairment can make the task even more difficult. However, due to their importance for the person's independence and quality of life, transfers are often seen as unavoidable. Due to their complexity and variability, learning how to transfer can be a challenging task for wheelchair user. Unfortunately, only people with SCI tend to receive formal training from medical professionals while other wheelchair users are often left to figure things out for themselves. Unsurprisingly, all participants highlighted the importance of training in order to develop effective transferring skills and some participants expressed the concern that their lack of training could negatively affect their safety and increase the likelihood of developing injuries overtime. In-person transfer training appears to be inaccessible for many wheelchair users and, when provided, might not be sufficient to provide wheelchair users with effective skills to perform real world transfers (Teeter et al., 2012; Yarkony, Roth, Meyer, Lovell, & Heinemann, 1990). The use of a web-based transfer training module has been shown to significantly improve the transferring technique of wheelchair users. Technique gains tested immediately after training and after a short follow-up period were comparable to the one obtained with in-person training (Worobey et al., 2017). The availability of online resources could help provide wheelchair users with much needed training material that will allow them to develop transfer skills when in-person training is not possible. Additionally, web-based open source material could be consulted on-demand when people are faced with new and challenging situations.

Transfer ATs, and in particular transfer boards, generally received positive feedback. Nonetheless, they were found to be of limited use when the circumstances became more challenging or the users were more skilled. This is interesting as it highlights the fact that current ATs seem to be designed to facilitate people with basic tasks, but their ability to "bridge the gap" is often insufficient for more challenging situations. Additionally, transfer boards, or other ATs for transfers, seemed to be targeted only towards people with reduced upper limb function. This makes them inadequate, or counterproductive in enhancing more skilled individuals. Part of the reason for this can be linked to the fact that in AT design there is a tension between the need to meet the specific needs of the disabled individual and the need to develop a product with the largest market base possible in order to generate sufficient profit (Yamauchi, 2009). This can lead to the tendency to develop a product based on a person with an average impairment in the average context. Challenging situations and particularly skilled wheelchair users therefore, fall outside of the target audience of the product, making mainstream ATs unsuitable for them. Engaging wheelchair users, and people with disabilities more generally, in targeted co-design projects, would help design for people beyond a fictional 'normal', who due to the nature and context of the activity or their capabilities, find themselves at the edges of the Gaussian curve (Barbareschi, Holloway, & Sprigle, 2017; Buehler et al., 2015).

Finally, results from the current study bring further attention to an issue that has recently been mentioned by several researchers. Experts who participated in the Independent Transfer Workshop (Koontz, Crytzer TM, & Cooper R, 2012) identified the need to include in future research studies more people wheelchair users without SCI in order to improve generalizability. The tendency to use the SCI group stereotype to represent WUs spreads beyond research and into clinical practice. WUs with impairments other than SCI had received little or no training on transferring technique and wheelchair skills. Furthermore, they are often unaware of the existence of ATs that might improve their abilities and they struggle to get assistance and funding for basic equipment from a health system that seems unable to deal with them because they "do not fit in the guidelines". The weight of this stereotype goes beyond the medical community and shapes public perception so strongly it causes WUs to modify their behaviour based on the expectations of others, like the actors on the stage described by Goffman, (2006).

8.4 Chapter summary

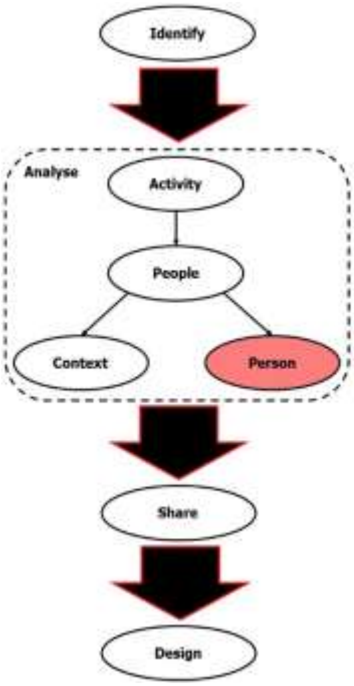

Figure 8-2 Diagram illustrating how the current study corresponds to the Analyse (Person) phase of the 2PAC framework

This chapter presents the fourth and last study from the Analyse phase of the 2PAC framework that focuses on the exploration of personal factors related to the performance of wheelchair transfers. Findings from the three studies illustrated in Chapters 5, 6 and 7 have shown how impairment, technique and environmental factors can affect the performance of transfers in wheelchair users' everyday lives. These objective investigations can help to identify and quantify some of the challenges and risks that people encounter when transferring to and from their wheelchairs. However, these studies can only give a general glimpse of wheelchair users' experiences in relation to transferring activities. Furthermore, these quantitative studies offer little insight on how wheelchair users cope with these challenges and how the needs and difficulties encountered when transferring could be translated into potential requirements for new ATs. To this end, a series of focus groups and semi structured interviews with both wheelchair users and OTs was conducted with the aim of gaining a deeper understanding of the perspectives, needs and concerns that wheelchair users encounter when transferring in their everyday lives, not only due to the built environment or their disability, but also in relation to their lifestyle and personal experiences.

The seven themes identified through this qualitative investigation highlight the importance of wheelchair transfers in relation to both the personal image and the quality of life on the individual. Transfers were described as gateways to independence which could progressively unlock new levels of personal mobility for the person, granting new opportunities for participation in life. However, their value comes at a cost as transfers are often described as difficult, painful and sometimes risky. Challenges encountered during transfers can be linked to a combination of personal and environmental factors. While issues related to the presence of large gaps, slippery surfaces or lack of space could be addressed through accessibility interventions, difficulties concerning pain, impairment's fluctuations and lack of confidence will more likely require the implementation of more personalised solutions. The use of a correct transferring technique plays an important role in reducing the effort required to complete a transfer and decreases the risk factors for both falls and upper limb injury development. Unfortunately, few wheelchair users have access to in-person training to develop transferring skills. The remaining people rely on a combination of peer observation, personal research and simple trial and error to figure out the movement strategies that better suit their needs. ATs were perceived as only partially successful in providing support to wheelchair users during the execution of transfers. Transfer boards and other devices were described as only useful for basic transfers and for individuals with reduced, but still sufficient, upper limb function. Despite this, most participants considered the development of new ATs as the best potential solution to most challenges associated with wheelchair transfers as it was felt they could be designed to address multiple difficulties and further adapted to suit the specific needs of the individual. The text box below shows the design implications that have been extracted from the results of the current study.

Design Implications:

1. New ATs for wheelchair transfers should support one (or more) of the important elements of transfers: balance, strength, technique and confidence
2. New ATs for wheelchair transfers should help people negotiate difficult environmental conditions such as gaps between surfaces, instability of transferring surfaces or uneven terrain
3. New ATs for wheelchair transfers should take into account the fact that the capabilities of the user might vary due to spasticity, tiredness or performance fluctuations due to the person's impairment
4. Many people never receive any guidance on how to perform safe and effective transfers and this is an important gap for new transfer ATs
5. Currently available ATs for wheelchair transfers mainly target users with "average" capabilities overcoming common environmental barriers. The design of new ATs for wheelchair transfer should focus on the bespoke needs of users dealing with more challenging circumstances.
6. The design of new ATs for wheelchair transfers should be focus on individuals according to their functional capabilities, rather than their medical condition and include wheelchair users with a wider range of impairments.

Chapter 9 Developing transfer assisting technologies with wheelchair users

One of the aims of this thesis is to develop a new approach that can promote the design of ATs for wheelchair transfers which are both useful and acceptable for prospective users. Of equal importance is the fact that the process that leads to the development of these ATs represents an empowering experience for wheelchair users promoting their sense of independence and generating the feeling of ownership towards the AT. In order to be deemed useful, an AT will have to address challenges and difficulties that are meaningful to the user. Moreover, when performing the targeted activity, the use of the AT will need to provide a significant relative advantage in relation to the functional needs of the user, which are usually dictated by the individual's impairment combined with the requirements created by the physical context where the task is performed (Cook & Polgar, 2014; Deibel, 2013; M. Scherer, 2017). However, as seen in Chapter 3, the acceptance of ATs is an extremely complex phenomenon which is definitely influenced by the perceived usefulness of the AT, but it is also determined by the compatibility of the AT with the users' values and strategies (Riemer-Reiss, 1999; Roelands et al., 2002).

In keeping with user-centered design methods (Newell & Gregor, 2000; Sears & Hanson, 2012), it is essential to include people with disabilities in the investigation carried out at the beginning of the design process in order to ensure that their needs and goals are captured (Dawe, 2007; Prior, 2010). The correct identification of users' needs and aspirations is crucial to the development of useful ATs. Similarly, directly formulating design recommendations from interviews and other qualitative investigation with users can improve the acceptability of ATs as they will be able to prioritise factors that are more meaningful to them and voice concerns or perplexities about various features and ideas. Nonetheless, for ATs and AT design to become opportunities to truly empower people with disabilities their simple involvement as "subjects of investigation" or "design informants" will not be sufficient. In line with the principles of Design for User Empowerment outlined by Ladner (2015), only when people with disabilities cease to be passive recipients of the technologies designed for them and become the leaders of AT design will they be able to take full control of ATs and the impact these devices have on their lives. As shown by Hurst & Tobias (2011), empowering people with disabilities (and their caregivers) to develop their own ATs not only has a positive impact on the likelihood of adoption, but it also increases their sense of independence as they gain true ownership on their ATs.

In Chapter 4 the concept of PD was introduced and some of the benefits and challenges associated with its application to AT design were discussed. Involving people with disabilities as co-designers represents an opportunity for empowerment and leads to the development of better ATs. However, establishing the focus and level of collaboration needed for the success of the project comes with a high participation cost that might become a significant barrier for many people with disabilities. With the aim of improving the efficiency of PD and reducing the burden of participation while preserving the benefits of PD I developed the 2PAC framework illustrated in Section 4.4.3 of this thesis. The four-step process guided this research through the identification, analysis, information sharing and design of AT for wheelchair transfers. The framework clearly separates the phases of problem analysis and design, linking them by the act of synthesising and sharing the information collected during the investigation to focus and facilitate the generation of ideas for new ATs. In Chapters 5, 6, 7 and 8 I described the 4 studies that answered the RQ2 by investigating the different factors (Activity, People, Context and Person) influencing the performance of wheelchair transfers, consequentially shaping the needs and requirements for novel ATs.

This chapter presents the final study of this thesis, a co-design workshop on ATs for wheelchair transfers involving wheelchair users and designers as equal partners. As the handout produced to share the information collected during the previous studies was designed and distributed specifically for this workshop an overview of its structure and content will be provided. Hence the content of this chapter will cover the final two steps of the 2PAC framework: share and design. This study aims to test the efficacy of the 2PAC framework and investigates how the availability of information affects the co-design of ATs for wheelchair transfers, not only in terms of the ideas generated, but also in relation to the collaboration among participants and their experience throughout the workshop. To this end, alongside the presentation of the design concepts formulated, the interactions between participants and their feedback are also analysed.

9.1 Method

9.1.1 Handout

The aim of the handout was to help participants analyse challenges related to different aspects of wheelchair transfers and allow them to identify opportunities for new ATs without influencing their thinking. A simple paper format with a combination of text, diagrams and images was chosen against more sophisticated digital media as it was assumed participants would find it easier to consult. The booklet was structured in 5 different sections:

1. "An overview of independent wheelchair transfers" highlights the importance of transfers for independence in the everyday lives of wheelchair users. This section also provides a detailed description of the movement strategies adopted by individuals who transferred using different independent transferring techniques: sitting, standing and with the use of a transfer board
2. "The dark side of independent wheelchair transfers" contains a summary of the challenges and risks encountered by wheelchair users when transferring. This section explains how the large mechanical load associated with transfer performance can lead to upper limb injuries which severely affect the QoL of wheelchair users (Gutierrez, Thompson, Kemp, & Mulroy, 2007; Hogaboom, Worobey, et al., 2016). Finally, this section illustrates the relationship between transferring activities and the risk of falling (Nelson et al., 2010), emphasizing how falls can not only cause traumatic injuries but also reduce the confidence of wheelchair users and negatively affect their independence.
3. "Designing with users, not for users" starts by emphasizing the importance of ATs, explaining the issue of AT abandonment and drawing attention on how involving people with disabilities in the design of new ATs could prevent this from happening. After explaining the difficulties of carrying out PD for ATs design this section introduces the 2PAC framework and illustrates the aims and the purpose of the handout in light of the co-design workshop
4. "Activity, People, Context and Person" describes the aims, structure and main findings from the 4 studies presented in Chapter 5, 6, 7 and 8 of this thesis.
5. "Imagining the future…" illustrates some of the ATs design ideas that have been formulated by wheelchair users and OTs during the focus groups and semi-structured interviews carried out for the Person study described in the previous chapter.

A first version of the booklet was shared with 3 beta readers who had no experience with either design or disability research to test its clarity and readability. Appropriate modifications were made before distribution according to their feedback. A copy of the handout is available in Appendix A.

9.1.2 Participants

Seven designers (Ds) and three wheelchair users (WUs) took part in the PD workshop. The three WUs had different medical conditions, two transferred using an unassisted sitting technique (WU1, WU2), while the third (WU3) benefitted from the use of a transfer board. Unfortunately, we were unable to recruit WUs performing standing transfers for the event. Designers were recruited from academia (D1-4), charities (D7) and private companies (D5, D6). Their backgrounds varied from product to fashion design; physical computing to AT. Some designers had previous experience of ATs (D1, D3, D5, D7) and co-design (D1, D2, D3, D5), while others were new to both concepts.

9.1.3 Workshop

One week before the workshop all participants received a copy of the handout created for the study. Participants were prompted to contact the author if they wished to ask any questions. The researcher did not actively participate in the workshop but acted as moderator during group discussions and collected field notes throughout the day. At the beginning of day the researcher gave a brief presentation highlighting the main points of the handout provided to participants. Furthermore, the participants were carefully explained the aim and structure of the workshop, including the amount of time allocated to each individual phase.

During the initial phase of the workshop all participants were encouraged to have a group discussion on the content of the handout and identify the specific challenges they would like to tackle though AT design. Participants were told that once they identified their areas of interest, they were free to work all together, create small teams or work independently to generate and develop their ideas for the rest of the day. The rest of the workshop followed the format of Tell-Make-Enact proposed by Brandt, Binder, & Sanders (2012). Once teams were formed, participants were given 90 minutes to discuss their ideas and produce a short description or an annotated drawing of their design concept(s) (Tell). During the Make phase, lasting for 2 hours, participants were asked to generate at least one low-fidelity prototype of the design ideas they previously described. Teams were provided with Lego bricks and basic crafting materials (e.g. cardboard, foam, fabric, glue...) for the prototyping activities (Walsh, Foss, Yip, & Druin, 2013). Additionally, a set of small wooden dolls and 3D printed models of wheelchairs, shown in Figure 9-1, were provided to participants to facilitate envisioning and basic testing of their design ideas. At the end of the day, teams were asked to present and discuss their ideas with the other participants, showing the functionality of their prototypes and describe the details of the AT they thought more significant (Enact).

Figure 9-1 Participants testing their ideas for a transfer board using a wooden doll and a wheelchair model

9.1.4 Data analysis

Throughout the day, the conversations among participants were audio recorded. Non verbatim transcription of the conversations were triangulated with field notes collected by the researcher, in order to understand the dynamic of the workshop and the interactions between participants. Additionally, at the end of the workshop semi-structured interviews were conducted with all participants to capture additional details about their experience and the perceived usefulness of the handout provided. Interview questions were simple and mainly focused on the perceived value of the workshop, favourite aspects of the day, suggestions for improvements, usefulness and readability of the handout. Audio recordings of the interviews were transcribed and analysed using an inductive coding procedure up to saturation (Weed, 2017). Codes were grouped into relevant themes according to the approach outlined by Braun & Clarke, 2006.

9.2 Results

9.2.1 Dynamic of the workshop and participant's interaction

Initially the discussion among participants focused around transferring issues that were highlighted in the handout. In particular, participants were interested on the implications of the lack of transfer training for people who had a medical condition that was not SCI. Drawing from personal experience, WU1 and WU2 explained to other participants that many people do not receive any training for transfers, or wheelchair skills in general, and that even when that training is provided, it is usually generic and not necessarily helpful when dealing with specific challenges. As the conversation progressed, wheelchair users started to discuss more practical concerns that affected them personally, such as the difficulty encountered when performing transfers featuring height gaps between the two surfaces or when transferring from a soft surface that offers little support to the upper limbs. Others difficulties that were highlighted were specific to particular types of transfers such as the challenged posed by the need of transfer to and from a bath tub. Interestingly, when discussing personal difficulties, wheelchair users often referred to the content of the handout to explain important concepts in a way that they thought would have been more easily understood (WU3 "*As it shows you here [points to a picture on the handout], when I transfer to my car seat, which is higher, I have to lean very far forward. Otherwise I can't lift myself enough"*).

After discussing these issues among themselves, all participants agreed to focus their efforts towards the design of a new AT aimed at facilitating the performance of transfers between surfaces of different heights. Several designers, particularly D7 and D4, were also interested in the challenge related to the provision of training for wheelchair transfers. However, they felt that the issue was too complex for the scope and timeframe of the workshop, due to the needs to consider difficulties associated to different transfer techniques and impairments. Furthermore, although the three wheelchair users acknowledged the importance of the issue, they did not displayed any personal interest in its solution. Although all participants seemed to agree on the idea of focusing their efforts towards the design of an AT that could facilitate wheelchair transfers when significant height gaps exist, they decided to split into two separate teams as there were two distinct points of view on the type of AT to design. The split was mainly caused by the different views of wheelchair users concerning features of the AT. WU3 and WU2 preferred the idea of a stand-alone AT that was completely independent from the wheelchair, while WU1 thought that a device that could be embedded or attached to the wheelchair would offer more advantages in terms of portability and convenience for the user. Regardless of their views on particular features of the technology, low tech and affordable solutions were advocated from all three WUs as they were described as more reliable and accessible. Throughout the initial discussion and the team formation phase, wheelchair users assumed the role of "Topic experts", leading the identification of the most significant challenges related to the performance of wheelchair transfers, while designers were occasionally asking question for clarification or supporting wheelchair users' statements according to their own experience. In contrast, designers, particularly D5 and D1, assumed the role of "Process guardians" often reminding the group of the need to focus on one or two main issues, due to the time constraints imposed by the structure of the workshop.

Team 1, composed of four designers and one WU (D1, D2, D6, D7, WU1), decided to focus on the design of AT that could be embedded on the wheelchair itself, while Team 2, featuring three designers and two WUs (D3-5, WU2, WU3), chose to focus on the design of a stand-alone AT. Once divided into teams, participants started brainstorming on potential design ideas. In both groups, during the initial phases of brainstorming designers were more imaginative and started to propose different ideas for potential solutions, whereas wheelchair users were more likely to use their personal expertise to highlight advantages and drawbacks of different design concept (D3 "*You could cover a board with a material that allows you to slide in one direction but prevents you from falling back*", WU2 "*Yes, but you have to make sure that that material is not skin abrasive or it could cause lesions*"). Once the teams focused on more concrete design ideas, wheelchair users gained more confidence in proposing their own solutions, although they still tended to look at the designers to confirm that their ideas were feasible (WU1 "*I think you could elevate the system using a mechanism similar to the one you have in office chairs… That wouldn't be too difficult right?*"). Interestingly, despite the fact that, by the end of this phase, wheelchair users in both teams had clear ideas of what the new AT would look like they refrained completely from producing sketches of it as they felt their skills were inadequate (WU2 "*If I try to explain it to you would you be able to draw it? I am terrible at it…*").

Throughout the Tell phase, the power balance within both groups was clearly in favour of wheelchair users. While designers were generally more proactive in proposing potential ideas for new AT, wheelchair users employed their practical knowledge to decide which ideas held the potential to succeed and which were deemed to be more likely to fail (D3 "*Why don't we create something with a conveyor belt system that slowly moves you across the surface?*", WU3 "*If you use a motor there, you'll need a battery and the thing will get far too heavy to be of any use*"). Amongst the designers themselves, the dynamic of the teamwork was slightly different between the two groups. In team 2, D5 emerged clearly as a group leader, while the power distribution in Team 1 was more balanced. This was also somehow also reflect in their workflow. Team 1 appeared to be more creative but also less organized, while Team 2 focused early on fewer ideas but tried to develop them in more detail.

By the beginning of the Make phase both teams had clear ideas concerning the functionality of their AT designs and participants were mainly concerned about finding the best way to illustrate them. Throughout the development of the prototypes the core ideas remained unchanged. However, particularly in Team 1 designs underwent adjustments as participants realised more efficient way to achieve the same function (D7 *"If rather than pulling up the sides we use a cranking system it will be a lot easier to raise and people could stop a different heights*"). Throughout this phase of the workshop the balance shifted again as designers' expertise became crucial to decide which materials were more appropriate to build prototypes of the team's ideas and what the most efficient way to assemble them was. Wheelchair users were actively engaged in realising the prototypes, but they relied on designers to direct them through the process.

Even within the Make phase, the teamwork dynamic was different between the two groups. Team 1 exhibited a more balanced collaboration where all teammates worked on both prototypes together without distributing specific tasks to different individuals according to their skills or expertise. On the other hand, in Team 2, exhibited a more structured approach. D5 had access to a design laboratory adjacent to the location where the co-design workshop was hosted and proposed to his teammates that they could develop a full-scale prototype of their AT design. The suggestion was strongly supported by all teammates and this led to a rigid task distribution that was required to complete the prototype in time. D5 manufactured the base of the AT, whereas D3 and WU3 prepared the attachments for it and D4 and WU2 assembled them together.

Finally, in the Enact phase both teams presented their final AT designs to each other. In both groups presentations were delivered in a joint manner by both wheelchair users and designers. Interestingly however, throughout the presentations wheelchair users and designers assumed specific task related roles according to their area of expertise. While designers were more concerned to properly illustrate the technical details of each design ideas, wheelchair users took care of explaining the functionality of the AT and its advantages for potential users in relation to real life situations.

9.2.2 Design ideas

The three ATs designs that were developed, prototyped and presented by the two groups at the end of the workshop were:

Team 1: The Equalizer

The first group produced two different designs for a device, called "The Equalizer" which would be able to raise the seat of the wheelchair, up to a max of 10-15 cm, to allow for easier transfers from and towards higher surfaces. Their first design, shown in Figure 9-2, featured a small crossed frame mechanical system that could be secured to the wheelchair seat and placed underneath the wheelchair cushion. The yellow button on the right would activate the mechanism and allow the seat to rise. Pneumatic, hydraulic or spring based mechanisms were proposed as actuators alongside a geared system that would store energy while the wheelchair user propels the chair. To keep energy demand low and minimize the weight of the device, the wheelchair user would be required to perform a small lift to relieve their weight from the cushion and allow the Equalizer 1 to rise to the desired height. The Equalizer 1 also featured small extractable transfer board that could be used to help bridge the gap between the wheelchair and the other surface the person is transferring onto.

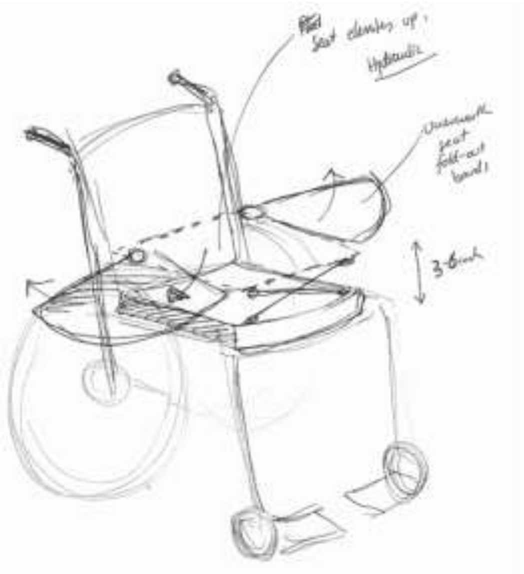

Figure 9-2 The Equalizer Version 1, sketch (left) and prototype (right)

The second design for the Equalizer, shown in Figure 9-3, included a sling system based on a simple piece of robust fabric, attached to two lateral supports. Once the wheelchair user raises themselves from the seat the fabric can be made more tense, by a cranking mechanism or a small electrical motor that wraps the fabric edges around the top part of the arm rests, until it provides a higher seat for the person.

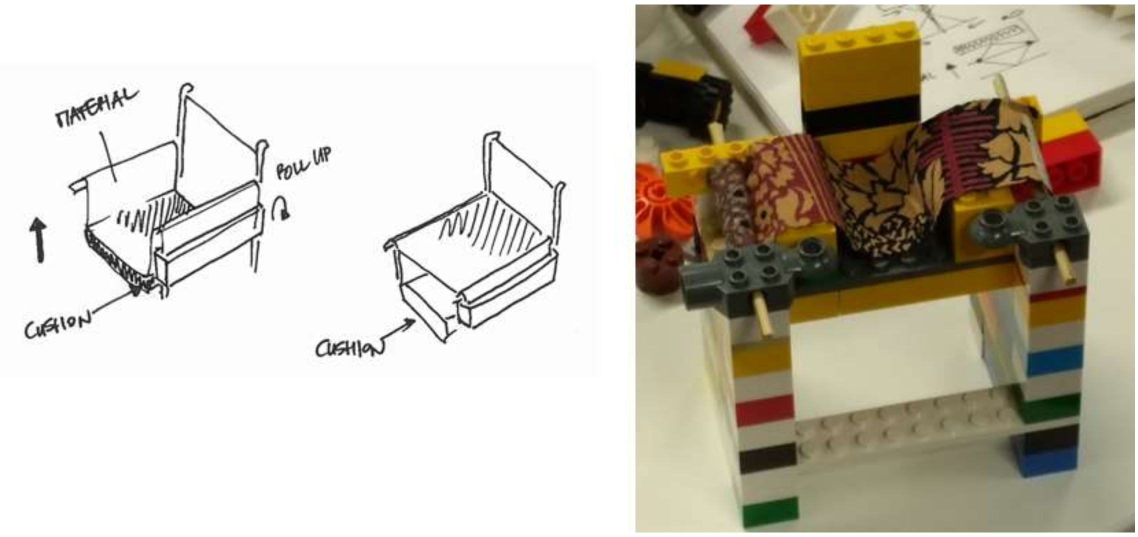

Figure 9-3 The Equalizer Version 2, sketch (left) and prototype (right)

<u>Team 2: The Slide-non-Slip transfer board</u>

The second group instead focused on the design of a modified “boomerang shaped” transfer board, called “Slide-non-Slip (SnS) transfer board”, shown in Figure 9-4, which would allow the wheelchair user to slide across it without slipping backwards when performing transfers uphill. A layer of foam or silicone based material designed with an “overlapping dragon scales pattern” on the upper surface would allow the wheelchair users to slide in one direction without any additional effort, but it would also prevent them from sliding in the opposite direction. The SnS transfer board can also be used to help wheelchair users control their descent when transferring downhill.

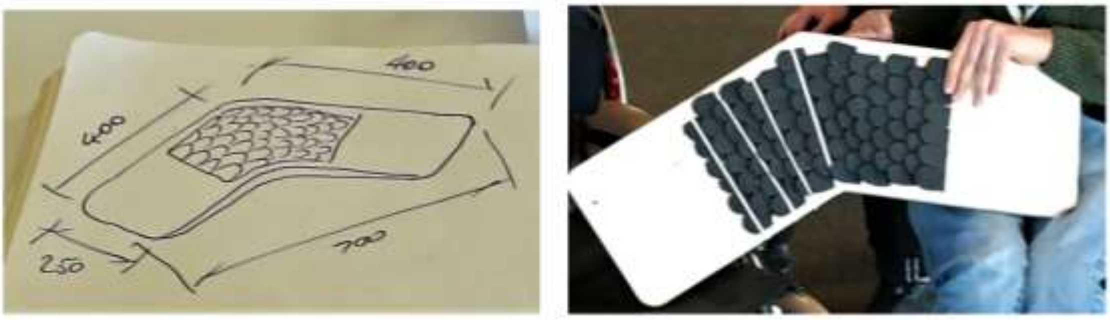

Figure 9-4 The Slide-non-slip transfer board, sketch (left) and prototype (right)

9.2.2 Participants’ feedback and experience

<u>The Workshop</u>

Feedback from both wheelchair users and designers was extremely positive. Participants found the workshop engaging and particularly enjoyed the diversity of experiences and backgrounds that each individual brought to the table. Wheelchair users felt that the scope of the event was significant to them and could help bring attention to one of the everyday challenges which is often overlooked. Designers particularly enjoyed the opportunity to work on a problem that was both well-defined yet incredibly broad. (D5 "*It was a very good problem to work on. Overall it was very big, but it also had so many aspects that it was possible for us to pick a particular side and work on something where we could achieve significant progress within the day*").

The combined presence of wheelchair users and designers was recognized as the most important successful feature of the day. From the point of view of wheelchair users this allowed them to experiment first hand with how their needs and suggestions could be translated into more concrete design ideas and specifications. Designers were able to tap into the personal experiences of wheelchair users and incorporate their ideas into graphic representations and physical prototypes (WU1 "*This event worked so well because you got both wheelchair users and designers here. If it was down to me to design and do all the fiddly stuff having no fine motor skills we wouldn't have gotten anywhere. But on the other hand, if you didn't have users like myself, in the end you would have probably had ideas for assistive technologies that were very pretty but not very useful…*").

Another aspect that all participants found both enjoyable and meaningful was the fact that they had the opportunity to select the area that they wished to work on and organise themselves in teams accordingly (WU2 "*Having the chance to team up with other people that want to work on the same idea was brilliant. It makes things a lot easier because you don't have to negotiate all the time on what is important*"). On one side, participants acknowledged that the initial discussion subtracted precious time from their brainstorming and prototyping activities. However, the ability to select a specific challenge that they wished to solve also made them more invested in the project.

Alongside their positive feedback, participants also identified potential area of improvement in the way the workshop was conducted. For example, in line with what was observed during the workshop, D2 highlighted how drawing activities have a significantly higher entry threshold that might discourage wheelchair users from attempting to express their ideas visually as they don't feel confident in their own skills (D2 "*Maybe, if you had pictures or premade sketches that people could draw over it could help people to communicate ideas more easily even if they don't know how to draw*"). Despite the effort made during recruitment the number of wheelchair users present at the workshop was considerably lower than the number of designers. Some participants (W2, D1) felt that having more wheelchair users present at the event would have helped explore various problems faced by people with different impairments or needs. However other participants felt that the number of wheelchair users, or participants in general, was sufficient to the workshop and it allowed them the freedom to pursue different projects. (D6 "*It's is particularly good also the fact that we had enough people to work on two separate things so it's not that we all had to unite behind one idea from the beginning…*").

The Handout

The handout was considered a crucial tool that facilitated communication and collaboration among all participants. Sharing knowledge with both wheelchair users and designers helped all people to understand the fundamentals of wheelchair transfers, their complexity and their importance. Additionally, it allowed participants to identify potential areas of interest ahead of the workshop and keep their discussions focused on the problem they were trying to solve. (D7 "*I think having the handout before helped to make sure that everybody was speaking the same language from the beginning and made people focus on the real problem straight away. It also helped people understand why we are here together and the value of what we are trying to achieve*"). Having all participants briefed before the workshop on the most important aspects of wheelchair transfers was also found to facilitate sharing of opinions and debate, particularly in the initial discussion that resulted in the formation of the two groups (D4 "*The discussion at the beginning was very insightful. It was clear that people were prepared, it made their opinions stronger and it made them more comfortable in sharing them. I think this was very impressive considering the fact that they basically just sat down and they were able to engage on a conversation on the problem straight away*").

Interestingly, the information identified as most valuable within the handout was different for each participant depending on their background and experience. Designers with no previous experience with wheelchair activities and transfers, such as D2, D3, D4 and D6 found detailed descriptions of transferring techniques particularly useful. While D1, D5 and D7 stated that the personal accounts provided by wheelchair users during interviews and focus groups allowed them to capture the depth and complexity of the problems surrounding wheelchair transfers. However, designers were not the only ones who learned useful information from the handout. Among the wheelchair users, WU3 explained how the data provided concerning the load on the upper limbs, and the risk of falling during transfers helped him understand the potential reasons for his difficulties and made him more motivated to look for a solution. On the other hand, WU1 who was born with an impairment admitted to having been incredibly surprised when he realised how important training for transferring can be for people with acquired impairments; learning how to transfer had been a natural process for him "*Understanding the needs* *of other users help us empathise with them because sometimes [it] is hard to see outside our own bubble, and I think if we do put ourselves in other's people shoes we can create better solutions for a problem*".

Although participants' opinions on the handout were generally very positive, several participants suggested potential improvements that could make it both more comprehensive and more impactful. In particular, WU3 and D2 felt that the handout was missing a section dedicated to the exploration of the various AT available on the market to facilitate wheelchair transfers. Additionally, D6 suggested that a more visual styles where explanations of difficulties and issues encountered during wheelchair transfers were accompanied by pictures would have helped to contextualise these information and facilitate the generation of potential solutions.

9.3 Discussion

Despite the low number and the limited amount of available time, participants in both teams were successfully able to conceptualise, prototype and present elaborate design ideas for ATs aimed at facilitating the performance of independent wheelchair transfers. Regardless of their backgrounds and previous experience, all participants described the workshop as an extremely enjoyable experience and felt that their contribution helped to shape the final ideas developed by their team. The clear structure of the co-design workshop and the hands-off approach adopted by researchers also helped participants to self-manage expectations and reduce frustrations that might arise in relation to an unclear decision making process or misunderstandings about the aim of the project (Bossen et al., 2012). The handout provided to participants helped to establish a clear focus from the beginning and gave individuals more confidence in expressing their ideas as they felt "prepared" on the subject. Furthermore, the booklet acted akin to a boundary object, as described by Star & Griesemer (1989), that participants referred to when trying to foster shared understanding of unfamiliar or more complex concepts.

A positive collaboration was quickly established among participants and maintained for the duration of the workshop. However, the analysis of the interactions between wheelchair users and designers highlighted the fluctuation of power balance between the two groups throughout the individual phases of the workshop. Interestingly, the group which was, at each stage of the workshop, in the more powerful position to make decision concerning the development of the AT, was not necessarily the most knowledgeable one or the one providing the most creative input. For example, during the initial discussion that led to the formation of the teams, the conversation was mostly dominated by wheelchair users as they were the ones with the deepest knowledge of the challenges encountered when transferring to and from the wheelchair. However, thanks to their expertise, designers were able to quickly identify the areas where potential AT intervention could generate the most successful outcomes and used their knowledge to stir the conversation in the direction they felt was most productive.

On the other hand, during brainstorming activities designers became significantly more proactive and articulated numerous ideas for potential ATs. Nevertheless, the power of decision making was held by wheelchair users who relied on their practical knowledge to evaluate the potential benefits and drawbacks of the different design concepts and propose changes where they felt appropriate. Once team members settled on their idea for the new transfer ATs, the power shifted again in favour of the designers. This was particularly evident during sketching activities as wheelchair users completely relied on designers to translate their thoughts into drawings. However, even during making activities, despite the fact that wheelchair users were actively engaged in the realization of ATs prototypes alongside their teammates, they looked at designers to provide leadership and necessary guidance to successfully complete the task.

On one side, this highlights how, despite the lack of any "making" experience, prototyping activities, particularly if carried out with easy to use tools such as Lego bricks or pre-cut cardboard shapes, are often perceived as more accessible than traditional "artistic" tasks. Thus, prototyping activities yield greater potential in empowering non-professionals, including people with disabilities, to express their own ideas within a PD team. On the other hand, even for activities with a lower entry threshold users did not feel like they had sufficient skills to take the lead and were happy to rely on the guidance of teammates with more expertise. In a way this resonates with the concepts illustrated by Ladner (2015) that sees technical expertise as an essential requirement for participation in certain stages of the design. Although wheelchair users involved in the current study were able to actively take part in almost all the activities during the workshop, their lack of technical expertise prevented them to take a more powerful role.

Despite the difficulties that they might have encountered, one of the most positive aspects of the feedback received from participants during the final interviews was related to the sense of ownership that they felt about the design concepts generated. In contrast with what is reported by Bowen et al. (2013), wheelchair users perceived themselves not only as informants who contributed to the design but as actual co-designers. This was further demonstrated by the fact that, during the Enact phase wheelchair users and designers were able to present their AT together in respect to their own strength and expertise. While the shift in power between users and designers throughout the various phases of the workshop was somehow unexpected, participants were able to find a satisfactory balance by the end of the workshop.

Overall, the current approach proved to be successful in accelerating the co-design process and facilitating the communication and cooperation among teammates. This allowed participants to have a significant impact on the design outcomes of the project without requiring extensive involvement that might become burdensome for people with disabilities or, in the worst case, simply prevent participation (Petrie et al., 2006). Although time commitment and the potential burden of participation are of particular concern for people with disabilities, this technique can be of broad use, and certainly within the current study was at least as beneficial for the wheelchair users as it was for the designers.

Regardless of the information shared with participants, both the specific constraints of the project and the composition of the PD team will considerably affect the outcomes of the workshop. In the current study for example, part of the initial discussion among workshop's participants revolved around the need to provide guidance and resources to people who did not received any training on transferring skills. However, participants felt that the problem was too complex for the timeframe allowed by the participatory design workshop and that the issue required clinical skills that none of them felt confident in providing. This seems to suggest that the same handout could be used to facilitate a number of co-design workshops for transfers ATs. The combination of a new set of participants with different backgrounds and the variation in the format and duration of the participatory design workshop are likely to produce different design ideas which strengthens the value of the document produced.

In their analysis of the methods used during 18 co-design workshops, Lucero, Vaajakallio, & Dalsgaard (2012) stated that the composition of the PD team and the structure of the workshop are not the only elements that will influence its outcomes. In the authors' opinion both the space in which the workshop is carried out and the materials available to participants will significantly affect the ideas generated and the unfolding of the design process (Lucero et al., 2012). Although in the current study the space in which the workshop was carried out did not have a significant effect on the interactions between participants or the design ideas generated, the choice of sketching and prototyping techniques and materials might have limited the ability of wheelchair users to contribute more during specific phases of the workshop. In future studies, it would be worth considering the adoption of sketching and prototyping technique with lower entry threshold to facilitate increased active participation of wheelchair users.

Finally, the content of the handout proved to be successful in informing participants on the challenges related to wheelchair transfer and the most factors that should be considered when designing new ATs to facilitate them. However, in the future, including additional information related to currently available ATs, adopting a more visual style could facilitate participants' ideation process during the workshop. Alternatively, choosing a different and more interactive means of communication could allow participants to tailor the amount and delivery of information to their liking, promoting a deeper and more inspiring shared knowledge.

9.4 Chapter summary

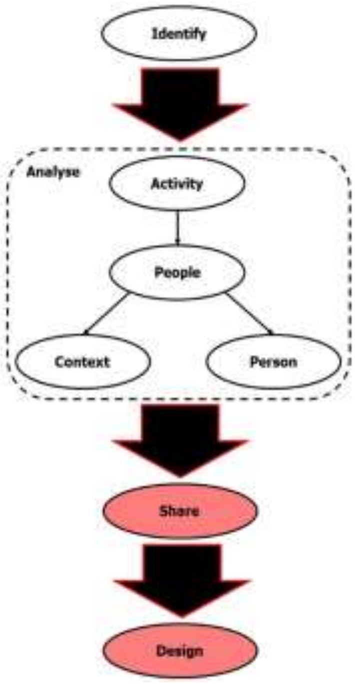

Figure 9-5 Diagram illustrating how the current study corresponds to the Share and Design phases of the 2PAC framework

This chapter presents the last study of this thesis, corresponding to the Share and Design phases of the 2PAC framework (see Figure 9-5). As illustrated in Chapter 4, where the framework was first introduced, findings from the 4 previous studies described in Chapter 5, 6, 7 and 8 were used to develop a framing document which was given to wheelchair users and designers ahead of a PD workshop. The aim of this handout was to facilitate a focused and accelerated PD process, with wheelchair users and designers working symbiotically. Additionally, it was hoped that handout would have helped to empower wheelchair users, by increasing their confidence in collaborating with designers to develop design concepts for new ATs.

Overall, findings from the current PD workshop were extremely positive. At the beginning of the workshop the ten participants engaged easily in a global discussion where they identified specific challenges that they wished to tackle and organised themselves into two separate teams according to the approach they deemed more suitable for developing ATs that could facilitate people when transferring between surfaces featuring considerable height gaps. Three design concepts were presented by participants at the end of the day. Two were for a device, called the Equalizer, to be attached to the wheelchair and could be used to raise the seat and allow the person to transfer more easily to and from a higher seat. The third design idea was for a transfer board that, thanks to a scaled pattern realised with soft foam will enable the wheelchair users to transfer to and from a higher seat in smaller steps without the risk of sliding backwards.

When observing the interactions among participants a power shift between wheelchair users and designers throughout the different phases of the workshop. This dynamic balance seemed to reflect the different expertise of each participant’s group and while it is not a negative phenomenon it certainly deserves further investigation.

The feedback provided by participants in the semi-structured interviews at the end of the workshop was also extremely positive. Both wheelchair users and designers described the event as meaningful and engaging as the collaboration between them was judged to be essential to the development of useful and acceptable ATs. Furthermore, all participants found the handout helpful as the knowledge gained from it made them feel prepared and resulted in increased confidence when sharing their opinions. Potential improvements to the current approach could be made by intensify recruiting and achieving a better balance of wheelchair users and designers. Additionally, adopting a more visual style for the handout and promoting the use of sketching and prototyping techniques with lower entry threshold could facilitate the generation of ideas and improve the active engagement of both users and designers.

Chapter 10 General discussion

Whenever we think about a wheelchair user we are likely to picture a person sitting in their wheelchair; perhaps pushing it or being pushed by a carer, maybe even an athlete competing in a Paralympic event (Sapey, Stewart, & Donaldson, 2005). However, it is not very often that people consider how a person gets into and out of their wheelchair. Transferring to and from the wheelchair is a vital skill that enables independence for many wheelchair users (Slavin et al., 2009). The ability to perform an independent transfer between the car seat and the wheelchair was rated as the most important skill for independence by both Paralympians and "regular" manual wheelchair users (Fliess-Douer et al., 2012). Furthermore, performing wheelchair transfers is essential for many ADLs such as getting out of bed, taking a shower or using a toilet (Morgan et al., 2017). Unfortunately, wheelchair transfers are also physically demanding and the high mechanical load associated with their performance can, over time, lead to the development of upper limbs injuries (Hogaboom, Diehl, et al., 2016; Hogaboom et al., 2013; Tsai et al., 2014). Injuries such as CTS and rotator cuff tears will cause wrist and shoulder pain (Mercer et al., 2006; Yang et al., 2009). Pain reduces the person's ability to transfer and to propel their wheelchair, leading to a decrease in independence, participation and QoL (Gutierrez et al., 2007). Moreover, the performance of wheelchair transfers has also been associated with the risk of falling, which could cause traumatic injuries and decrease people's confidence in their own ability to perform transfers (Akhigbe et al., 2015; Jørstad et al., 2005; Nelson et al., 2010; Opalek et al., 2009).

Currently, there are some ATs such as grab bars, transfer boards and lifts which can partially facilitate the performance of wheelchair transfers (Boninger et al., 2005; Toro et al., 2012). However, most of these devices are part of a larger range of accessibility modifications which are only available in selected environments (usually the person's home and car). Transfer boards are the only portable AT for wheelchair transfers that are commonly used by many wheelchair users (Zhuang, Stobbe, Hsiao, Collins, & Hobbs, 1999). Transfer boards offer several advantages such as low cost, portability and ease of use, but still require users to have good coordination and sufficient upper limb strength in order to transfer independently. Finally, transfer boards offer few advantages for challenging transfers such as when the presence of a height gap between the two transferring surfaces causes the transfer board to create a slope that might be too difficult to climb for the person.

Considering the difficulties and risks associated with the performance of wheelchair transfers and their importance for daily independence, the design and development of new ATs could have an important impact on the life of many wheelchair users. However, it is worth remembering that ATs are part of a system that revolves around the person using the AT, the activity for which the person is using the AT and the context in which the activity takes place (Cook & Polgar, 2014). Failing to understand this complex relationship leads to a scarce consideration of users' needs, priorities and will result in ATs that are likely to be abandoned by users (Phillips & Zhao, 1993). The abandonment of ATs causes a waste of time, energy and money for all parties involved (Federici et al., 2016). Furthermore, AT abandonment is particularly concerning as it can have a knock-on effect for users who end up blaming themselves for the failure of that technology, leading to lowering of subsequent expectations and the enforcement of negative feelings towards AT (Bühler & Knops, 1999; King, 1999). The design of new ATs should always be preceded by a thorough investigation of the activity, its social and physical context, the difficulties associated with its performance and the characteristics of the users.

The use of a well targeted UCD approach can help to correctly capture the needs and goals of prospective users in order to increase the likelihood of AT's acceptance and reduce the risk of abandonment (Riemer-Reiss & Wacker, 2000). However, this approach still sees people with disabilities in a mainly passive role and places them at the receiving end of the design chain. ATs have a tremendous impact on the life of people with disabilities, not only from a functional point of view, but also in the way people with disabilities perceive themselves and are perceived by others (Pape et al., 2002). For this reason people with disabilities should be given the possibility to impact the design of new ATs in the same measure that they are impacted by it. The benefits of using a PD approach to involve people with disabilities in the initial steps of the design of new ATs go beyond its democratic nature or the creation of more usable products and services (Kanstrup, 2003; Robinson et al., 2009). In fact, by involving people with disabilities as co-designers and blurring the hierarchical top-down structure that is common in the traditional structure of ATs design, PD offers an opportunity for empowerment increasing confidence and independence for people with disabilities not just through the outcomes of ATs' design but through its process (Hurst & Kane, 2013; Hurst & Tobias, 2011). However, building the level of collaboration between users and designers that allows PD to flourish often requires time and prolonged participation of both users and designers (Shah & Robinson, 2007). The time commitment and the effort required by all parties to successfully carry out PD projects is likely to become too great a barrier in a field where recruitment of participants is already an extremely challenging aspect of research (Dee & Hanson, 2016; Petrie et al., 2006; Sears & Hanson, 2012).

The 2PAC framework that is presented in this thesis aims to help wheelchair users and designers work collaboratively to produce usable and acceptable ATs for wheelchair transfers. Moreover, the scaffolding structure provided by the framework intends to focus the design effort and ensures power balance between wheelchair users and designers, thus reducing the burden of participation while maximising its impact. The framework, illustrated in Chapter 4, drives the studies presented in this thesis from the investigation of the different aspects that define and influence the performance of wheelchair transfers (Activity, People, Context, Person), to the collation of the relevant information to establish the needs and requirements for transfers. This culminates in their use to inform and facilitate the final PD process. In the next section, I summarise the key findings from the various studies. Then I reflect on the YouTransfer, YouDesign project and analyse the factors that contribute to improve participation and engagement among research participants. Afterwards I discuss the application of the 2PAC framework, highlighting challenges encountered due to the changing role of the researcher and debating about its potential for generalizability. Finally, I reflect on the general limitation of the YouTransfer, YouDesign project and briefly illustrate the steps that would be necessary to develop the design concepts generated into functioning and accessible ATs.

10.1 Summary of research findings

The aim of this thesis was to develop a way to facilitate the PD of new ATs for wheelchair transfers. To achieve this goal it was necessary to gain a deeper understanding of the way transfers are performed in the everyday lives of wheelchair users. In line with existing findings (Fliess-Douer et al., 2012; Morgan et al., 2017; Slavin et al., 2009), all participants highlighted how the ability to transfer safely to and from their wheelchair was extremely important for their everyday independence and QoL (see Chapters 5 to 9). Transfers were described as an essential requirement for many ADLs and participants reported investing great effort in learning how to transfer in the best way they could (see Chapter 8). Despite their efforts, many people feel tense when transferring and are not satisfied of their own abilities (see Chapter 6).

In literature, the performance of wheelchair transfers is associated with both the development of upper limbs injuries, due to the high mechanical load, and risk of falling (Hogaboom, Diehl, et al., 2016; Hogaboom, Worobey, et al., 2016; Ummat & Kirby, 1994). However, results from the study presented in Chapter 5 show that, when compared with the performance of independent sitting transfers, the use of a standing technique or a transfer board can reduce the load withstood by the upper limbs. Nonetheless, it also causes poorer quality of transfer potentially associated with a greater risk of falling. Despite the greater mechanical load associated with them, people who transfer using an independent sitting technique, reported higher frequency and lower difficulty when transferring in their everyday lives compared to both standing and assisted transfers (see Chapter 6). This can be at least partially explained by the fact that, a number of people who use an independent sitting technique when transferring have a SCI as a primary medical condition. Individuals with SCI are more likely to have received transfer training from peers or medical professionals as a part of their rehabilitative journey (see Chapter 8). Wheelchair users who have received appropriate training are more aware of the importance of using a correct technique and they invest grater effort in making sure they transfer in a safe and efficient manner, thus potentially reducing the difficulty of transfers (see Chapters 6 and 8). The difficulty of various transfers is not only influenced by the technique used by the individual, but it will also depend on the physical context in which the transfer takes place. The different environmental constraints associated with the performance of different types of transfers (bed, car, toilet couch) cause significant changes in the movement strategies used by the person, which can affect both the reported difficulty and the quality of the transfer (see Chapters 6 and 7). Regardless of the specific environmental context in which they were found, certain factors such as large (vertical or horizontal) gaps, soft or slippery surfaces and lack of space were described as always challenging to negotiate (see Chapters 6, 7 and 8).

While some difficulties and risk associated with wheelchair transfers are heavily affected by the transferring technique, which is in turn mainly determined by the person’s medical condition (see Chapters 5 to 8), others are common to all wheelchair users. The occurrence and exacerbation of pain due to the performance of transfers is such a common occurrence among wheelchair users that participants described it as an unwelcome but unavoidable side effect of transfers (see Chapters 6 and 8). In addition to the discomfort experienced due to the pain itself, people who complain of upper limb pain during transfers are more likely to feel tense when transferring (see Chapter 6). This underlying tension causes them to rush the transfer or adopt movement strategies that are counterproductive, increasing both the risk of falling and developing injuries (see Chapter 8). Similarly to pain, the fear of falling was found to be common to most participants, regardless of their individual characteristics (see Chapter 8).

Finally, the use of ATs to facilitate wheelchair transfers was also reported as common by most participants (see Chapters 6 and 8). In general the likelihood of ATs use was found to be only affected by the weight of the person (see Chapter 6). On the other hand, the choice of the specific ATs is determined by a combination of personal and environmental factors (see Chapters 6 to 8). In general, existing ATs received positive reviews from participants. However, despite being described as helpful, most people found that they fell short of meeting the desired requirements particularly when dealing with challenging situations or users that were either particularly skilled or encountering greater difficulties (see Chapter 6 and 8).

The main findings originated from the studies were then synthesised and collated into a single, easy to read document (see Appendix A) that was distributed among the participants of the final PD workshop. The purpose of the handout was to help participants, regardless of their background, in identifying opportunities for new ATs aimed at facilitating the performance of wheelchair transfers. In doing this I aimed to provide focus to the PD process without influencing its outcomes and promote effective and seamless communication between wheelchair users and designers to maximise the impact of participation in a short timeframe and guarantee power balance among participants (see Chapter 9). The handout proved to be a successful tool in facilitating productive collaboration between wheelchair users and designers throughout the co-design workshop. As highlighted by Kensing (1983) the access to relevant information was found to be key to the meaningful participation of users in the design process. Not only had the information provided allowed participants to quickly identify the challenges related to wheelchair transfers that they wished to target, but the shared knowledge contained in the booklet helped them to establish a common language that was used to illustrate the value of their ideas throughout the day. By the end of the workshop all participants felt that their contribution made a positive impact on the development of the design concept, fostering a sense of empowerment and ownership towards the ATs ideas that were generated (see Chapter 9).

Overall, the work presented in this thesis shows how a systematic and comprehensive approach to the investigation of wheelchair transfers allows to understand how the difficulties encountered by many wheelchair users are the result of the complex interactions between personal, functional and environmental factors. By broadening the focus of previous research, I was able to highlight how certain issues associated with the performance of wheelchair transfers are common to all users and across various circumstances, whereas others are dependent from either the technique used for transferring, the characteristics of the individual or the environmental context in which the transfer takes place. This knowledge is not only useful to guide future research, but can be directly employed to facilitate the co-design of new ATs for wheelchair transfers in a way that empowers wheelchair users and maximises the impact of their contribution while reducing the burdens associated with prolonged participation. Drawing from the findings described in previous chapters and summarised above, in the next section I reflect on the concepts of engagement and participation and their different meaning in relation to PD and the work presented in this thesis.

10.2 Reflections on engagement and participation

PD seeks to involve users and other stakeholders as partners, alongside designers and researchers in the design of new products and services. But is participation truly the right word for it? In the Oxford English Dictionary, the verb participate is defined as “to take part, or share, with a person in a thing”. While this definition is largely in line with the aims of this thesis it is also somehow restrictive. Being able to get as many wheelchair users as possible involved in the YouTransfer, YouDesign project was definitely important for the scope of this thesis. However, even more than the number of participants involved, the primary concern was to empower wheelchair users and enable them to provide a meaningful contribution that could shape the design of ATs. To achieve this goal, it is not sufficient for people with disabilities to take part passively in a research study or design workshop, but they will need to fully engage in the project and become the driving force that directs the efforts of researchers and designers. If participation can be passive, engagement, defined as “the action of occupying the attention or efforts of someone towards something”, expresses an active concept that sees the person becoming the protagonist of the situation rather than one of the many actors involved in the performance. In this light, participation can be described as a necessary, but not sufficient condition for engagement. Therefore, the YouTransfer, YouDesign project pushes the boundaries of traditional PD by minimising the burden of participation for wheelchair users and promoting their engagement in PD of ATs for transfers.

But what motivates people to take part in research studies and what causes them to become engaged in a project once they decided to participate? The choice to take part in research studies is mostly a rational one and researchers have identified several factors that can encourage, or discourage potential participants (Clark, 2010; Elskamp, Hartholt, Patka, van Beeck, & van der Cammen, 2012; Fry & Dwyer, 2001; Hughes, 1998; Mfutso-Bengo, Masiye, Molyneux, Ndebele, & Chilungo, 2008; Trauth et al., 2000). As highlighted several times within this thesis, participation in research studies and PD design projects comes with a cost for people who agree to take part. Unsurprisingly, among the main reasons that cause people to refuse to take part in research studies, most are of practical nature (Elskamp et al., 2012; Mfutso-Bengo et al., 2008). Lack of time, difficulty to travel to the facility where the study takes place and mobility or health problems are often the main factors that discourage people from taking part in research studies (Elskamp et al., 2012; Mfutso-Bengo et al., 2008). These practical concerns are likely to be more severe among people with disabilities due to increased likelihood of health problems, access issues and difficulties when travelling by public transport (Carlsson, 2004; Havercamp, Scandlin, & Roth, 2004).

Despite the time and effort that it requires, some people still decide to take part in research studies as they perceive that it can be a beneficial experience for them. Among the potential benefits reported by research' participants some are of more practical nature such as financial rewards, having the possibility of modifying future policies that could affect themselves, increasing self-awareness, or, in the case of medical intervention studies, the possibility to access new treatment that would otherwise be unavailable (Fry & Dwyer, 2001; Madsen et al., 2002). Others are more interested in less tangible benefits such as the cathartic feeling that can derive from being listened to by the researcher, the feeling of empowerment generated by taking a more active behaviour or having the possibility to interact with individuals in similar situations (Clark, 2010; Fry & Dwyer, 2001). Finally, some people are mainly motivated by altruistic motives and agree to take part in research studies in the hope that it would help a friend, a family member or even stranger (Clark, 2010; Fry & Dwyer, 2001; Trauth et al., 2000).

Regardless of their individual reasons, it is worth noticing that the main factor that appears to play a role in the decision of participating, or not, in a research study is the person's evaluation regarding the value of the study (Clark, 2010; Hughes, 1998; Trauth et al., 2000). Understandably, if people think that the topic of the project is insignificant or irrelevant to themselves, or others, and unlikely to have an impact, they will not be motivated to participate. Drawing from Roger's diffusion of innovations theory (Rogers, 2010) it can be argued that people will only be willing to commit their time and efforts towards research projects that present a potential relative advantage towards issues that are compatible with their values and priorities.

If participation is the result of a choice that the person makes, engagement is the product of the interaction between different factors that fall outside the individual's control. When analysing the personal experiences of profound engagement reported by over 100 participants during the Peak Experience Exercise, Hoffman et al. (2005) identified six common elements across different stories: risk, support for spontaneity, novelty, challenges that match skills, community and creative action. Some of these elements are similar to the ones previously identified as reasons that motivate participation.

Intense engagement is more likely to occur when the person is involved in a task that is important to them (Hoffman et al., 2005). Particularly, individuals tend to be engaged if the outcomes of the task they are involved with are uncertain, if they are allowed freedom to express themselves and their contribution is aimed towards the creation of something (Hoffman et al., 2005). Furthermore, situations where people find themselves outside their comfort zone yet confronted with a challenge that is difficult but not overwhelming are more likely to be associated with intense engagement (Hoffman et al., 2005). Finally, the possibility of interacting with a supporting but not overbearing community increases the engagement of the single individual (Hoffman et al., 2005).

One of the main factors which contributed to the success of the YouTransfer, YouDesign process was the fact that the chosen activity was of crucial concern for the target user group. The ability to transfer has a great functional impact on the lives of wheelchair users and, due to its consequences in terms of personal independence, it deeply affects how wheelchair users perceive themselves. Wheelchair transfers can also change other people's perceptions. When we think about wheelchair users it is the image of the wheelchair, not the person that we associate with disability. As made clear by Shakespeare (2013), "impairment is a necessary but not sufficient element to the disability relationship". Theoretical approaches to disability, which move beyond the more traditional medical and social models of disability (Institute of Medicine, Board on Health Sciences Policy, & Committee on Disability in America: A. New Look, 2006), such as critical realism, interpret disability as a broad term which encompasses a full spectrum of factors (from physical or cognitive impairment, to lifestyle and societal characteristics) that interplay to create the reality experienced by people with disabilities (Shakespeare, 2013; S. J. Williams, 1999). This broadened approach is reflected in the International Classification of Functioning*,* Disability and Health (ICF) that describes disability as being constructed by the interactions between three domains: the individual, society and the system of support (which includes ATs) (World Health Organization, 2001). The skill of performing safe and effective independent wheelchair transfers has the ability to impact upon each of these three spheres and, therefore is of prime importance to the experiences of wheelchair users. This was confirmed several times within the project as the wheelchair users involved at each stage of this research were invested as they felt that both new research and new AT solutions that facilitate independent wheelchair transfers were needed and long overdue.

The structure provided to the project by the 2PAC framework was also successful at several levels. Firstly, the interconnected yet separate nature of the studies allowed wheelchair users the freedom to regulate their participation according to their own wishes. All participants expressed a willingness to be contacted about future studies within the YouTransfer, YouDesign project and four were able to take part in more than one study. To further address potential participation barriers deriving from difficulties related to the need to reach the location of the study funds to cover participants travel expenses were always offered and, where possible such as for the study presented in Chapter 8, different times and locations were arranged according to the availability of wheelchair users and OTs. Secondly, the simple and transparent structure of the project helped participants to understand the purpose of their participation and provided additional meaning to their efforts. If the goal of the project was defined, the outcomes were instead uncertain. This made participants feel that their contribution, even during the early stages, could lead to substantial changes in what AT would be designed as a result and how it would be developed. Finally, participants' awareness of the modular structure of the project, where results from one study were used to inform the planning of the following and directly contributed to the development of the final AT concepts generated, helped to create a sense of communal effort among them. At the beginning of each study, wheelchair users were briefed on the goals of the project and on the findings gathered up to that point. Recognising that other people had invested time and effort in the success of the project and the knowledge that their contribution could be beneficial to future participants promoted both altruistic behaviour and sense of community.

Elements that facilitated participation and engagement were not only part of the overall structure of the project but they were also present in the single studies, particularly in the final PD workshop described in Chapter 9 of this thesis. Design is by definition a creative activity with an uncertain outcome and no single correct solution (Buchanan, 1992). Generating ideas for new ATs to facilitate wheelchair transfers provided an ideal opportunity for engagement among participants as it allowed them to express their creativity and problem solving skills to tackle a challenging problem that has a direct impact on wheelchair users' lives. The loose structure of the workshop provided participants with the freedom to shape their own experience while they organised themselves in teams and explored the available tools and chose the materials to build the prototypes of their ideas. Additionally, the participatory nature of the workshop was a novel experience for most participants and enabled them to form teams with individuals that had the same goals but different skillsets so that they could support each other in their creative endeavours. Finally, both the availability of the handout and the collaboration between wheelchair users and designers contributed to make more accessible and achievable a task that might have otherwise been overwhelming.

10.3 The changing role of the researcher

Within this thesis, particularly in Chapters 4, 9 and 10, I discussed extensively the importance of the role played by people with disabilities in research studies and PD projects. However, throughout a complex project featuring studies carried out with different methods such as the YouTransfer YouDesign project, the researcher also ends up having to change their approach according to the methodology and the scope of the study. As illustrated in the previous section, at the beginning of each study, apart from the survey described in Chapter 6, I would not only carefully explain the characteristics of the study about to take place, but would also introduce the scope and the structure of the whole project to the participant and provide a briefing related to the findings originated by previous studies. Although it might be argued that such an approach could bias participants' responses, the differences among various studies prevented this from happening. Furthermore, clarity on the structure and scope of the overall project increased the trust in the both the project and myself, which promoted a meaningful contribution and helped to establish correct expectations in the participants about what the study was going to be like and what I, as a researcher, was looking for (Brown, Reeves, & Sherwood, 2011; Stone & Priestley, 1996).

During data collection of quantitative biomechanics or observational studies such as the ones presented in Chapters 5 and 7 my role as a researcher was mainly that of a director. I carefully designed and planned both studies and, if no technical issues requiring troubleshooting arose, my duty was mainly to clearly explain the experimental protocol to the participant and ensure that the study followed the desired format. In this context the researchers are often seen as the experts by the participant as they have the knowledge about both the experimental protocol and the technology employed to collect the data. The researcher can also provide additional clarifications if needed and should always make sure that the participant is safe when performing the desired task. During the observational studies described in Chapters 5 and 7, thanks to my previous experience as a physiotherapist, I acted as a spotter when wheelchair users were transferring and I was ready to provide assistance upon request. During the context study described in Chapter 7, I was also responsible to ensure that participants took adequate resting breaks between different transfer scenarios in order to avoid fatigue. As expected, during the survey study illustrated in Chapter 6, my role as a researcher was virtually non-existent once the survey was launched. The online nature of the survey made it impossible me to fully brief participants and only a brief explanation of the nature of the project was provided in the introductory page of the study. Overall, in quantitative research studies the role of the research is mainly passive and their influence on the results are often small.

On the other hand, during qualitative studies such as the ones presented in Chapters 8 and 9, the role of the researcher is of much greater concern. As highlighted by Denzin & Lincoln (2008), in qualitative research the researcher is an instrument for data collection. Their attitudes and behaviour can influence the results of the study as much as the choice of an instrument to measure breathing rather than heart rate would influence the results of a study measuring physical effort during sport activities. Interestingly, in qualitative studies, the role of the researcher becomes more active and at the same time less authoritative. Although both aspects were equally important in the interviews/ focus group study and in the PD workshop, the reason behind this was different. When carrying out semi-structured interviews or focus groups I needed to be responsive in order to adjust my questions to the narrative of expression of the participant to elicit important facts, experience and opinions that shape the perception of the person (Slembrouck, 2015; Weiss, 1995). Furthermore, during focus groups I needed to act as a moderator to make sure that opinions were expressed by all participants and the conversation was not controlled by individuals who might have a more extrovert or dominant nature (D. L. Morgan & Krueger, 1997). In this context it was particularly important for me to take an equal or inferior role rather than an authoritative one towards participants. Knowing that they were the experts in the conversation allowed wheelchair users to express themselves freely and prompted them to provide detailed explanations on challenges related to the performance of transfers that might have otherwise being considered already familiar to a researcher who was seen as more knowledgeable and authoritative, particularly due to my clinical background. Moreover, if I appeared too confident in my own expertise this could have be perceived as patronising by people with disabilities, particularly considering that, as an able bodied person, I would not have had any first-hand experience of disability (Stone & Priestley, 1996).

In the context of the PD workshop I adopted a hands-off approach in order to avoid influencing the ATs concepts generated by both teams. Throughout the workshop, and especially during the initial discussion, I acted as a facilitator with the aim to promote a lively discussion on the various challenges related to the performance of wheelchair transfers that participants were interested in tackling (Sanders & Stappers, 2008). As much as possible, my aim was to maintain a passive role as to not interfere with the ability of participants to organise themselves. Nevertheless, I needed to be responsive in case participants started to divert too much from the goal of the workshop, as I had to be ready to redirect the flow of conversation towards the topic and potentially remind participants of the time constraints associated to the workshop. However, this was unnecessary, as when the conversation started too digress for too long, one of the designers made sure that the group converged back to the focus of the workshop and reminded to the others that if they wanted to achieve their goal by the end of the day it was necessary to keep their discussion focused.

10.4 The 2PAC framework beyond wheelchair transfers

The 2PAC framework has been specifically formulated to facilitate the involvement of wheelchair users and to promote an equal collaboration with designers within the PD of transfers ATs. However, its simple and systematic approach could be applied more broadly to a variety of projects focussing on the PD of ATs for people with disabilities. The tensions identified in relation to meaningful contribution, power of decision-making and prolonged engagement (see Section 4.4.1) are common to all PD projects involving people with disabilities and the four steps of the Analyse phase were derived from ATs adoption models that are applicable to people with different needs and medical conditions (See Section 3.3 and Section 4.4.2). However, the application of the 2PAC framework to a different AT problem and involving people with different disabilities will require the researcher to consider the need to make necessary adjustments for the success of the project.

For example, wheelchair transfers were identified as a specific challenge that was relevant to the wheelchair users' population mainly through research of available literature. On the other hand, important challenges for other populations might not be as well documented and, particularly for uncommon disabilities which are likely under-researched, issues identification could require extensive consultation with target users and healthcare professionals who have specific expertise. For the YouTransfer, YouDesign project the four steps of the Analyse phase were completed through a series of qualitative and quantitative studies. All four studies were deemed necessary as the available literature on wheelchair transfers focused mainly on biomechanical analysis carried out in a laboratory and mostly involving people with SCI generating results that are poorly generalizable and not representative of real life situations (Crytzer et al., 2015; Gagnon, Koontz, et al., 2009; A. Koontz et al., 2012; Nyland et al., 2000). However, the same approach might be not necessary for future applications. Significant information could be collected also through literature reviews or analysis of pre-existing databases, potentially speeding up the investigation phase, depending on the focus of the project and the availability of information.

Finally, the PD design phase relies on the assumption that participants will be able to understand and take advantage of the information shared by the researcher. For this reason, the application of the 2PAC framework to PD projects involving young children or people with reduced cognitive capabilities might not be feasible or would require significant modifications, such as the use of alternative forms to present the information and/or the use of proxies in order to enable users' participation and support engagement (Holone & Herstad, 2013; Moraveji, Li, Ding, O'Kelley, & Woolf, 2007).

10.5 What is next? From design ideas to ATs

Although participants' feedback and results collected throughout the YouTransfer, YouDesign project have been extremely positive, it should be acknowledged that the proposed method for informed participatory design and its application can only be considered truly successful after the production of tangible outcomes. When considering the necessary steps to develop the design concepts presented by participants at the end of the PD workshop illustrated in Chapter 9, I developed an updated version of the 2PAC framework, shown in Figure 10-1, which includes four additional steps.

Develop and Test

Although these two phases are often presented individually, their iterative nature makes them difficult, if not pointless, to separate in functional terms. The development of the ideas generated during the design phase should be carried out alongside a frequent consultation with potential users. If possible, users involved during testing iterations should be a combination of new users and users who took part in the previous phases. This will achieve the double aim of making sure that the development follows the direction set by the users and reducing bias.

Share (2)

The core principle of democracy in participatory design should be applied not only to its methodology, but also to its outcomes. Once satisfactory functional devices have been realized, AT designs and associated detailed instructions on how to replicate them should be shared with charities and made publicly available to the maker community in order to improve the accessibility for potential users. In recent years AT design is becoming an increasingly popular topic within the maker community. However, as it is shown by Buehler et al. (2015) most of the design ideas available in these virtual communities have been generated by hobbyists with an interest in engineering. ATs ideas developed through a PD process that involves both designers and people with disabilities could have a greater chance of success.

The fact that they have been designed according to the direct inputs of multiple people with disabilities guarantees an awareness to multiple aspects of the disability that may not have been immediately evident to makers without specific knowledge who developed a device in order to help a friend or a family member. Additionally, these devices have been realised on the basis of solid and extensive research which guarantees that these designs have been developed under supervision and underwent evaluation that is likely to make them more useful, safe and reliable.

Redesign

This final phase of the design process is desirable but, unfortunately, never guaranteed and often completely out of the researcher's hand. Once designs are released in the public domain, other researchers, AT designers and users will be able to replicate the devices and, hopefully, make their own adaptations. The community of users and makers should be encouraged to share improved and modified versions of the original designs in order to facilitate sustainability and generate better ATs through design in use and design after design (Bjögvinsson, Ehn, & Hillgren, 2012; Fischer & Ostwald, 2002). Considering the limitation of the research domain, where funding schemes and agendas make it difficult to maintain a long term involvement on a project, seeking partnership with charities and disabled people's organizations could be a viable way to guarantee long term engagement.

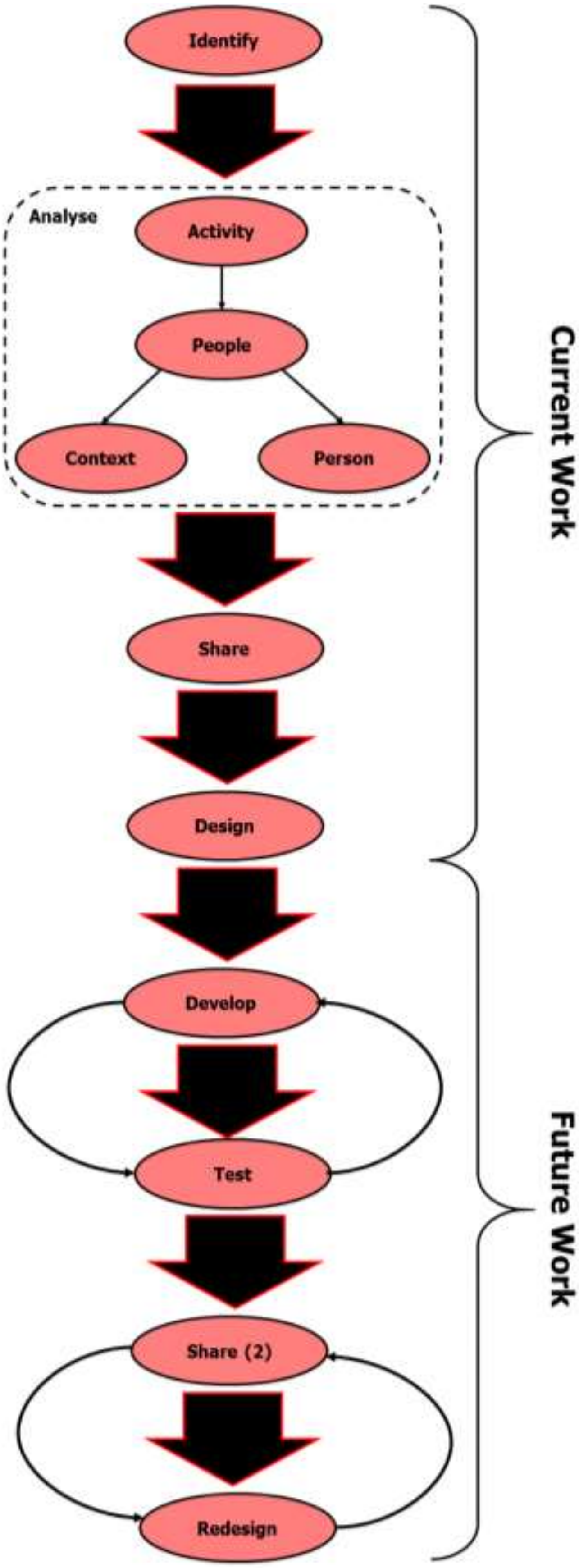

Figure 10-1 Diagram showing all the 8 steps of the 2PAC framework from the identification of the problem to the redesign of deployed ATs

Chapter 11 Conclusions

The work presented in this thesis addresses the following research question:

How can wheelchair users be engaged and empowered to contribute to the design of new assistive technologies for independent wheelchair transfers that respond to their real needs?

In order to provide a comprehensive answer I divided this question in two sub-questions: respectively focussing on:

1. Facilitating the engagement of wheelchair users in PD while reducing the burden associated with participation
2. Identifying the factors that due to their influence on the performance of wheelchair transfers will play a significant role in the need for AT.

To answer the first sub-question, I developed a framework, called 2PAC, which provides a modular structure guiding the PD process from problem identification and analysis to the sharing of information to facilitate the collaboration between wheelchair users and designers promoting meaningful engagement and providing focus to the design effort. To answer the second sub-question, I conducted a series of mixed-methods studies according to the steps for problem analysis defined by the 2PAC framework. Findings from these studies confirm the prime importance of transfers in the everyday lives of wheelchair users and show how the performance of transfers, and consequentially the need for new ATs, is affected by a combination of factors ranging from the individual's characteristics, the transferring technique adopted, the use of ATs, the occurrence of pain and the environmental characteristics in which the transfer takes place. Finally, I developed a framing document based on the results obtained from previous studies that was distributed among participants ahead of a PD workshop on generating ideas for transfers ATs which involved both wheelchair users and designers. The handout proved to be an effective tool in empowering participants, providing focus to the generation of relevant design ideas and facilitating an equal collaboration between wheelchair users and designers, thus maximising the impact of participation within the short timeframe available.

In short, the contributions of this thesis to knowledge can be classified in two different ways: first, it contributes to the methodological debate about the involvement of people with disabilities in the PD of ATs; second, it contributes to the practical understanding of the challenges and risks associated to the performance of wheelchair transfers in real life across individuals with different medical conditions and transferring techniques.

This thesis also opens up new interesting endeavours for future research across the fields of wheelchair studies, mobile computing and PD design. The research presented in this thesis focused on the early stages of PD for wheelchair transfers' ATs. However, in the previous chapter I discussed how the 2PAC framework could potentially be applied to various PD projects aimed at the development of ATs involving people with different types of disabilities. Furthermore, I expanded the 2PAC framework to include the additional steps that would be necessary to develop the design concept generated during the PD workshop into ATs that are freely available to disabled users who might benefit from them. Findings from the work presented in this thesis have also important clinical implications as they highlight the need to provide appropriate transfer training to all wheelchair users regardless of their medical condition and the potential benefits of tailoring this training according to the more prominent risks associated with the transferring technique used by the individual.

Furthermore, in the studies presented in Chapter 5 and 7, I employed the TAI to evaluate the quality of wheelchair transfers performed across various scenarios by individuals using different transferring techniques. However, the evaluation based on the TAI requires the presence of a trained healthcare professional which makes it unsuitable to continuous evaluation in real-world settings where wheelchair transfers actually take place. The use of wearable sensors and ubiquitous computing could be employed to provide long term and "in the wild" evaluation of wheelchair transfers performance which offers benefits both clinical monitoring and wheelchair users' self-awareness. In Appendix F I present results from preliminary testing of the accuracy of a portable evaluation system that uses simple machine learning algorithms, on data collected from a single chest mounted tri-axial accelerometer, to evaluate the performance of wheelchair transfers and detect their occurrence in real-world settings. In Chapter 9 I discussed how, despite of the value of the handout, the outcomes of the PD workshop were heavily influenced by both the time constraints and the background of participants. Future repetitions of the workshop with different time constraints and involving participants with different expertise would not only produce new ideas for future ATs but also help to clarify the relationship between these factors.

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Appendix A. Handout for participatory design workshop

YouTransfer, YouDesign

ALL YOU NEED TO KNOW AHEAD OF OUR PARTICIPATORY DESIGN WORKSHOP

UCLIC

Global Disability Innovation Hub

A PhD project by

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TABLE OF CONTENTS

THE AIM OF THIS GUIDE

The aim of this guide is to introduce key concepts to both wheelchair users and designers so that all participants can better understand the challenges faced by wheelchair users when transferring and the key concepts of co-design ahead of our participatory design workshop.

HOW TO USE THIS GUIDE

Hopefully, reading from start to finish will be an enjoyable experience. However, you might prefer to dive into the specific challenge we are facing and look at the types of transfers described in pages 5-8. If you want to learn more about participatory design (sometimes called co-design), jump to page 9. If you are interested in finding out the results of our previous studies have a look at pages 10-16.

AN OVERVIEW ON INDEPENDENT WHEELCHAIR TRANSFERS

Being able to transfer in and out of the chair is one of the most important skills for wheelchair users who wish to be independent in their everyday lives. The number of times that a person transfers to and from the wheelchair in a single day varies greatly and depends on habits, disability, environment, lifestyle and personal preferences. Regardless of the individual factors, common activities such as getting out of bed, taking a shower, driving a car, practising sports or using a toilet usually require the person to transfer out of his/her chair. For example, if a person is unable to stand and take a few steps, he/she will probably transfer five or six times every day to complete a regular morning routine. And all this happens before the person even gets to the breakfast table!

Crucially, if a person is not able to transfer independently there is currently no available alternative that can completely eliminate the need of human assistance.

FIGURE 1 WHO DO YOU THINK IS MOST INDEPENDENT?

The way in which a person transfers in and out of the wheelchair is heavily influenced by several factors such as:

- The physical capabilities of the person
- The type of transfers that he/she is performing
- The eventual use of assistive technologies

INDEPENDENT YPES OF TRANSFERS

Generally, when people perform an independent transfer, they will exhibit one of two techniques, standing or sitting. Although both individual and environmental characteristics can cause the transfer strategy to change significantly, each technique can be described by a series of events that are common to most users.

STANDING TRANSFERS

	To perform a standing transfer the person will usually position the chair in the desired position, place both feet on the ground and move their buttocks towards the front of the chair.
	Most users will then lean forward with the trunk while simultaneously pushing down on the wheelchair wheels (or armrest) to get up.
	Once standing, the person will take a few steps to pivot in the desired direction. Even if able to stand unsupported, users generally use their hands to hold onto nearby supports to increase their balance.
	To safely sit down on the target surface, the person generally must bend his/her knees while flexing the trunk slightly forward
	Often, one or both hands will be placed on the target surface or on nearby supports to help control the descent.
	Transfer complete!

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	To safely sit down on the target surface, the person generally must bend his/her knees while flexing the trunk slightly forward
	Often, one or both hands will be placed on the target surface or on nearby supports to help control the descent.
	Transfer complete!

UNASSISTED SITTING TRANSFERS

For unassisted sitting transfers the initial set up phase will be very similar. The person will first position their wheelchair close to the surface on which he/she wishes to transfer on.

Usually the chair will be placed at a slight angle from the target surface and the person will scoot towards the front of the seat.

Some users will place both feet on the floor while others might prefer to leave them on the footplate.

The person will then place one hand (the leading hand) close to the target surface and will then leave one hand (the trailing hand) on the wheelchair.

The transfer itself is usually achieved with a quick forward lean of the trunk, which will release weight from the buttocks...

...accompanied by a pivoting motion that brings the shoulder of the person in the opposite direction of the transfer (this particular motion is called the head-hip relationship due to the fact that the head will move in the opposite direction to the hips).

Transfer complete!

ASSISTED SITTING TRANSFERS

Sitting transfers can be carried out unassisted (as described above) or with the aid of a transfer board. Transfer boards are low tech assistive technology that create a bridge between the wheelchair and the other surface the person is transferring to or from. They are usually made in wood or hard plastic. Transfer board are available in different sizes and can be mainly found in two different shapes: straight and curved (these are called banana boards).

FIGURE 2 STRAIGHT TRANSFER BOARD

FIGURE 3 BANANA BOARD

	In many respects transfer board sitting transfers are very similar to unassisted sitting transfers. First the person places the wheelchair in the desired position
	Then, he/she will have to slide the board underneath the buttocks closer to the target surface.
	Only when the transfer board is securely placed, the person will position leading and trailing hands respectively on the target surface and the wheelchair.
	Then he/she would slide bit by bit across the transfer board...
	...until he/she reaches the target surface.
	Transfer complete!

THE DARK SIDE OF INDEPENDENT WHEELCHAIR TRANSFERS

Unfortunately wheelchair transfers are not only very important for many users, they are also very difficult. Transferring in and out of the wheelchair requires sufficient strength, in either the upper or lower limbs, to bear the weight of the whole body and sufficient balance to shift the body from one surface to the other. The forces generated along the person's arms, when pushing on the armrests to get up or while supporting the body during a sitting transfer, can damage the shoulder, wrist and elbow. Any injury to the upper limbs can pose a severe threat to the independence and wellbeing of any wheelchair user as they rely on their arms for most activities; from pushing the wheelchair to reaching and transferring.

Repeated sitting wheelchair transfers have been linked, by several researchers, to shoulder injuries and carpal tunnel syndrome. Transfers have also been described as one of the most painful activities to perform for people who are already suffering from a shoulder injury. Although this has never been investigated, the same could happen to the lower limbs of people who transfer with standing technique, particularly if they are weakened by non-use and pre-existing medical conditions.

Transferring to and from the wheelchair can is dangerous both in the short and long term. Falls occurring during the performance of transfers are responsible for 16.9% of wheelchair related accidents, and transfer activities have been identified by users as a major risk factor for wheelchair related tips and falls. Falls can not only cause traumatic injuries to the individual but they can also decrease his/her confidence and consequentially reduce the level of autonomy.

FIGURE 4 DID YOU KNOW THAT TRANSFERS ARE RESPONSIBLE FOR MANY ARM INJURIES AND WHEELCHAIR FALLS?

DESIGNING WITH USERS, NOT FOR USERS

Assistive technologies have the potential to enhance the capabilities of an individual and provide the means for functional independence. However, a large number of assistive technologies are abandoned soon after prescription or acquisition. Poor consideration of the users' needs and priorities is generally the strongest predictor of assistive technologies abandonment.

When a person decides to discard an assistive technology, he/she can become frustrated and end up blaming him/herself for the failure of that technology. People invest time, money and effort into selecting assistive technologies that are considered suitable. The disappointment in the performance can lead to a feeling of helplessness and frustration, lowering the expectations and extending the negative judgement the person has towards the possibility of any assistive technology having a positive impact on their life.

One way to make sure the users' needs are, not only included, but at the core of the design of new assistive technologies, is through an approach called participatory design (or co-design). Participatory design is based on the concept that an equal and fair collaboration between users and designers could lead to the development of assistive technologies that are more useful and acceptable. There are three main benefits offered by this approach:

1) It enables users to shape the design of future assistive technologies without needing to speak the technical language of designers.
2) It helps users to formulate their ideas in tangible terms by understanding what is possible from a design prospective.
3) It provides designers with insights to understanding the needs that go beyond their personal experience.

It is widely agreed that participatory design is only successful when there is a mutual learning environment that allows equal collaboration between all parties involved. However, particularly for projects focusing on technologies for people with disabilities, this is often incredibly hard to achieve. Designers lack a deep understanding of the challenges that disabled people have to face, while users can often struggle to formulate their needs in a way that is meaningful to designers. Additionally, the experiences of each disabled person are different from others and it can be challenging to expand individual points of view into a more global perspective.

One way to facilitate this exchange between users and designers is to provide all parties with complete and useful information about the problem they are trying to solve. Traditionally participatory design is combined with ethnography research (observational study of people) to provide participants with insights into the problem they are trying to solve. However, in the case of developing assistive technologies for wheelchair transfers this might not be enough. To this end, we developed a four steps process called **2PAC (People, Person, Activity, and Context)** to collect relevant information on different aspects of wheelchair transfers. The next four sections of this booklet will walk you through the main findings derived from previous studies on wheelchair transfers that we have undertaken over the last 18 months, in the same order in which they have been carried out. **We hope that this body of shared knowledge will facilitate the exchange between users and designers and help all participants to collaboratively generate ideas for assistive technologies that are rooted in the reality of wheelchair transfers and respond to the needs of users.**

ACTIVITY: THE EFFECT OF TECHNIQUE AND TRANSFER BOARD USE

In December 2016 seven people participated in a small laboratory study that looked at the effect of different transferring techniques (assisted sitting, unassisted sitting and standing) on the upper limbs' load and the quality of the transfer itself. The load on the upper limbs was measured by monitoring the reaction forces underneath both hands (forces that are generated when the person pushes against a surface) during transfers. The quality of transfer was evaluated using a clinical scale, which was chosen as it represents an indicator of transfers' safety.

FIGURE 5 EFFECT OF SITTING, STANDING AND TRANSFER BOARD TECHNIQUE ON ARM LOAD AND TRANSFER SAFETY

Results from our study confirm that standing and transfer board transfers generate reduced load on both upper limbs when compared to sitting transfers. However, the difference was very small between transfer board and unassisted sitting transfers. Regardless of the person's technique the load on the upper limb was found to be considerably high. Forces are always greater on the trailing arm compared to the leading side and they can be as high as 22% of the person's body weight for standing transfers. During unassisted sitting transfers the trailing arm might have to bear over 41% of the individual's weight and the load is only reduced to 35% when the person is using a transfer board. At a glance these numbers might not tell you much, but to give you an idea think about the fact that for a person of average weight (70Kg), this means that one arm alone will need to sustain a load of nearly 29kg!

The risk of developing upper limb injuries was lower for individuals performing standing and transfer board transfers. However, when we assessed the quality of their transfers we found it to be poorer and less safe. This can potentially reflect in an increased risk of falling.

Between February and June 2016 we carried out a survey that aimed to investigate the relationships between the performance of wheelchair transfers and the other factors involved, including the individual's characteristics, motivation, presence of upper limb pain, use of assistive technologies and environmental conditions. We received 42 responses from both manual and power wheelchair users that had different disabilities and performed wheelchair transfers with different technique.

As expected, the majority (88%) of the respondents stated that they considered transferring an extremely important skill for their everyday life and declared to have invested great effort in performing wheelchair transfers safely and effectively. However, being strongly motivated to acquire a skill, did not appear to be sufficient to obtain the desired results as less than a third of the participants said they were completely satisfied of their transfer skills.

Bed, bathroom and car transfers were identified as the most commonly performed transfers, and transfers between wheelchairs and to/from couches or chairs around the house were also quite popular. Only thirteen people said they often transferred onto office chairs, restaurants and/or cinema seats, plane seats and various exercise or rehabilitative devices such as hand bikes and standing frames.

In terms of difficulty, some of the most common transfers were rated as more difficult.

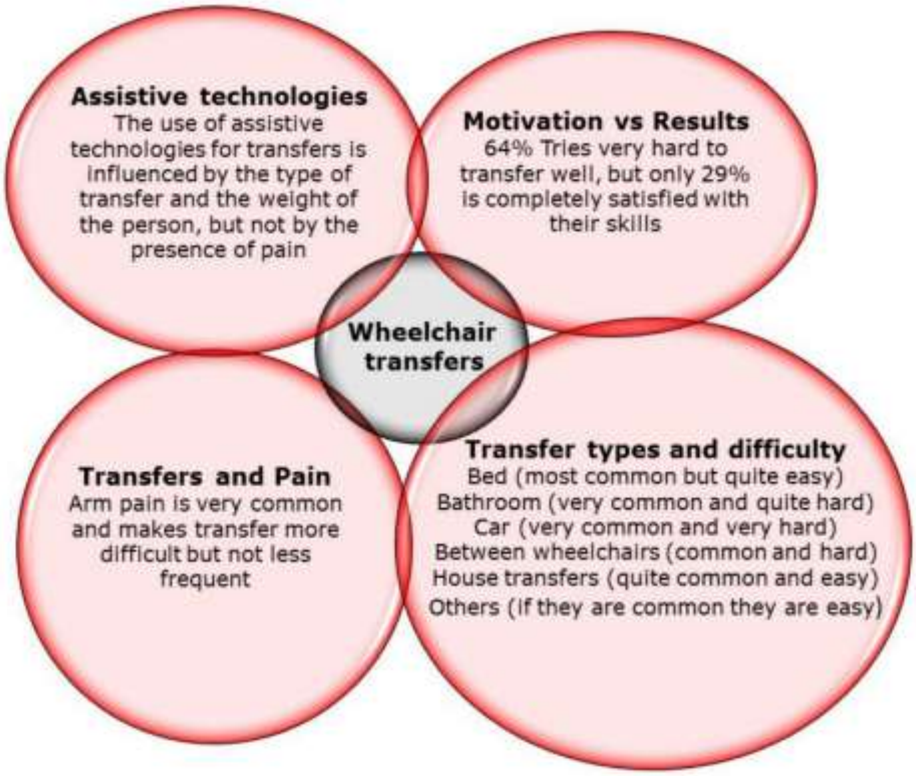

FIGURE 6 SUMMARY OF SURVEY'S FINDINGS

Over 90% of respondents said they have experienced pain in at least one area of the upper limbs during the last six months and over 60% said that the pain was exacerbated by transfers. As expected pain was found to increase difficulty of transfers and decrease person's level of confidence. However, the presence of pain did not affect the number of transfers that people performed in a day.

The vast majority of respondents, 73.8%, declared they benefitted, in one or more situation, from the use of an assistive technology or from the presence of fitted modification such as swivel seats, grab bars or adapted vehicles. Grab bars are found almost exclusively within the house, particularly in the bathroom, while only four individuals reported having special handles mounted in their car in order to ease their transfers. On the other hand, the use of transfer boards was found slightly more common for car transfers (33.3%) compared to bed (23.3%) or other house transfers (20%). The decision to adopt assistive technology seemed to be unrelated to the presence or intensity of upper limb pain. On the other hand, subjects reporting use of assistive technologies were found to weigh more which suggests that assistive technologies can become a valuable tool when a task becomes too strenuous.

CONTEXT: THE SETTING MATTERS

Between June and July 2016 we organized a research study, in collaboration with the Georgia Institute of Technology (GeorgiaTech) that aimed to explore how technique and perceived difficulty during wheelchair transfers change according to the setting in which they are performed. We recruited thirteen wheelchair users with different disabilities and we asked them to transfer four times in three out of four scenarios (bed, bathroom, couch and car).

We measured height differences for all transfers and videotaped the execution to compare the differences in performance. After each transfer participants were asked to rate, on a 10-point scale, the effort that it took them to complete the task. The three indoor settings (bed, bathroom, couch), shown in the pictures below, were standardized for all subjects as we reconstructed them within the university facilities.

FIGURE 7 BED, COUCH AND TOILET SCENARIOS FOR THE STUDY

Due to the great variability between different car models and their impact on transfer performance, we chose to use the person's own vehicle when investigating car transfers. Cars were divided in three categories according to their type: sedan (normal city car), accessible minivan and jeep. Four participants drove a jeep where the height of the driver seat was over 1.5 meters from the ground. However, only two of them transferred directly onto the driver's seat while the other two transferred onto the seat of a car lift.

FIGURE 8 DIFFERENT CARS USED IN THE EXPERIMENT

The strategy used to perform the transfer was greatly affected by both the technique of the subject and the scenario of the transfer. Eleven participants exhibited the same technique across all transfers, while 2 participants changed technique according to the environment in which the transfer was performed (see pictures below). Overall, indoor scenarios presented similar characteristics between them, while car transfers presented strategies that where considerably different, not only to other scenarios, but also across different subjects due to the uniqueness of the set up.

FIGURE 9 DAVID HAS AN INCOMPLETE SPINAL INJURY AND HE TRANSFERS MAINLY USING AN UNASSISTED SITTING TECHNIQUE. HOWEVER, HE IS ABLE TO PUSH HIMSELF UP TO SIT IN HIS CAR USING A SPECIALLY MOUNTED BAR AND THE CAR DOOR

FIGURE 10 MICHAEL IS ABLE TO TRANSFER UNASSISTED IF THE CHAIR AND THE OTHER SURFACE ARE CLOSE AND LEVEL, BUT HE NEEDS TO USE A TRANSFER BOARD WHEN DEALING WITH HEIGHT AND WIDTH GAPS

Changes involved mainly different positions of the hands and feet. Although these might seem minor at first, they can have a great effect on both the load on the upper limbs and the risk of falling during the transfer. Regardless of the settings, during standing and transfer board transfers people will often change the position of their hands as they progress along the transfer. This doesn't seem to be a problem for people who transfer using a transfer board, as they are supported throughout the whole transfer. For people who used a standing technique, this shift of hand position might put them at risk of falling due to a lack of support. People who performed standing transfers seemed keener to use grab bars or other supports, when available, to pull or push themselves in a standing position and improve balance throughout the transfers. On the other hand, participants using transfer boards or unassisted sitting technique were more likely to position their hand flat or in a fist on both transferring surfaces.

Interestingly, we found no relationship between transfer quality rated by the clinicians and the perceived difficulty reported by the subject. One possible explanation for this is that wheelchair transfers become so ingrained in the daily routine of users who live in the community, that individuals become used to perform them with certain strategies that might be unorthodox for a therapist.

What: Over the last three months we organized a series of interviews and group discussions that involved eleven wheelchair users, and in one case four occupational therapists, in the attempt to understand the experience of wheelchair users in relation to transfers.

How: We asked participants questions concerning their transfer technique, the difficulties they encounter daily, how they deal with pain and fear of falling and what their thoughts on assistive technologies were. To capture the personal dimension of transfers we also asked all wheelchair users to describe or present a video of a transfer they thought was particularly important to them.

Findings: The diagram below shows the themes we extracted from the interviews. When describing important factors in the performance of wheelchair transfers three elements were recurrently cited: technique, confidence, and strength.

Strength: Insufficient strength can limit an individual in the types of transfer that he or she can perform. Upper limb strength was described as a necessary requirement for sitting transfers *and* standing transfers.
Technique: The most crucial element of a good sitting transferring technique is a sufficient forward lean of the trunk, which creates momentum to relieve weight from the buttocks and helps to guide the body in the correct direction. However, achieving a sufficient forward lean was also considered the most difficult skill to achieve, particularly for people that lack of trunk control. The concept of correct technique seemed to be both less defined and less important for individuals performing standing transfers. The priority for people was to maintain balance; and little consideration was given to
Confidence: Lack of confidence in their technique, strength or balance can lead people to perform transfer incorrectly. When feeling insecure, some people tend to transfer too fast just to "get over and done with it", which can lead to falls or injuries, while others might have hesitations that limit their movements and make the transfer more difficult due to a backward position of the centre of mass and lack of momentum. The individual's level of confidence can be affected by several factors from a reduction in the physical capabilities to a challenging environment. Additional training, practice and the presence of a spotter to supervise the transfer can often be of help.

These factors can also be affected by internal and external factors.

- **Internal difficulties** such as spasticity, balance issues, are often related to the disability itself or due to pain and tiredness. Several users also pointed out how fluctuation in their disability, due to their particular medical condition, can pose extreme challenges has they force them to constantly evaluate and change their strategies based on their available capabilities.
- **External difficulties** were various and often described in association with a particular transfer. Large gaps in height and width were one of the most commonly reported difficulties alongside lack of space, inefficiency of wheelchair brakes, instability of transferring surfaces and the degree of bucket of the seat.

Specific concerns included:

- absence of breaks on sports wheelchairs

- presence of wet conditions making it harder to slide along a transfer board
- uneven and sloped terrain when transferring into or out of a car
- footplates for standing transfers
- Unfamiliar situations e.g. planes, hotels, friend's houses

Although most participants highlighted the importance of using a safe and efficient transfer technique, **we discovered that only few wheelchair users have received appropriate training to learn how to transfer.** Individuals with a spinal cord injury were the only ones who received training and guidance to develop safe transfer skills. Among the others, some users reported having learned mainly from peer observation, while other participants relied solely on their own experience and learned through a long trial and error process.

Avoiding falls when performing wheelchair transfers was found to be one of the primary concerns for most participants. Both peoples' possible reaction, and the resulting injuries were a source of concern for people. However, fear of falling wasn't necessarily seen as a negative thing as it prompts the user to take care of his/her technique and avoid unnecessary risks. Excessive fear though led to a reduction in both confidence and transfer technique.

Pain in the upper or lower limbs was also commonly associated with wheelchair transfers performance. Some participants described how pain caused them to change the way in which they perform certain transfers, facilitate them or reduce their frequency. However, when transfers were considered important for their daily routine they were performed regardless of the pain.

Perceptions: People reported feeling the pressure of being seen as 'completely disabled' by people – clinicians and the public – and that by transferring into a chair at a table for example they help to break that stereotype This was particularly important to those who did not have a spinal cord injury.

Summary: Participants' answers highlighted the great importance that people attributed to the ability to transfer in and out of the wheelchair. Transfers represent a gateway to independence for both novice and expert users. Interestingly, transfers also appear to have an intrinsic value in their ability to challenge stereotypes associated with wheelchair users, by presenting a separate image of the user and the chair.

IMAGINING THE FUTURE...

At the end of the group discussions or the interviews we asked all participants to describe an assistive technology they wish they could have to facilitate them when transferring in and out of the wheelchair. Suggestions varied greatly from small wheelchair modifications to more complex independent devices.

Wheelchair modifications included retractable footplates that would not get in the way of the person's feet or extendable armrests that could offer support to stand up for a transfer. Others focused more an improved version of transfer boards. Improvements varied from low tech solution such as telescopic or collapsible transfer boards that could be easily carried around and function as a portable tray when needed. Alternative ideas involved more complex board that would be fit to deal with greater height gaps, such as transfer board with steps or transfer boards with an embedded sliding seat that could lock in place allowing the user to break the transfer into smaller motions. One participant advocated for a motorized transfer board featuring a conveyor belt mechanism that could safely carry users with more limited mobility. However, ideas were not only related to transfer boards. Other suggestions included a device that could be used to level all transfers by raising the height of the lower surface, a system that could keep the shoulders in a stable and safe position during transfers, a portable support system attached to the wheelchair that would allow the user to pull him/herself up to reach a standing position, or a glove that could be used to increase the grip when relying on slippery supports during transfers.

Finally, several participant mentioned the need for resources, and not necessarily assistive devices, which could help people learning how to transfer by providing suggestions, feedback, guidelines and tips for safe and efficient technique regardless of the medical condition of the individual. Instructions would need to be flexible enough to be adaptable to different individuals and span across various situations. The importance of the visual nature of this information was underlined multiple times as a simple verbal explanation was considered not sufficient ("*You have to be able to show it, not just explaining it. If I don't see it I am never going to get it*").

....NOW IS YOUR TURN!

We hope that the information we provided you in this booklet were useful and interesting for you. If you are a designer and did not know much about wheelchair transfers, hopefully now you'll have a clearer idea of how important they are and what are the main factors involved in their performance. If you are a wheelchair user, you already had a great deal of experience with transfers. However, we hope that reading this booklet helped you reflect on your on your own experience and gained more insights on different aspects of wheelchair transfers.

Now is your turn. Use your creativity, get inspiration from the knowledge you have gained, work alone or partner with others and create something great!

Appendix B. Information sheets and consent forms

B.1 Sample information sheet and consent form for Georgia Tech study

GEORGIA INSTITUTE OF TECHNOLOGY

Project Title: Measuring wheelchair transfer performance
Principal Investigator: Sharon Sonenblum, PhD
Research Student: Giulia Barbareschi, PT

Research Consent Form:
You are being asked to be a volunteer in a research study being conducted by Georgia Tech. This research study is looking at the use of wearable sensors to evaluate performance of wheelchair transfers in everyday life.

Purpose:
The purpose of this study is to look at your transfer technique and your perceived difficulty during transfers to different, everyday surfaces.

Exclusion/Inclusion Criteria:
Participants in this study must be adults between the ages of 18 to 65, who use a manual or power wheelchair as their primary means of mobility and have at least 6 months of experience using a wheelchair. You must perform seated or standing wheelchair transfers independently (i.e., without the help of another person). It is ok if you use a transfer board.

Potential subjects may not participate if they have pain in their hand, arm or shoulder that may be triggered or made worse by performing transfers. If you have any other medical conditions that are likely to be exacerbated by performing repeated transfers, such as angina, exercise induced asthma, uncontrolled hypertension you may not be eligible to participate.

Procedures:
If you decide to be in this study, you will be asked to participate in the following:

The experiment will last for approximately 2 and a half hours. If you agree to participate in this study we will set up a suitable date and time for your session, which will take place at the Georgia Institute of Technology (GaTech). If you usually perform wheelchair transfers onto and out of your car seat, you will be asked to come to GaTech driving your car so we can observe how you normally perform wheelchair-car transfers. If you usually need a transfer board to perform transfers from/to your wheelchair, please bring it along for your session.

During your visit, you will be asked to complete a short survey that asks questions about yourself, your health, your wheelchair and the types of transfers you perform (e.g. wheelchair-bed, wheelchair car), and routine activities.

We will give you a small accelerometer sensor (dimensions are 47 mm x 35 mm x16 mm), that needs to be secured to the top of your sternum with a small piece of skin safe double sided tape. Please let us know if you have any skin sensitivities that may be irritated by the tape and we can discuss whether or not to proceed. Then you will be asked to perform transfers from your

Monitoring wheelchair users transfer performance in the community
Principle Investigator: Sharon Sonenblum, PhD

wheelchair (you can use a transfer board if you usually do so) to another everyday surface and back, while we collect data with our sensor. Video will also be recorded to allow researchers to assess your technique using a standardized scale. You will be asked to perform two transfers to and from 3 of the following surfaces (depending on availability and your comfort level).

- Car
- Toilet
- Bed
- Another chair

After each transfer, you will be also asked to rate the difficulty of the transfer. We will ask you to rest for at least 5 minutes between transfer scenarios, and you are welcome to rest for additional time as needed. The entire protocol includes 12 transfers, but if you feel like the experiment is too tiring, you can simply stop at any time.

At the end of the data collection, we might ask some additional follow up questions.

Risks or Discomforts:

The following risks/discomforts may occur as a result of your participation in this study:

1. The risks to you during this study include those that may occur during transferring to and from your wheelchair. To be eligible to participate, you must be independent in transfer, so that the risks are no different than those present with every transfer you perform daily. You will be provided with rest time between transfers to reduce fatigue.
2. The presence of the accelerometer on your chest may affect your comfort and removal of the adhesive could be uncomfortable. If you have any skin sensitivities that might be impacted by the use of medical adhesive, please let the researchers know and we will discuss if proceeding is appropriate. Discomfort associated with removal of the adhesive should clear up quickly.

Benefits:

There are no direct benefits to you from participation in this study. However, you may gain a better understanding of the factors that can affect your safety and the amount of effort required when you transfer into and out of your wheelchair. This research will help clinicians, researchers and wheelchair users understand how different situations can affect movement and performance of wheelchair transfers. It may also help clinicians to develop more targeted education programs during acute rehabilitation.

Compensation to You:

You will be compensated with a $25 gift card for your time and effort.

Confidentiality:
The following procedures will be followed to keep your personal information confidential in this study: The data collected about you will be kept private to the extent allowed by law. To protect your privacy, your records will be kept under a code number rather than by name. Your records will be kept in locked files and only study staff will be allowed to look at them. Your name and any other fact that might point to you will not appear when results of this study are presented or published. Video data will be collected as a part of this study in order to allow for evaluation of transfer technique. The video cannot be anonymized (as the face is visible) but the video file will be encrypted and stored on a password-protected server. The tapes will be accessible only to the research team and the tapes will be destroyed after data analysis is complete.

Your privacy will be protected to the extent allowed by law. To make sure that this research is being carried out in the proper way, the Georgia Institute of Technology IRB may review study records. The Office of Human Research Protections may also look over study records during required reviews.

Costs to You:
There are no directly costs to you, other than your time, for being in this study.

In Case of Injury/Harm:
Prompt medical attention will be provided or arranged for by the research staff in the event of injury. Neither the Principal Investigator nor Georgia Institute of Technology has many provisions for payment of costs associated with any injury resulting from participation in this study.

Participant Rights:
- Your participation in this study is voluntary. You do not have to be in this study if you don't want to be.
- You have the right to change your mind and leave the study at any time without giving any reason, and without penalty.
- Any new information that may make you change your mind about being in this study will be given to you.
- You will be given a copy of this consent form to keep.
- You do not waive any of your legal rights by signing this consent form.

Questions about the Study:
If you have any questions about the study, you may contact Dr. Sharon Sonenblum at telephone 404-385-0633, or ss427@gatech.edu.

Monitoring wheelchair users transfer performance in the community
Principle Investigator: Sharon Sonenblum, PhD

Questions about Your Rights as a Research Participant:

If you have any questions about your rights as a research participant, you may contact

Ms. Melanie Clark, Georgia Institute of Technology
Office of Research Integrity Assurance, at (404) 894-6942.

If you sign below, it means that you have read (or have had read to you) the information given in this consent form, and you would like to be a volunteer in this study.

____
Subject Name

____
Subject Signature **Date**

____
Signature of Person Obtaining Consent **Date**

B.2 Sample information sheet for focus group/interview study

Information Sheet for Participants in Research Studies

You will be given a copy of this information sheet.

Title of Project: **YouTransfer; YouDesign**

This study has been approved by UCLIC's Research Department's Ethics Chair
[Project ID No]: UCLIC/1516/010

Principal investigator:
Catherine Holloway,
UCL Interaction Centre,
66-72 Gower Street
London WC1E 6BT
United Kingdom
+44 (0)20 7679 1568
c.holloway@ucl.ac.uk

We would like to invite you to participate in this research project directed by researchers at UCL. You should only participate if you want to; choosing not to take part will not disadvantage you in any way. Before you decide whether you want to take part, it is important for you to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information.

Who are we recruiting?
We would like to invite wheelchair users that perform independent wheelchair transfers to participate in this research project which will be held on the 31st of January.

Why is this study being done?
We aim to explore factors that can affect the performance of wheelchair transfers and how assistive technologies could help increase people independence and improve performance.

Where will the study take place?
The sessions will take place at the Charles Lack Lecture Theatre, Herbert Seddon Teaching Centre, RNOH, Stanmore.

How long will the study take?
If you do wish to participate, we will select some volunteers to attend a 1-day hack that will last from 11:30 to 17:00 (lunch will be provided).

What will I be doing?
We will ask participants to send us one or more videos of them performing different types of wheelchair transfers (such as transfer to/from a car seat, transfer between wheelchairs and transfer to/from a bed).

The day of the hack will be divided between two activities. After presenting the scope of the hack and giving participants the chance to introduce themselves we will ask participants to show the videos they sent us and videos will be used to stimulate discussion.

The second activity will consist in a more structured group discussion analysing specific aspects related to wheelchair transfers such as occurrence of falls, evaluation of transfer difficulty and perception of performance. During this focused discussion we will also invite participants to reflect on existing assistive technologies for wheelchair transfers, their advantages and shortcomings. Finally we'll ask participants to share ideas, requirements and suggestions for future assistive technologies.

Upon the completion of the focus group, we will use the information you have provided, along with other data we have been collecting, to create a handout. This information pack will be given to other wheelchair users that will be trying to put your suggestions into practice and generate design ideas based on the data we collected.

What are the risks in this study?
There are minimal associated risks given the qualitative nature of this research and the "non-sensitive" topic of the group. However, we would stress that if you experience any emotional discomfort due to the topic being discussed you can make

the researcher aware of this and you can leave the group at any time.

Possible benefits:
There is no direct benefit to subjects participating in the study. The main benefit will be primarily intellectual in that you will have a greater understanding of what factors can affect your ability to transfer to and from your wheelchair. This may be useful as it could help identify issues and perhaps seek additional training or considering the adoption of available aids. We are unable to provide compensation for participants but we will be refunding travel expenses to all participants.

Arrangements for ensuring anonymity and confidentiality:
All data will be handled according to the Data Protection Act 1998 and will be kept anonymous. Only UCL researchers working with Dr. Holloway will analyse these data. With your permission, we may want to use an extract of the video recording for teaching, conferences, presentations, publications, and/or thesis work.

It is up to you to decide whether or not to take part. If you decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason.

What if something goes wrong? If this study has harmed you in any way or if you wish to make a complaint about the conduct of the experiment use the details below for further advice and information:

Yvonne Rogers,
66-72 Gower Street,
UCLIC,
London,
WC1E 6BT
Email: y.rogers@ucl.ac.uk
Telephone: +44 (0)20 31087073

Thank you for reading this information sheet and for considering take part in this research.

B.3 Sample information sheet for participatory design workshop

Information Sheet for Participants in Research Studies

You will be given a copy of this information sheet.

Title of Project: **YouTransfer, YouDesign: Developing Technologies for Wheelchair Transfers**

This study has been approved by UCLIC's Research Department's Ethics Chair
[Project ID No]: UCLIC/1516/010/Staff Holloway/Barbareschi

Principal investigator:
Catherine Holloway,
UCL Interaction Centre,
66-72 Gower Street
London WC1E 6BT
United Kingdom
+44 (0)20 7679 1568
c.holloway@ucl.ac.uk

We would like to invite you to participate in this research project directed by researchers at UCL. You should only participate if you want to; choosing not to take part will not disadvantage you in any way. Before you decide whether you want to take part, it is important for you to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information.

Who are we recruiting?
We would like to invite wheelchair users and designers to participate in this research project held on Thursday the 6th of April 2017

Why is this study being done?
The aim is bring together wheelchair users and designers to generate ideas for new technologies that can facilitate people when transferring in and out of their wheelchairs.

Where will the study take place?
The study will take place at the Global Disability Innovation Hub office located 26 East Bay Lane, London, E15 2GW, UK

How long will the study take?
If you do wish to participate, we will select some volunteers to attend a co-design workshop that will last from 10:00 to 17:00 (lunch will be provided).

What will I be doing?

During the design workshops, you and other participants, will be trying to formulate your own ideas for new assistive technologies aimed at improving performance of wheelchair transfers. Participants will be both designer and wheelchair users with various backgrounds.

Before the session all participants were provided with a written handout that includes information on wheelchair transfers that we collected during research carried out in the last 18 months. The aim of the handout is to introduce key concepts to both wheelchair users and designers so that all participants can better understand the challenges faced by wheelchair users when transferring and the key concepts of co-design ahead of our participatory design workshop.

The workshop will start with a group discussion on some of the concepts presented in the handout to allow yourself and other participants to identify the areas that you would like to work on. You will be then let free to develop your ideas, alone or in collaboration with others, according to your preferences. Ideas for assistive technologies will be refined according to a model called 'Tell, Make, Enact' where people will be asked first to describe the form and function of the technology they wish to develop, then make a rough physical prototype of it and, finally, mimic its functioning to other participants.

Towards the end of the workshop we will ask you to provide us with feedback on the event itself and on the value of the information provided in the handout.

What are the risks in this study?
There are minimal associated risks given this primarily a design research experiment.

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Possible benefits:
This study will help to develop assistive technologies for wheelchair transfers which aim at being both effective and acceptable. Thus, you will have the opportunity to guide the direction of assistive technology design and research.

Arrangements for ensuring anonymity and confidentiality:
All data will be handled according to the Data Protection Act 1998 and will be kept anonymous. Only UCL researchers working with Dr. Holloway will analyse these data. With your permission, we may want to use an extract of the video recording for teaching, conferences, presentations, publications, and/or thesis work. Activity on the online platform will be moderated by a member of the research team and a general report based on the transcript will be produced. Quotes and forum screenshots might be used in future publications, but any personal detail (including username) will be removed in order to anonymise participants. Details of design ideas and anonymized quotes from transcripts will be used for academic publications, future studies and general diffusion.

It is up to you to decide whether or not to take part. If you decide to take part, you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part, you are still free to withdraw at any time and without giving a reason.

What if something goes wrong? If this study has harmed you in any way or if you wish to make a complaint about the conduct of the experiment use the details below for further advice and information:

Yvonne Rogers,
66-72 Gower Street,
UCLIC,
London,
WC1E 6BT
Email: y.rogers@ucl.ac.uk
Telephone: +44 (0)20 31087073

Thank you for reading this information sheet and for considering take part in this research.

B.4 Sample consent form for studies

Informed Consent Form for Participants in Research Studies

(This form is to be completed independently by the participant after reading the Information Sheet and/or having listened to an explanation about the research.)

Title of Project: **YouTransfer, YouDesign**

This study has been approved by UCL Interaction Centre's Research Department's Ethics Chair
[Project ID No]: UCLIC/1516/010/Staff Holloway/Barbareschi

Participant's Statement

I ……………………………………………………………………………

agree that I have:

- read the information sheet;
- had the opportunity to ask questions and discuss the study;
- received satisfactory answers to all my questions or have been advised of an individual to contact for answers to pertinent questions about the research and my rights as a participant and whom to contact in the event of a research-related injury.
- I understand that my participation will be taped/video recorded and I am aware of and consent to the analysis of the recordings.
- I understand that I must not take part if I am not physically able to do the tasks

For the following, please circle "Yes" or "No" and initial each point.

- I agree for the video recording to be used by the researchers in further research studies

  YES / NO initial: ____________

- I agree for the video recording to be used by the researchers for teaching, conferences, presentations, publications, and/or thesis work

  YES / NO initial: ____________

- I understand that I will have the opportunity to confirm these decisions after I have seen my video recording.

  YES / NO initial: ____________

- I agree to be contacted to take part in any future studies.

  YES / NO initial: ____________

I understand that I am free to withdraw from the study without penalty if I so wish. I understand that I consent to the processing of my personal information for the purposes of this study only. I understand that any such information will be treated as strictly confidential and handled in accordance with the provisions of the Data Protection Act 1998.

Signed: Date:

Investigator's Statement

I ……………………………………………………………………………

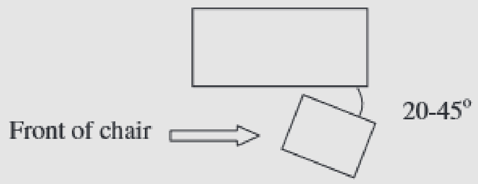
confirm that I have carefully explained the purpose of the study to the participant and outlined any reasonably foreseeable risks or benefits (where applicable).

Signed: Date:

Appendix C. Instruments used for wheelchair studies

C.1 TAI score version 3.0 part 1

Please evaluate the subject on each transfer separately. Circle the appropriate response: Y = Yes, N = No, N/A = Not applicable

	Transfer			
Part 1	1	2	3	4
1. The subject's wheelchair is within 3 inches of the object to which he is transferring on to.	Y N N/A	Y N N/A	Y N N/A	Y N N/A
2. The angle between the subject's wheelchair and the surface to which he is transferring is approximately 20-45 degrees. 	Y N N/A	Y N N/A	Y N N/A	Y N N/A
3. The subject attempts to position his chair to perform the transfer forward of the rear wheel (i.e., subject does not transfer over the rear wheel).	Y N N/A	Y N N/A	Y N N/A	Y N N/A
4. If possible, the subject removes his armrest or attempts to take it out of the way. • If help is required, the subject asks an assistant in a clear and assertive manner.	Y N N/A	Y N N/A	Y N N/A	Y N N/A
5. The subject performs a level or downhill transfer, whenever possible. • Seat cushion is at least level with the surface to which the subject is transferring.	Y N N/A	Y N N/A	Y N N/A	Y N N/A
6. The subject places his feet in a stable position (on the floor if possible) before the transfer. • If help is required, the subject asks an assistant to position his feet in a clear and assertive manner.	Y N N/A	Y N N/A	Y N N/A	Y N N/A
7. The subject scoots to the front edge of the wheelchair seat before he transfers (i.e. moves his buttocks to the front 2/3rds of the seat). • If help is needed, the subject asks an assistant to scoot him to the front 2/3rds of the chair in a clear and assertive manner. (The subject specifically tells the evaluator what position on the chair he needs to be scooted to.)	Y N N/A	Y N N/A	Y N N/A	Y N N/A
8. Hands are in a stable position prior to the start of the transfer. • Push off hand is close to the body. • Leading hand is close to where he will be landing.	Y N N/A	Y N N/A	Y N N/A	Y N N/A
9. A handgrip is utilized correctly by the leading arm **(when the handgrip is in the individual's base of support.)** • If no handgrip is available or outside the individual's base of support, the hand should be placed flat on the transfer surface.	Y N N/A	Y N N/A	Y N N/A	Y N N/A
10. A handgrip is utilized correctly by the trailing arm **(when the handgrip is in the individual's base of support.)** • If no handgrip is available or outside the individual's base of support, the hand should be placed flat on the transfer surface.	Y N N/A	Y N N/A	Y N N/A	Y N N/A
11. Flight is well controlled • The transfer is smooth and uses coordinated movements. • The person appears to be safe and able to complete the skill in a controlled manner.)	Y N N/A	Y N N/A	Y N N/A	Y N N/A
12. Head-hip relationship is used • The head moves in the opposite direction of the hips to make the transfer easier to perform. • Not applicable for subjects who have good upper limb and trunk strength or subjects who perform a dependent transfer with a lift.	Y N N/A	Y N N/A	Y N N/A	Y N N/A
13. The lead arm is correctly positioned (**The arm should NOT be extremely internally rotated and should be abducted 30-45 deg.)**	Y N N/A	Y N N/A	Y N N/A	Y N N/A
14. The landing phase of the transfer is smooth and well controlled (i.e., hands are not flying off the support surface and the subject is sitting safely on the target surface.)	Y N N/A	Y N N/A	Y N N/A	Y N N/A
15. If an assistant is helping, the assistant supports the subject's arms during the transfer.	Y N N/A	Y N N/A	Y N N/A	Y N N/A

C.2 Wheelchair transfers description sheet

Subject ID:____________________

Wheelchair Transfer Description Sheet

Bed Transfer

Technique:

Transfer 1	Transfer 2	Transfer 3	Transfer 4
☐ Sitting	☐ Sitting	☐ Sitting	☐ Sitting
☐Standing	☐Standing	☐Standing	☐Standing
☐Transfer Board	☐Transfer Board	☐Transfer Board	☐Transfer Board

Height Difference:

Transfer 1	Transfer 2	Transfer 3	Transfer 4
☐ Higher ☐ Lower	☐ Higher ☐ Lower	☐ Higher ☐ Lower	☐ Higher ☐ Lower
☐ 0-5 cm	☐ 0-5 cm	☐ 0-5 cm	☐ 0-5 cm
☐ 5-15 cm	☐ 5-15 cm	☐ 5-15 cm	☐ 5-15 cm
☐ >15 cm	☐ >15 cm	☐ >15 cm	☐ >15 cm

Direction of Transfer:

Transfer 1	Transfer 2	Transfer 3	Transfer 4
☐ Left ☐ Right	☐ Left ☐ Right	☐ Left ☐ Right	☐ Left ☐ Right

Number of Scoots:

Transfer 1: Transfer 2: Transfer 3: Transfer 4:

Number of False Starts:

Transfer 1: Transfer 2: Transfer 3: Transfer 4:

Total Transfer Time:

Transfer 1: Transfer 2: Transfer 3: Transfer 4:

Feet Position:

Transfer 1	Transfer 2	Transfer 3	Transfer 4
☐ Footrest	☐ Footrest	☐ Footrest	☐ Footrest
☐Floor	☐Floor	☐Floor	☐Floor
☐Other________	☐Other________	☐Other________	☐Other________

Leading Arm Position:

Transfer 1	Transfer 2	Transfer 3	Transfer 4
☐Target Surface (flat)	☐Target Surface (flat)	☐Target Surface (flat)	☐Target Surface (flat)
☐Target Surface (frame)	☐Target Surface (frame)	☐Target Surface (frame)	☐Target Surface (frame)
☐Other________	☐Other________	☐Other________	☐Other________

Trailing Arm Position:

Transfer 1	Transfer 2	Transfer 3	Transfer 4
☐Start Surface (flat)	☐Start Surface (flat)	☐Start Surface (flat)	☐Start Surface (flat)
☐Start Surface (frame)	☐Start Surface (frame)	☐Start Surface (frame)	☐Start Surface (frame)
☐Other________	☐Other________	☐Other________	☐Other________

Comments:

Subject ID:____________________

Couch Transfer

Technique:

Transfer 1	Transfer 2	Transfer 3	Transfer 4
☐ Sitting	☐ Sitting	☐ Sitting	☐ Sitting
☐Standing	☐Standing	☐Standing	☐Standing
☐Transfer Board	☐Transfer Board	☐Transfer Board	☐Transfer Board

Height Difference:

Transfer 1	Transfer 2	Transfer 3	Transfer 4
☐ Higher ☐ Lower	☐ Higher ☐ Lower	☐ Higher ☐ Lower	☐ Higher ☐ Lower
☐ 0-5 cm	☐ 0-5 cm	☐ 0-5 cm	☐ 0-5 cm
☐ 5-15 cm	☐ 5-15 cm	☐ 5-15 cm	☐ 5-15 cm
☐ >15 cm	☐ >15 cm	☐ >15 cm	☐ >15 cm

Direction of Transfer:

Transfer 1	Transfer 2	Transfer 3	Transfer 4
☐ Left ☐ Right	☐ Left ☐ Right	☐ Left ☐ Right	☐ Left ☐ Right

Number of Scoots:

Transfer 1: Transfer 2: Transfer 3: Transfer 4:

Number of False Starts:

Transfer 1: Transfer 2: Transfer 3: Transfer 4:

Total Transfer Time:

Transfer 1: Transfer 2: Transfer 3: Transfer 4:

Feet Position:

Transfer 1	Transfer 2	Transfer 3	Transfer 4
☐ Footrest	☐ Footrest	☐ Footrest	☐ Footrest
☐Floor	☐Floor	☐Floor	☐Floor
☐Other________	☐Other________	☐Other________	☐Other________

Leading Arm Position:

Transfer 1	Transfer 2	Transfer 3	Transfer 4
☐Target Surface (flat)	☐Target Surface (flat)	☐Target Surface (flat)	☐Target Surface (flat)
☐Target Surface (frame)	☐Target Surface (frame)	☐Target Surface (frame)	☐Target Surface (frame)
☐Other________	☐Other________	☐Other________	☐Other________

Trailing Arm Position:

Transfer 1	Transfer 2	Transfer 3	Transfer 4
☐Start Surface (flat)	☐Start Surface (flat)	☐Start Surface (flat)	☐Start Surface (flat)
☐Start Surface (frame)	☐Start Surface (frame)	☐Start Surface (frame)	☐Start Surface (frame)
☐Other________	☐Other________	☐Other________	☐Other________

Comments:

Subject ID:____________________

Bathroom Transfer

Technique:

Transfer 1	Transfer 2	Transfer 3	Transfer 4
☐ Sitting	☐ Sitting	☐ Sitting	☐ Sitting
☐Standing	☐Standing	☐Standing	☐Standing
☐Transfer Board	☐Transfer Board	☐Transfer Board	☐Transfer Board

Height Difference:

Transfer 1	Transfer 2	Transfer 3	Transfer 4
☐ Higher ☐ Lower	☐ Higher ☐ Lower	☐ Higher ☐ Lower	☐ Higher ☐ Lower
☐ 0-5 cm	☐ 0-5 cm	☐ 0-5 cm	☐ 0-5 cm
☐ 5-15 cm	☐ 5-15 cm	☐ 5-15 cm	☐ 5-15 cm
☐ >15 cm	☐ >15 cm	☐ >15 cm	☐ >15 cm

Direction of Transfer:

Transfer 1	Transfer 2	Transfer 3	Transfer 4
☐ Left ☐ Right	☐ Left ☐ Right	☐ Left ☐ Right	☐ Left ☐ Right

Number of Scoots:

Transfer 1: Transfer 2: Transfer 3: Transfer 4:

Number of False Starts:

Transfer 1: Transfer 2: Transfer 3: Transfer 4:

Total Transfer Time:

Transfer 1: Transfer 2: Transfer 3: Transfer 4:

Feet Position:

Transfer 1	Transfer 2	Transfer 3	Transfer 4
☐ Footrest	☐ Footrest	☐ Footrest	☐ Footrest
☐Floor	☐Floor	☐Floor	☐Floor
☐Other_________	☐Other_________	☐Other_________	☐Other_________

Leading Arm Position:

Transfer 1	Transfer 2	Transfer 3	Transfer 4
☐Target Surface (flat)	☐Target Surface (flat)	☐Target Surface (flat)	☐Target Surface (flat)
☐ Grab Bar/Frame	☐ Grab Bar/Frame	☐ Grab Bar/Frame	☐ Grab Bar/Frame
☐Other_________	☐Other_________	☐Other_________	☐Other_________

Trailing Arm Position:

Transfer 1	Transfer 2	Transfer 3	Transfer 4
☐Target Surface (flat)	☐Target Surface (flat)	☐Target Surface (flat)	☐Target Surface (flat)
☐ Grab Bar/Frame	☐ Grab Bar/Frame	☐ Grab Bar/Frame	☐ Grab Bar/Frame
☐Other_________	☐Other_________	☐Other_________	☐Other_________

Comments:

Subject ID:________________

Car Transfer

Technique:

Transfer 1	Transfer 2	Transfer 3	Transfer 4
☐ Sitting	☐ Sitting	☐ Sitting	☐ Sitting
☐Standing	☐Standing	☐Standing	☐Standing
☐Transfer Board	☐Transfer Board	☐Transfer Board	☐Transfer Board

Height Difference:

Transfer 1	Transfer 2	Transfer 3	Transfer 4
☐ Higher ☐ Lower	☐ Higher ☐ Lower	☐ Higher ☐ Lower	☐ Higher ☐ Lower
☐ 0-5 cm	☐ 0-5 cm	☐ 0-5 cm	☐ 0-5 cm
☐ 5-15 cm	☐ 5-15 cm	☐ 5-15 cm	☐ 5-15 cm
☐ >15 cm	☐ >15 cm	☐ >15 cm	☐ >15 cm

Direction of Transfer:

Transfer 1	Transfer 2	Transfer 3	Transfer 4
☐ Left ☐ Right	☐ Left ☐ Right	☐ Left ☐ Right	☐ Left ☐ Right

Number of Scoots:

Transfer 1: Transfer 2: Transfer 3: Transfer 4:

Number of False Starts:

Transfer 1: Transfer 2: Transfer 3: Transfer 4:

Total Transfer Time:

Transfer 1: Transfer 2: Transfer 3: Transfer 4:

Feet Position:

Transfer 1	Transfer 2	Transfer 3	Transfer 4
☐ Footrest	☐ Footrest	☐ Footrest	☐ Footrest
☐Ground	☐Ground	☐Ground	☐Ground
☐ Inside Car	☐ Inside Car	☐ Inside Car	☐ Inside Car
☐Other________	☐Other________	☐Other________	☐Other________

Leading Arm Position:

Transfer 1	Transfer 2	Transfer 3	Transfer 4
☐Target Surface (flat)	☐Target Surface (flat)	☐Target Surface (flat)	☐Target Surface (flat)
☐ Grab Bar/Frame	☐ Grab Bar/Frame	☐ Grab Bar/Frame	☐ Grab Bar/Frame
☐Steering Wheel	☐Steering Wheel	☐Steering Wheel	☐Steering Wheel
☐Other________	☐Other________	☐Other________	☐Other________

Trailing Arm Position:

Transfer 1	Transfer 2	Transfer 3	Transfer 4
☐Target Surface (flat)	☐Target Surface (flat)	☐Target Surface (flat)	☐Target Surface (flat)
☐ Grab Bar/Frame	☐ Grab Bar/Frame	☐ Grab Bar/Frame	☐ Grab Bar/Frame
☐Steering Wheel	☐Steering Wheel	☐Steering Wheel	☐Steering Wheel
☐Other________	☐Other________	☐Other________	☐Other________

Comments:

C.3 CR-10 Borg Scale for wheelchair transfers

Car Transfer

☐ 1 Really Easy
☐ 2 Easy
☐ 3 Moderate
☐ 4 Sort of Hard
☐ 5 Hard
☐ 6
☐ 7 Really Hard
☐ 8
☐ 9 Really Really Hard
☐ 10 The hardest thing I can do

☐ 1 Really Easy
☐ 2 Easy
☐ 3 Moderate
☐ 4 Sort of Hard
☐ 5 Hard
☐ 6
☐ 7 Really Hard
☐ 8
☐ 9 Really Really Hard
☐ 10 The hardest thing I can do

☐ 1 Really Easy
☐ 2 Easy
☐ 3 Moderate
☐ 4 Sort of Hard
☐ 5 Hard
☐ 6
☐ 7 Really Hard
☐ 8
☐ 9 Really Really Hard
☐ 10 The hardest thing I can do

☐ 1 Really Easy
☐ 2 Easy
☐ 3 Moderate
☐ 4 Sort of Hard
☐ 5 Hard
☐ 6
☐ 7 Really Hard
☐ 8
☐ 9 Really Really Hard
☐ 10 The hardest thing I can do

Toilet Transfer

☐ 1 Really Easy
☐ 2 Easy
☐ 3 Moderate
☐ 4 Sort of Hard
☐ 5 Hard
☐ 6
☐ 7 Really Hard
☐ 8
☐ 9 Really Really Hard
☐ 10 The hardest thing I can do

☐ 1 Really Easy
☐ 2 Easy
☐ 3 Moderate
☐ 4 Sort of Hard
☐ 5 Hard
☐ 6
☐ 7 Really Hard
☐ 8
☐ 9 Really Really Hard
☐ 10 The hardest thing I can do

☐ 1 Really Easy
☐ 2 Easy
☐ 3 Moderate
☐ 4 Sort of Hard
☐ 5 Hard
☐ 6
☐ 7 Really Hard
☐ 8
☐ 9 Really Really Hard
☐ 10 The hardest thing I can do

☐ 1 Really Easy
☐ 2 Easy
☐ 3 Moderate
☐ 4 Sort of Hard
☐ 5 Hard
☐ 6
☐ 7 Really Hard
☐ 8
☐ 9 Really Really Hard
☐ 10 The hardest thing I can do

Bed Transfer

☐ 1 Really Easy
☐ 2 Easy
☐ 3 Moderate
☐ 4 Sort of Hard
☐ 5 Hard
☐ 6
☐ 7 Really Hard
☐ 8
☐ 9 Really Really Hard
☐ 10 The hardest thing I can do

☐ 1 Really Easy
☐ 2 Easy
☐ 3 Moderate
☐ 4 Sort of Hard
☐ 5 Hard
☐ 6
☐ 7 Really Hard
☐ 8
☐ 9 Really Really Hard
☐ 10 The hardest thing I can do

☐ 1 Really Easy
☐ 2 Easy
☐ 3 Moderate
☐ 4 Sort of Hard
☐ 5 Hard
☐ 6
☐ 7 Really Hard
☐ 8
☐ 9 Really Really Hard
☐ 10 The hardest thing I can do

☐ 1 Really Easy
☐ 2 Easy
☐ 3 Moderate
☐ 4 Sort of Hard
☐ 5 Hard
☐ 6
☐ 7 Really Hard
☐ 8
☐ 9 Really Really Hard
☐ 10 The hardest thing I can do

Appendix D. Survey on wheelchair transfers

D.1 Initial draft of the survey on wheelchair transfers

Questionnaire on Wheelchair Transfers and Assistive Technologies

Introduction to the Study

Dear Wheelchair User,

We would like to invite you to participate in a study that aims at understanding how people perform wheelchair transfers, what factors might make them more difficult and how effective assistive technologies are in facilitating them.

We are interested in knowing how you transfer into and out of your wheelchair. We will use this information to capture a snapshot of how many transfers are conducted by wheelchair users, how they are conducted and if people are in pain while performing a transfer. We are interested in the interplay between the environment a transfer is conducted and how this consequently impacts on the transfer. This survey is completely anonymous and you will not be identified through any of the information you provide us with.

This study is part of a PhD project sponsored by University College London. There are no direct benefits from participating in the study, however this information is needed to help us prioritise research to help wheelchair users stay active for as long as possible.

You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study.

We welcome any questions you may have prior to your decision to participate. If you have any question or you would like any information on the study, please email giulia.barbareschi.14@ucl.ac.uk. Thank you for your consideration.

Kind Regards,

Giulia Barbareschi

PhD Student, Biomedical Instrumentation Group, University College London

Transfers Characteristics

Q1: Do you need assistance to transfer into and out of your wheelchair?

- ◯ No, I transfer independently
- ◯ Yes, I need some help from someone else
- ◯ Yes, I am dependent on someone else to transfer

Q2: Do you transfer using a standing or sitting technique?

- ◯ Sitting
- ◯ Standing

Q3: On average, how many times do you transfer into and out of your wheelchair in a day?

[ ]

Q4: Which of these types of transfers do you normally perform?Tick all the appropriate items

- ☐ Bed
- ☐ Car
- ☐ Between different wheelchairs
- ☐ Bathroom (Eg. shower, bath, toilet)
- ☐ House transfers (Eg. couch, dining table)
- ☐ Other

If you have chosen "other", please specify:

[ ]

Q5: How difficult do you find each type of transfer?
Please rate each of the previously selected on a scale from 1 to 7 where 1 is very easy and 7 is very hard

	1 (very easy)	2	3	4	5	6	7 (very hard)
Bed	◯	◯	◯	◯	◯	◯	◯
Bathroom	◯	◯	◯	◯	◯	◯	◯
Car	◯	◯	◯	◯	◯	◯	◯
House Transfers	◯	◯	◯	◯	◯	◯	◯
Between Wheelchairs	◯	◯	◯	◯	◯	◯	◯
Other	◯	◯	◯	◯	◯	◯	◯

Q6: For each of the following statements please indicate how true it is for you using a scale from 1 to 7 where 1 is not at all true and 7 is very true

	1 (not at all true)	2	3	4	5	6	7 (very true)
I think that transfering into and out of my wheelchair is an important skill	○	○	○	○	○	○	○
I try very hard to transfer safely and effectively into and out of my wheelchair	○	○	○	○	○	○	○
I am satisfied of the way I transfer into and out of my wheelchair	○	○	○	○	○	○	○
I feel very tense when I transfer into and out of my wheelchair	○	○	○	○	○	○	○

Presence /Absence of Pain

Q7: Have you had any recurring pain at any of these locations in the last 6 months?Tick all the appropriate items

- ☐ Shoulder
- ☐ Elbow
- ☐ Wrist
- ☐ Hand
- ☐ I haven't had any pain in the last 6 months
- ☐ Other

If you have chosen "other", please specify:

Q8: If you answered yes to any of the previous please grade from 1 to 7 how intense is your pain where 1 is very light and 7 is very severe?

	1 (very light)	2	3	4	5	6	7 (very severe)
Shoulder	○	○	○	○	○	○	○
Elbow	○	○	○	○	○	○	○
Wrist	○	○	○	○	○	○	○
Hand	○	○	○	○	○	○	○
Other	○	○	○	○	○	○	○

Q9: Is your pain made worse by transfers?

○ Always ○ Sometimes ○ Rarely ○ Never

AT Use/Non Use

Q10: Do you currently use any of the assistive technologies listed below?Tick all the appropriate items

- ☐ Transfer Board
- ☐ Hoist
- ☐ Grab Bars
- ☐ Fitted modifications (such as swivel seats or modified car)
- ☐ I don't use any assistive technology
- ☐ Other

If you have chosen "other", please specify:

Q11: If you answered yes to the previous question for what type of transfer do you normally use which assistive technology?Tick all the appropriate items

	Transfer Board	Hoist	Grab Bar	Fitted Modifications	Other
Bed	☐	☐	☐	☐	☐
Bathroom	☐	☐	☐	☐	☐
Car	☐	☐	☐	☐	☐
House Transfers	☐	☐	☐	☐	☐
Between Wheelchairs	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐

Q12: If you use any assistive technology/ies how easy/ hard do you find it/them?
Please rate each of the previously selected on a scale from 1 to 7 where 1 is very easy and 7 is very hard

	1 (very easy)	2	3	4	5	6	7 (very hard)
Transfer Board	○	○	○	○	○	○	○
Hoist	○	○	○	○	○	○	○
Grab Bar	○	○	○	○	○	○	○
Fitted Modifications	○	○	○	○	○	○	○
Other	○	○	○	○	○	○	○

Motivation fo use/ non use

Q13: Which elements make your assistive technologies more difficult to use?Tick all the appropriate items

- ☐ Space constraints
- ☐ Uncertainty about correct way to use them
- ☐ I don't have any problem when using them
- ☐ Weight
- ☐ Unstable positioning
- ☐ Other

If you have chosen "other", please specify:

Q14: What do you like about the assistive technology/ies for wheelchair transfers that you currently use?

- ☐ I don't use any assistive technology
- ☐ Intuitive to use
- ☐ Relieves weight from my arms
- ☐ Other
- ☐ Easy to use
- ☐ Portable
- ☐ Make me feel more secure

If you have chosen "other", please specify:

Q15: If you do not use any assistive technology what are the main reasons for not doing so?

- ☐ Space constaints
- ☐ I don't need them
- ☐ I was not aware they were available
- ☐ Other
- ☐ Difficult/Impossible to carry around
- ☐ I don't know how to use them
- ☐ Too expensive

If you have chosen "other", please specify:

Subject Characteristics

Q16: Please enter your gender

◯ Male ◯ Female

Q17: Please enter your age

I am [ ] years old

Q18: Please enter your weight (specify if kg or pounds)

Q19: Please enter your height (specify if inches or cm)

Q20: How long have you been a wheelchair user?

Q21: What is the medical condition that caused you to need a wheelchair?
Eg. SCI (specify level), MS, amputation (specify)

Q22: What type of wheelchair do you PRIMARILY use?

◯ Rigid Frame Manual Wheelchair
◯ Foldable Frame Manual Wheelchair
◯ Power Assisted Chair (E-motion wheels)
◯ Electric Wheelchair
◯ Other

If you have chosen "other", please specify:

Q23: Do you use any other type/s of wheelchair/s? Tick all the appropriate items

- ☐ Rigid Frame Manual Wheelchair
- ☐ Foldable Frame Manual Wheelchair
- ☐ Power Assisted Chair (E-motion wheels)
- ☐ Electric Wheelchair
- ☐ Other

If you have chosen "other", please specify:

Comments

Q24: Thanks for taking this survey and participating in our study. Do you have any comment on the survey you just completed?
Is there anything else you would like to add? Would you like to provide us with any comment/feedback on the study?

Thanks for your help!

D.2 Final version of survey on wheelchair transfers

Questionnaire on wheelchair transfers and assistive technologies

Introduction to the Study

Dear Wheelchair User,
We would like to invite you to participate in a study that aims at understanding how people perform wheelchair transfers, what factors might make them more difficult and how effective assistive technologies are in facilitating them.
We are interested in knowing how you transfer into and out of your wheelchair. We will use this information to capture a snapshot of how many transfers are conducted by wheelchair users, how they are conducted and if people are in pain while performing a transfer. We are interested in the interplay between the environment a transfer is conducted and how this consequently impacts on the transfer. This survey is completely ananymous and you will not be identified through any of the information you provide us with.
This study is part of a PhD project sponsored by University College London. There are no direct benefits from participating in the study, however this information is needed to help us prioritise research to help wheelchair users stay active for as long as possible.
You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study.
We welcome any questions you may have prior to your decision to participate. If you have any question or you would like any information on the study, please email giulia.barbareschi.14@ucl.ac.uk. Thank you for your consideration.
Kind Regards,
Giulia Barbareschi
PhD Student, Accessibility Research Group, University College London

Transfers Characteristics

Q1: Do you need assistance to transfer in and out of your wheelchair

○ No, I transfer independently
○ Yes, I need some help from someone else
○ Yes, I am dependent on someone else to transfer

Q2: Do you transfer using a standing or sitting technique?

○ Sitting ○ Standing

Q3: On average, how many times do you transfer in and out of your wheelchair in a day?

☐

Q4: Which of these types of transfers do you normally perform?
Tick all that are appropriate

☐ Bed
☐ Car
☐ Between different wheelchairs
☐ Bathroom (Eg. shower, bath, toilet)
☐ House transfers (Eg. couch, dining table)
☐ Other

If you have chosen "other", please specify:

☐

Q5: How difficult do you find each type of transfer?
Please rate each of the previously selected on a scale from 1 to 7 where 1 is very easy and 7 is very hard

	1 (very easy)	2	3	4	5	6	7 (very hard)
Bed	○	○	○	○	○	○	○
Bathroom	○	○	○	○	○	○	○
Car	○	○	○	○	○	○	○
House Transfers	○	○	○	○	○	○	○
Between Wheelchairs	○	○	○	○	○	○	○
Other	○	○	○	○	○	○	○

Q6: For each of the following statements please indicate how true it is for you using a scale from 1 to 7 where 1 is not at all true and 7 is very true

	1 (not at all true)	2	3	4	5	6	7 (very true)
I think transfering in and out of my wheelchair is an important skill	○	○	○	○	○	○	○
I try very hard to transfer safely and effectively in and out of my wheelchair	○	○	○	○	○	○	○
I am satisfied of the way I transfer in and out of my wheelchair	○	○	○	○	○	○	○
I feel very tense when I transfer in and out of my wheelchair	○	○	○	○	○	○	○

Presence /Absence of Pain

Q7: Have you had any recurring pain at any of these locations in the last 6 months? Tick all that apply.

- ☐ Shoulder
- ☐ Elbow
- ☐ Wrist
- ☐ Hand
- ☐ I haven't had any pain in the last 6 months
- ☐ Other

If you have chosen "other", please specify:

Q8: How intense is the pain?
If you answered yes to any of the previous could you grade from 1 to 7 how intense is your pain where 1 is very light and 7 is very severe?

	1 (very light)	2	3	4	5	6	7 (very severe)
Shoulder	○	○	○	○	○	○	○
Elbow	○	○	○	○	○	○	○
Wrist	○	○	○	○	○	○	○
Hand	○	○	○	○	○	○	○
Other	○	○	○	○	○	○	○

Q9: Do you have pain when you transfer?

○ Always ○ Sometimes ○ Rarely ○ Never

AT Use/Non Use

Q10: Do you currently use any of the assistive technologies listed below?
Tick all the appropriates

- ☐ Transfer Board
- ☐ Hoist
- ☐ Grab Bars
- ☐ Fitted modifications (such as swivel seats or modified car)
- ☐ I don't use any assistive technology
- ☐ Other

If you have chosen "other", please specify:

Q11: If you answered yes to the previous question for what type of transfer do you normally use which assistive technology?
Tick all the appropriate

	Transfer Board	Hoist	Grab Bar	Fitted Modifications	Other
Bed	☐	☐	☐	☐	☐
Bathroom	☐	☐	☐	☐	☐
Car	☐	☐	☐	☐	☐
House Transfers	☐	☐	☐	☐	☐
Between Wheelchairs	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐

Q12: If you use any assistive technology/s how easy/ hard do you find it/them?
Please rate each of the previously selected on a scale from 1 to 7 where 1 is very easy and 7 is very hard

	1 (very easy)	2	3	4	5	6	7 (very hard)
Transfer Board	○	○	○	○	○	○	○
Hoist	○	○	○	○	○	○	○
Grab Bar	○	○	○	○	○	○	○
Fitted Modifications	○	○	○	○	○	○	○

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Other	○	○	○	○	○	○	○

Motivation fo use/ non use

Q13: Which elements make your assistive technologies more difficult to use?
Tick all the appropriate

- ☐ Space constraints
- ☐ Uncertainty about correct way to use them
- ☐ I don't have any problem when using them
- ☐ Weight
- ☐ Unstable positioning
- ☐ Other

If you have chosen "other", please specify:

Q14: If you do not use any assistive technology what is the main reason for your choice?

- ☐ Space constaints
- ☐ I don't need them
- ☐ I was not aware they were available
- ☐ Other
- ☐ Difficult/Impossible to carry around
- ☐ I don't know how to use them
- ☐ Too expensive

If you have chosen "other", please specify:

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Subject Characteristics

Q15: Please enter your gender

○ Male ○ Female

Q16: Please enter your age

I am [ ] years old

Q17: Please enter your weight (specify if kg or pounds)

[ ]

Q18: Please enter your height (specify if inches or cm)

[ ]

Q19: How long have you been on a wheelchair?

[ ]

Q20: What is the medical condition that caused you to need a wheelchair?
Eg. SCI (specify level), MS, amputation (specify)

[ ]

Q21: What type of wheelchair/s do you use?

○ Rigid Frame Manual Wheelchair
○ Foldable Frame Manual Wheelchair
○ Power Assisted Chair (E-motion wheels)
○ Electric Wheelchair
○ Other

If you have chosen "other", please specify:

Comments

Q22: Thans for taking this survey and participating in our study. Do you have any comment on the survey you just completed?
Did you find it clear and easy to undestand? Would you like to provide us with any comment on the study?

Thanks for your help!

Appendix E. Scripts for focus groups

E.1 Script for focus group with OTs

Introduction

Good morning and thank you for taking the time to come here today. My name is Giulia Barbareschi, and I am a PhD student at the UCL Interaction Centre. The aim of this group is to learn how technology should be shaped to help people perform better wheelchair transfers. You've been invited as you are all health professionals who provide training for people that need to learn how to transfer in and out of their wheelchair. I am particularly interested in your views because we believe that assistive technologies should be designed keeping in mind clinical recommendations, and we would like understand what your recommendations are.

Today we ‘ll be discussing your thoughts and opinions about seated wheelchair transfers and assistive technologies. We basically want to know what wheelchair users find hard when performing and learning to perform transfers and what might be done to help wheelchair users perform better transfers. There are no right or wrong answers but only differing points of view. Please feel free to share your point of view even if it differs from what others have said. Keep in mind that we're just as interested in negative comments as positive comments, and at times the negative comments are the most helpful.

Before we begin, let me suggest some things that will make our discussion more productive. Please speak up—only one person should talk at a time. We're tape (and/or video) recording the session because we don't want to miss any of your comments. We ‘ll be on a first-name basis, and in the later reports there will not be any names attached to comments.

My role here is to ask questions and listen. I won't be participating in the conversation, but I want you to feel free to talk with one another. I'll be asking about ten questions, and I'll be moving the discussion from one question to the next. There is a tendency in these discussions for some people to talk a lot and some people not to say much. But it is important for us to hear from each of you tonight because you have different experiences. So if one of you is sharing a lot, I may ask you to let others talk. And if you aren't saying much, I may ask for your opinion. We can get started by going around the table and doing and introduce everybody.

Questions:

1. Tell us your name and how long have you been an occupational therapist (Opening Question – not more than 1 minute per person)
2. If you think about wheelchair transfers what is the first word that comes to mind and why? (Introductory question – max 10 mins in total)
3. Could you give me an example of one thing that people find hard when learning how to transfer? What strategies do you use to help them overcome that problem? (Transition Question –15 mins)
4. How do you judge if a transfer one of your patients just performed was safe and well executed? (Key Question –15 mins)
5. What do you think could help people transfer more safely and effectively? (Write on flipchart) (Key Question -15 mins)
6. Can you name some assistive technology that can be used to make wheelchair transfers easier? What do you think of them? (Transition Question – 10 mins)
7. How could currently available devices be improved? Would different devices be more useful?
8. Assume you have two minutes to talk to a designer about what you want from a piece of technology that can help people transfer more safely and/or with less effort. What would you say?
9. Give a short summary reminding participants of the scope of the project and what has been discussed in the group. Is there anything else you think we should consider? (Final Question – 5/10 mins)

E.2 Script for focus group with wheelchair users

Introduction

Good morning and thank you for taking the time to come here today. My name is Giulia Barbareschi, and I am a PhD student at the UCL Interaction Centre. The aim of this group is to learn how technology should be shaped to help people perform better wheelchair transfers. You've been invited as you are all wheelchair users that perform transfers on a daily basis. I am particularly interested in your views because we believe that assistive technologies should be designed keeping in mind satisfy your needs and suggestions, and we would like understand what they are.

Today we ‘II be discussing your thoughts and opinions about wheelchair transfers and assistive technologies. We basically want to know what you find difficult when you are transferring in and out of your wheelchairs and what might be done to help you perform better transfers. There are no right or wrong answers but only different points of view. Please feel free to share your point of view even if it differs from what others have said. Keep in mind that we're just as interested in negative comments as positive comments, and at times the negative comments are the most helpful.

Before we begin, let me suggest some things that will make our discussion more productive. Please speak up—only one person should talk at a time. We're tape (and/or video) recording the session because we don't want to miss any of your comments. We ‘II be on a first-name basis, and in the later reports there will not be any names attached to comments.

My role here is to ask questions and listen. I won't be participating in the conversation, but I want you to feel free to talk with one another. I'll be asking about ten questions, and I'll be moving the discussion from one question to the next. There is a tendency in these discussions for some people to talk a lot and some people not to say much. But it is important for us to hear from each of you today because you have different experiences. So if one of you is sharing a lot, I may ask you to let others talk. And if you aren't saying much, I may ask for your opinion. We can get started by going around the table and doing and introduce everybody.

Questions

1. Tell us your name and how long have you been a been a wheelchair user (Opening Question – not more than 1 minute per person)

2. I asked all of you if it is was possible to email me a video of yourself transferring some of you were able to email me, some were not able to. This is absolutely fine, what we are going to do is I am going to show in this direction the videos one by one and I am going to ask you why did you chose a specific transfer. Was it because of the location, was it because it was convenient or was it because you think that particular transfer shows a technique problem that you might have specifically…. If you weren’t able to email me the video is fine I will ask you to describe it if you don’t mind. (Video presentation – 5 minutes per person)

3. If you think about wheelchair transfers what is the first word that comes to mind and why? (Introductory question – max 10 mins in total)

4. Could you give me an example of one thing that you find hard when transferring? What strategies do you use to overcome that problem? (Transition Question –10 mins)
5. Did you ever fall while performing a transfer? How did it happen? (Transition Question -10 mins)
6. How do you judge if a transfer one of you just performed was safe and well executed? (Key Question –15 mins)
7. What do you think could help you transfer more safely and effectively? (Write on flipchart) (Key Question -15 mins)
8. Can you name some assistive technology that can be used to make wheelchair transfers easier? What do you think of them? (Transition Question – 10 mins)
9. How could currently available devices be improved? Would different devices be more useful?
10. Assume you have two minutes to talk to a designer about what you want from a piece of technology that can help you transfer more safely and/or with less effort. What would you say?
11. Give a short summary reminding participants of the scope of the project and what has been discussed in the group. Is there anything else you think we should consider? (Final Question – 5/10 mins)

Appendix F. Use of a low cost, chest-mounted accelerometer to evaluate transfer skills of wheelchair users during everyday activities

F.1 Introduction

Globally, there are over 70 million wheelchair users and there is a growing need for wheelchairs to fill the mobility gap for people who are unable, or struggle, to walk [58]. In the USA, there was a four-fold increase in wheelchair use between 1969 to 1995, with a rise from 409,000 to 1.7 million wheelchair users [37]. This is a trend we can expect to continue as the population ages and more people live longer with long-term conditions that affect their ability to walk. Wheelchairs can be manual, electric of have 'power assist', which gives additional power with each push. Regardless of the type of wheelchair being used, the wheelchair user will need to get into and out of the wheelchair. This is called transferring. Our paper focuses on manual wheelchair users (MWUs). MWUs make up approximately 86% of the wheelchair population in the UK; 34% are pushed by someone else (e.g. a carer or partner) and 52% push themselves [48].

Transfers occur frequently, although they are often completed quite quickly. A MWU might start their day transferring from the bed to their wheelchair to go to the bathroom, and then from the wheelchair to the toilet, back to the wheelchair and then into the shower, back to the wheelchair. Indeed, transferring is something that is necessary and happens a great many times a day – between 14 and 18 on average [43,47]. Transfers occur between the wheelchair and other surfaces and they are affected by a variety of factors such as height and stability of the surface and space freely available around the surface. While these factors may be, to a certain extent, under a person's control in one's home, the complexity increases when transferring occurs outside the home [9]. Depending on the environment and the characteristics of the person, each transfer will have its own challenges [9,24]. This presents an interesting challenge for assessing the quality of transfers.

Learning how to transfer correctly is a critical skill for MWUs. It is the first step towards independent mobility. In order to maintain this independence MWUs must preserve the functioning in their wrists and shoulders. However, due to the exceptionally high loads, and the repetitive nature of this loading, MWUs frequently suffer from pain in the shoulders and wrists [8]. This pain is caused by musculoskeletal injuries, which can prevent people from being able to use their wheelchair independently. A recent study has shown that approximately 60% of MWUs surveyed suffered from shoulder pain when transferring [1]. Wrist pain and injury often accompanies shoulder injuries, with rates of between 49% and 74% [5] and subsequent reduction in activity and further risks of injury (e.g, due to increase weight) [12]. Keeping wheelchair users active and independent is hence important, as a lack of mobility or independence reduces quality of life [22]

Wheelchair skills training helps to prevent such injuries by teaching MWUs correct techniques for everyday activities such as pushing over a variety of surfaces and transferring onto and from a number of surfaces. Wheelchair Skills Training [6] is mostly delivered by clinicians within rehabilitation clinics. There is no routine way for wheelchair transfers to be monitored remotely in everyday life settings. In addition, the traditional methods do not take into considerations social and emotional factors that may have an impact on the way the movement is performed (e.g., feeling under pressure as other people may be waiting) as in the case of other motor difficulties or impairment [50,51]. More informal wheelchair skills training is provided through charities (e.g. Backup Trust in the UK) who provide peer-to-peer training. In addition, remote training has been piloted via an online course and this kind of training has been found to be more successful with clearer progress between subsequent evaluations in the clinics [59]. However, patients still needed to: 1_ rely on clinicians to evaluate their transfers and 2) had to return to a clinic for this to happen. Furthermore, the provision of wheelchair skills training is not universal and can depend on: geography (e.g. more prevalent in richer countries), medical diagnosis (e.g. spinal injury rehabilitation programs generally integrate wheelchair skills training, while other conditions such as stroke rehabilitation units might not have access) and funding [34]. The e-learning platform piloted by [59] shows the potential to improve the availability of transfer training, but would clearly benefit from a method for home/self-monitoring for MWUs that would ensure they did not need to depend on a clinician.

Wearable technologies offer the opportunity to provide monitoring and feedback to wheelchair users during their daily lives and therefore provide real-time feedback on activities and techniques, which are known to cause injury. Initial research in this area has focused on automatically detecting different types of activities from one another e.g. resting, pushing the wheelchair, performing household activities [11,21]. Most authors focus on the use of a wrist-worn sensor for activity monitoring [16,28,38]. A few have linked energy expenditure to accelerometer data [20,38], and one has investigated the quality of pushes, identifying a good style of pushing from a poor one [16]. Very little attention has been instead dedicated to transfers outside the clinical contexts. Our main contribution in this paper builds on these previous studies and focuses on the use of low-cost wearable sensors to enable the evaluation of the quality of wheelchair transfers across three everyday transfer scenarios. We do this focusing on the use of a chest-worn sensor, extracting features which we subsequently link to a subset of items from the Transfer Assessment Instrument (TAI), a clinically validated scale [41,57]. Our second contribution is an increased accuracy in automatically detecting wheelchair transfer occurrences through the same sensor with the long-term aims of continuously monitoring transfer skills. The study is based on data capture from wheelchair users performing transfers between different types of surfaces encountered in daily life. As a final contribution, we make the data set available on request to foster future research in this area. The longer term aim of the project is to develop a monitoring and feedback tool for wheelchair users which can give real-time feedback on transfers and other activities of daily living to help prevent upper limb injury and maximise the mobility of MWUs.

F.2 Related work

n this section, we present related work in the field of wheelchair transfer evaluation, and rehabilitation monitoring using wearable sensors, drawing where necessary on related rehabilitation areas to explore what is possible with ubiquitous computing. This highlights the opportunity for wearable sensors to measure transfer quality beyond clinical settings.

F.2.1 Monitoring wheelchair activities using portable sensors

Wheelchair users frequently suffer upper limb injuries and this has driven a number of biomechanics studies in laboratories featuring complex equipment such as force platforms and motion capture systems to measure the forces involved in wheelchair transfers [18,19]. Although laboratory based biomechanical studies provide accurate and an insightful understanding of transfer movements and strategies measured, they can only represent a very restricted subset of transfers. They, fail to capture the complexity of the challenge of transferring in environments such as beds, toilets and cars. Instead, they focus on transferring between two fixed, hard, rigid surfaces. Observational studies have reported that the performance of wheelchair transfers can vary significantly depending on the environment (free space around the surfaces, type and height of the surface) even across subjects with similar physical capabilities [24,32]. There is currently no method for capturing the quality of these types of transfers without an external, clinically trained observer feeding back to a wheelchair user.

To our knowledge, automatic monitoring of transfers in more real-life settings has attracted very limited attention. However, some initial work to develop wearable or 'chairable' technologies (i.e. technologies attached to the wheelchair) which measure the occurrence of Activities of daily Living (ADLs) of MWUs have been carried out. Initial wheelchair activity monitors have been confined to the estimation of energy expenditure while pushing and overall tracking of physical activity [20,26,44]. Wheel-mounted accelerometers have been used to measure the bouts of activity and distance travelled by wheelchair users [52,53]. Researchers have explored the establishment of vector magnitude accelerations cut-off points to measure the number of pushes from a wrist-worm accelerometer [38]. More recent work has used a support vector machine (SVM) classifier to classify pushes into 'Arc' (i.e. short in duration, and injury-causing) or 'Semi-circular' (i.e. longer in duration and injury-preventing) push styles [16]. This work represents the only attempt to measure the quality of a wheelchair user's movement through wearable devices. The vast majority of studies focus instead on simple classification of activities.

Classification of wheelchair activities using data collected from body worn or wheelchair mounted accelerometers and Inertial Measurement Units (IMUs) is being increasingly addressed in wheelchair studies. Researchers in [25] obtained an accuracy of 96.3% when using Quadratic Discriminant Analysis (QDA) to classify three classes of activity: resting (e.g. watching TV, working at a desk), arm ergometery (i.e. hand cycling exercise) and wheelchair pushing. The three types of activity are quite distinct in terms of arm movement, and they all occur over long periods of time. MWUs in the study were asked to wear a SenseWear arm-band. The main aim of the study was to link energy expenditure with MWU activities. In a similar study, conducted by the same group, it was found that a combination of IMUs placed on the wheelchair wheel and on the person's upper arm achieved an accuracy of 89.26% when classifying a series of ten representative wheelchair based activities including wheelchair propulsion on flat and sloped surfaces, playing wheelchair basketball, folding laundry and exercising using a resistance band [27]. A combination of a wheel mounted data-logger and wrist worn accelerometer was also used by [11] to classify a series of wheelchair activities, including wheelchair propulsion, transfers and other ADLs, into four different categories namely wheelchair propulsion, external pushing, sedentary upper limb activities and non-activity. Support Vector Machine algorithms achieved 80.6% accuracy when classifying activities in the four categories and the overall accuracy was improved to 89.4% when sedentary upper limb activities and non-activity were combined in the same category. However, transfers themselves were not individually detected. Each of these studies classified activities that are very different from one another, and consist of repetitive motions. Therefore, the high accuracy is not surprising, but they are useful in establishing evidence that body-worn accelerometers can be used to identify MWU activities.

Other researchers have instead focused on more clinically relevant outcomes, which are linked to the identification of indicators of shoulder injury. These include, the detection of different wheelchair propulsion styles and temporal-spatial parameters of wheelchair propulsion that have previously been linked to the load experienced from the upper limbs [7,46]. In a study carried out by [55] the authors detected the cadence of strokes during manual wheelchair propulsion using a simple threshold based algorithm that was also able to classify the intensity of each stroke based on the values of the acceleration's peaks measured by an accelerometer secured to the frame of the wheelchair. Promising findings for estimation of push-rim forces during propulsion were described by [40] when applying a bagging decision tree to data collected from three tri-axial accelerometer positioned respectively on the wheelchair wheel and the user's arm and wrist. Although the system showed limited accuracy in determining the exact force value with a mean absolute percentage of error of over 20%, correlation coefficients were high ranging from 86 to 88%.

There has only been a single study which has evaluated the accuracy of classification algorithms for detecting the occurrence of wheelchair transfers, alongside other activities [21]. The researchers used four accelerometers on: the wrists, chest and waist [21]. The experiment was highly successful and transfer recognition reached 100% accuracy for both quadratic discriminant analysis (QDA) and SVM. However, the study consisted of a highly controlled experimental set-up and involved the performance of repeated consecutive transfers for a set period of time, reducing movement differences between consecutive repetitions of the same activity. In addition, the transfers were only executed between two surfaces (two wheelchairs) rather than between different types of surfaces and different environmental real-life contexts. Therefore, it is not clear if the results generalize to real-life settings. Finally, despite the use of four, in-depth analysis of the contribution of the wrist worn sensors is reported and it is not clear to what extent the other sensors contribute to the recognition. This is particularly critical given that trunk worn sensors are, for example, useful for evaluating aspects of transfer quality [57] and wrist-worn sensors are not always appreciated by wheelchair users as they can interfere with the wheel during pushing [39]. Finally, the study did not investigate the quality of the movement. Unfortunately, to our knowledge there is no dataset of this type available to researchers interested in investigating transfer quality in more ecological settings.

F.2.2 Clinical evaluation of wheelchair transfers

The challenge of evaluating wheelchair transfers lies in being able to detect the quality of movement, something hitherto only been possible through clinical evaluation. Therefore, understanding the clinical process is important for understanding the selection of features. Wheelchair transfers have a crucial role in the everyday life of many wheelchair users. Wheelchair skills tests, which structure and inform rehabilitation programmes include at least one item that measures an individual's ability to transfer [33]. Despite this, in most clinical settings the evaluation of transfer performance is still mainly based on unstructured visual assessment conducted by physiotherapists and occupational therapists [13]. The most common type of transfer is an unassisted sitting transfer, which is now described and is the focus of this paper. This transfer is used by people unable to weight bear through the lower limb, such as people who have suffered a spinal cord injury.

To perform an unassisted sitting transfer the person will first position their wheelchair close to the surface on which he/she wishes to transfer to. Usually the chair will be placed at a slight angle from the target surface and the person will scoot towards the front of the seat. Some users will place both feet on the floor while others might prefer to leave them on the footplate. The person will then place one hand (the leading hand) close to the target surface and will then leave one hand (the trailing hand) on the wheelchair. The transfer itself is usually achieved with a quick forward lean of the trunk. This releases weight from the buttocks and is accompanied by a pivoting motion that rotates the trunk so that the shoulders point in the opposite direction to the direction of travel of the transfer. This motion might seem counter intuitive; however, it is critical to a successful transfer. This 'head-hip relationship' as it is called, means the head will move in the opposite direction to the hips during the transfer. The sequence of events for an unassisted sitting transfer is shown in Figure F-1

The Transfer Assessment Instrument (TAI) is a validated clinical scale used to evaluate the quality of sitting and standing wheelchair transfers performed by wheelchair users [41]. The TAI was refined by [57] in order to improve reliability and validity. This improved version (version 3.0) features two parts. Part 1 is composed of 15 items. Each item corresponds to a small component of the transfer such as the placement of a hand or the feet, or the smoothness of movement. Clinicians score each part of the transfer using a dichotomous scale. Part 2 provides an overall evaluation of repeated transfers using

12 items rated on a 4-point Likert scale. Areas of evaluation focus on transfer set-up, quality and the implementation of strategies to prevent upper limb injuries. Although the TAI is reliable, especially when used by people who have received appropriate training, it is only very recently that links between the TAI and the kinetics of the limbs' movement (using high cost sensors) have been established in biomechanical lab settings [56]. We aim to extend this work to be able to transform aspects of the TAI into low-cost sensors measurements that can be brought into real-life contexts and integrated into coaching apps.

Figure F-0-1 Sequence of movements used to perform an unassisted sitting transfer

F.3 The wheelchair transfer dataset

The aim of this study was to investigate the possibility of using low-cost wearable sensors to monitor and evaluate the quality of transfers in wheelchair users as they go about their daily activity, with the long-term goal of supporting training in real-life contexts. We divided the study into two parts. First, we investigated the possibility of evaluating each transfer when its start and end points are known as in a coaching session. In this part, we consider the scenario where the MWU is able to indicate the start and end points of the transfer, perhaps using a mobile application or a second sensor on the wheelchair. The mobile application could then present the evaluation results. This scenario is important, as a person may be specifically interested in evaluating progress in transferring to and from specific surfaces that s/he finds challenging. Asking MWUs to indicate the start and end points would increase the accuracy of the evaluation by removing noise due to incorrect detection of the transferring period. Second, we investigate the possibility of continuous monitoring. In this case, transfers occur, and are detected, as people carry out their daily activities. This would enable evaluations to occur more seamlessly and a summary of transfer evaluation results could then be available to the person when needed.

F.3.1 Participants

The study was approved by the Georgia Institute of Technology Institutional Review Board. Participants were recruited via recruitment flyers posted at medical facilities and local organizations for wheelchair users. Flyers were also distributed via social media and relevant online forums. Researchers directly contacted participants of previous research studies who expressed an interest in being contacted for future studies. Interested subjects were screened against the following criteria: age between 18 and 65 years, use of a manual or power wheelchair as their primary means of mobility for at least six months and able to perform wheelchair transfers independently. Participants were excluded if: (i) they were able to fully stand up when transferring, (ii) reported the use of a transfer board when transferring, (iii) were currently admitted to a hospital or a rehabilitation facility, (iv) reported having upper extremity pain that was exacerbated by transfers or (v) reported any medical condition that was likely to be exacerbated through the study protocol such as angina, exercise induced asthma, uncontrolled hypertension. Nine participants (8 Males, 1 Female) were recruited for the study. Eight participants reported Spinal Cord Injury (SCI) as a primary medical condition, whereas one participant reported Transverse Myelitis (TM). An overview of participants' characteristics is presented in Table F-1.

Table F-0-1 Overview of participants' characteristics

Participant	Gender	Age	Height (cm)	Weight (kg)	Medical Condition	Wheelchair Experience (years)
1	M	26	185	90	SCI C6	2.1
2	M	26	178	64	SCI C7	0.8
3	M	47	183	82	SCI T4	8.5
4	M	25	191	70	SCI T5	2.8
5	M	30	196	80	SCI C6	12
6	M	35	170	73	SCI T12	3.3
7	M	35	191	107	SCI T1	7.8
8	M	46	188	104	SCI T5	10.9
9	F	58	152	54	TM	9.5
Mean	N/A	36.44	181.56	80.44	N/A	6.41
SD	N/A	11.52	13.52	17.64	N/A	4.18

F.3.2 Wearable device and other material

In this study, we consider the use of one accelerometer placed on the chest of the user. The use of a single accelerometer was preferred to a multi-sensor system, as future applications for long term monitoring will need to be as unobtrusive as possible in order to maximise the ease of use for MWUs. The chest was chosen as it is the part of the body which dictates a good transfer (e.g. turning the trunk to align a good head-hip relationship) and is helpful in detecting the start (e.g. forward lean of the trunk) and end points of the transfer (e.g. controlled descent). The wrist was not chosen as, the usability of wrist-worn sensors can interfere with safe and effective pushing styles as the watch/bracelet can get caught in the spokes of the wheel [39]. In addition, the trunk is in motion throughout the wheelchair transfer cycle, whereas the arms are often stationary during key moments in the transfer [18,19]. From a clinical perspective, the movement of the trunk offers the most intuitive place for a body-worn accelerometer. A few studies have used a chest-mounted sensor together with others placed on the wrists, however, its contribution was not explored and the focus has been always centred on hand-worn sensors [21]. From a wearable perspective, it is important to understand how each sensor position contributes to the overall result, as different configurations may be necessary according to the need of the person. Figure F-2 shows the position of the sensor in our study.

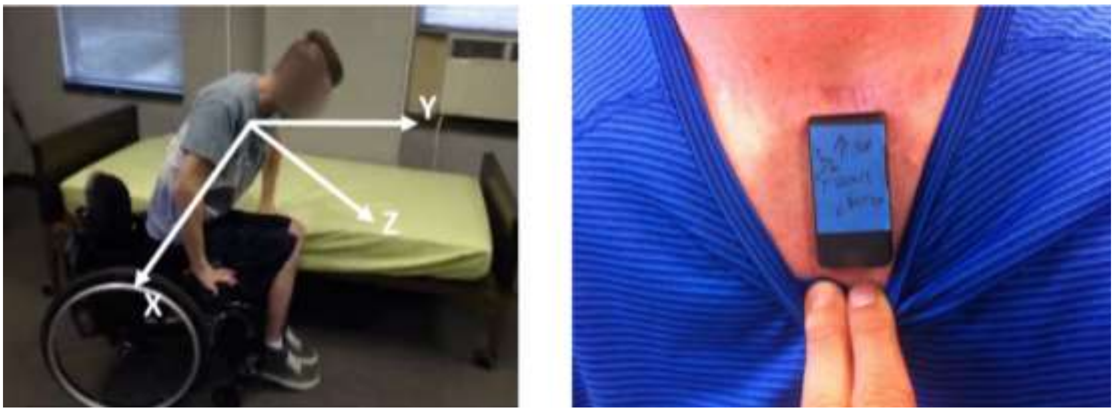

Figure F-0-2 Orientation of the accelerometer's axes in respect to the body during wheelchair transfers and position of the accelerometer on the participant's sternum

Trunk accelerations were recorded using a single wireless 3-axis accelerometer (range ±16g, resolution 16 bit, Gulf Coast Data Concepts, MS) sampling at 25Hz and secured to the upper third of the participant's sternum using double sided tape. The directions of the acceleration measured in respect to the individual body axes (X + up – down; Y + left – right; Z +front – back) are shown in Fig.2 a-b. To reduce noise, the accelerometer data were filtered using an 8th order low pass Butterworth filter with a cut off frequency of 10Hz. Two video cameras were used to record participants' transfers and used to label the recorded data for transferring quality performance, and to determine exact seat-off (start) and landing time (end). Data processing was carried out on Matlab R2015b and the accuracy of various classifiers was calculated using WEKA 3.8 data mining suite.

F.3.3 Data collection

For the data collection, an ecologically valid scenario was used consisting of three typical and very important daily transfers: to/from a bed, a toilet and a car. The first two represent necessary daily activities; and car transfers have previously been identified as the most crucial skill for personal independence and social/working life [14]. The Wheelchair-Bed scenario was recreated in the research facility and a real accessible bathroom in the building was used for the Wheelchair-Toilet scenario, whereas the participant's own vehicle was used for the Wheelchair-Car scenario. The car was parked in the parking facility of the research centre. Pictures showing the details of the three scenarios can be seen in Figure F-3.

Figure F-0-3 Bed, car and toilet transfer scenarios

Using their own wheelchair, participants were asked to move around the various spaces and perform two return transfers (i.e. to and from the wheelchair) for each of the scenarios: Wheelchair-Bed, Wheelchair-Toilet and Wheelchair-Car. The order of the three scenarios was randomized for each participant to avoid effect of fatigue. In addition, between each transfer, the person was asked to move around the room to ensure variability between the ways each transfer was executed. In the previous study by [21], the participant was asked to do repeated transfers to and from the same surface leading to transfers that were quite possibly similar in pattern and not reflective of the natural variability observed in daily life. Participants in our study were allowed sufficient resting time between the performances of transfers in order to avoid fatigue.

Accelerometer data were collected continuously for the duration of the experiment while the subjects rested and pushed the wheelchair between different scenarios. Each participant performed a maximum of 12 transfers for an average of a total of 40 min recording for each participant.

F.3.4 Data labelling

The data were labelled by two trained physiotherapists using the videos collected during the recording. Each physiotherapist was asked to go through the video and identify the start and end point of each transfer. In addition, they were asked to evaluate the quality of the transfer. Following the method proposed by [30], the TAI was reviewed to identify specific items that could be evaluated using an accelerometer. Only the 15 items listed in Part 1 of the TAI were considered, as in Part 2 the evaluator is asked to complete a series of Likert scales based on the overall evaluation of repeated transfers rather than the use of individual skills within a single transfer, which is more critical for real life feedback. The selected TAI items were:

1. Head Hip Relationship (item 12): The subject moves the head in the opposite direction of the hips to make the transfer easier to perform.
2. Controlled Flight (item 11): The transfer is smooth and uses coordinated movements. The person appears to be safe and able to complete the skill in a controlled manner.
3. Smooth Landing (item 14): The landing phase of the transfer is smooth and well controlled (i.e., hands are not flying off the support surface and the subject is sitting safely on the target surface.)

Other evaluation items were discarded as they referred to the positioning of the wheelchair rather than the use of specific transferring skills (items 1, 2, 3, 4, 5), evaluated static body positioning rather than movement (items 6, 8, 9, 10, 13), or were only applicable to transfers performed with the assistance of a caregiver (item 15). Finally, item 7 (scooting) was discarded as its clinical implications were unclear. Although the performance of scooting motions can reduce the gap between the starting and target surface and it is supposed to facilitate transfers, it has been previously linked to an increase of the extension moment measured at the leading shoulder which can potentially lead to overuse injuries [56].

Two trained physiotherapists evaluated each transfer identified in the video by assigning a dichotomous score (i.e. good or not-good) for these three characteristics in keeping with the guidelines of the TAI 3.0.

In order to segment the transfer data from the full accelerometer recording sequence, accurate timestamps for start of lift (when the buttocks of the subject lose contact with the initial surface) and landing (when the buttocks of the subject reach contact with the target surface) were obtained from the annotated videos. For each transfer, the accelerometer data were then partitioned in three time windows. Each time window corresponded to a time epoch where the selected TAI items could be evaluated. These were:

1. Head-hip Relationship: ±.75s interval around the marked start lift timestamp
2. Controlled Flight: ±.5s interval around the marked timestamps for start lift and landing
3. Smooth Landing: ±.75s interval around the marked landing timestamp

An annotated figure of the acceleration profiles and time windows observed during a wheelchair transfer is shown in Figure F-4.

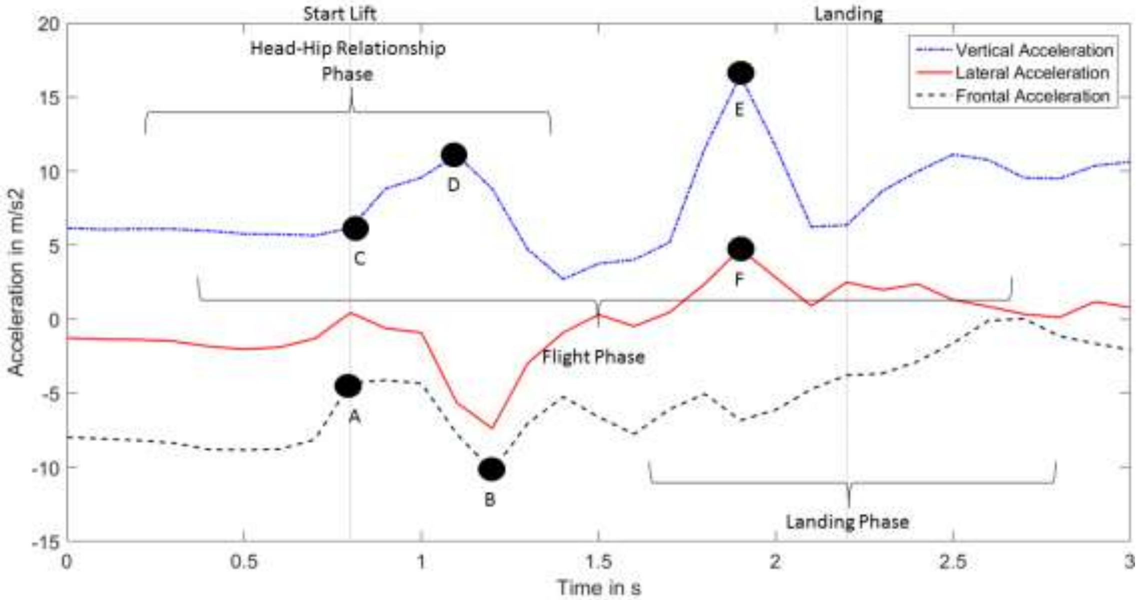

Figure F-0-4 Trunk accelerations in the Vertical (X), Lateral (Y) and Frontal (Z) direction observed during an unassisted sitting wheelchair transfer. The vertical dotted lines mark the timestamps identified for start lift and landing used to determine time windows for evaluation of Head-Hip Relationship, Controlled Flight and Smooth Landing items.

F.4 Automatic transfer quality evaluation

F.4.1 Features selection

All features for head-hip relationship and landing phase were selected, based on biomechanics characteristics of wheelchair transfers and confirmed by visual inspection of the data. We present below the rationale for the feature selection for each of the transfer aspects evaluated. Figure F-4 helps clarify the relationship of the selected features with the acceleration profiles generated in the three directions (X,Y,Z) during wheelchair transfers performed with various techniques. A complete list of the features for the Automatic Transfer Quality Evaluation is provided in Table F-2.

Table F-0-2 Summary of features calculated for Automatic Transfer Quality Evaluation. Features marked with the * were found to be relevant after the optimization procedure reported in the modelling section

Head-Hip Relationship Features	Controlled Flight Features	Smooth Landing Features
Minimum Frontal Acceleration*	Spectral Length of Acceleration	Maximum Vertical Acceleration
Range Frontal Acceleration*	Spectral Length of Velocity	Maximum Total Acceleration*
Maximum Frontal-Downward Acceleration*	Dimensionless Jerk	Range Total Acceleration*
Range Frontal-Downward Acceleration	Log Dimensionless Jerk	Mean Total Acceleration*
Maximum Total Jerk		Mean Vertical Acceleration
Minimum Frontal Jerk*		Root Mean Square Total Acceleration*

Head-Hip Relationship: The performance of a transfer using a correct head-hip relationship, requires the subject to perform a quick forward lean which causes a sharp decrease in the frontal acceleration values (Fig. 4: point B) (Minimum Frontal Acceleration, Minimum Frontal Jerk). A more sudden trunk flexion is usually more effective in relieving weight from the buttocks (Maximum Total Jerk). In order to gather more momentum, some subjects tend to move the trunk slightly backwards before bending forward leading to a greater range of frontal acceleration in the specified time window (Fig. 4: segment A-B) (Range Frontal Acceleration). The direction along which the trunk moves can be represented by a diagonal line that connects the trunk with a point slightly forward the tip of the person's feet. An approximation of the acceleration in that direction can be obtained from the sum of the acceleration values in the vertical direction and the inverse of the acceleration values in the frontal direction (Fig. 4: segments A-B and C-D) Maximum Frontal-Downward Acceleration, Range Frontal-Downward Acceleration). Therefore, the following features were used: Minimum Frontal Acceleration, Range Frontal Acceleration, Maximum Frontal-Downward Acceleration, Range Frontal-Downward Acceleration, Maximum Total Jerk, and Minimum Frontal Jerk.

Controlled Flight: A controlled flight can be described as a smooth transition from starting to target surface as the body follows a linear path without unexpected deviations. We, therefore, selected representative features according to pre-existing literature focusing on measuring smoothness of movements during rehabilitation [3,4]. The following features were selected: Spectral Length of Acceleration, Spectral Length of Velocity, Dimensionless Jerk, Log Dimensionless Jerk.

Smooth Landing: The moment in which the subject's buttocks land on the target surface is characterized by a sharp peak of acceleration in the vertical direction (E) combined with a smaller peak in the lateral direction (F) (Maximum Vertical Acceleration, Maximum Total Acceleration). This would likely be reflected in higher average values of acceleration in the observed window of time (Mean Total Acceleration, Mean Vertical Acceleration, Root Mean Square Total Acceleration). Hard landings will likely cause large variations in the trunk accelerations as the trunk moves to regain stability (Range Total Acceleration). The following features were used: Maximum Vertical Acceleration, Maximum Total Acceleration, Range Total Acceleration, Mean Total Acceleration, Mean Vertical Acceleration, Root Mean Square Total Acceleration.

F.4.2 Modelling and results

After the physiotherapists' evaluations, the collected dataset contained the ratio of good/bad transfer instances for each evaluation item. These were: Head-Hip Relationship 59/49, Controlled Flight 106/2, and Smooth Landing 61/47. Due to the unbalanced nature of the dataset for the controlled flight item, featuring only 2 bad instances out of 108, the automatic evaluation for this item was not performed. The Correlation-based Feature Subset Selection method [23] was used to optimize the feature selection process. The resulting selected features (from the list in Table 2) are:

1. Head-Hip Relationship: Minimum Frontal Acceleration, Range Frontal Acceleration, Maximum Frontal-Downward Acceleration, Minimum Frontal Jerk
2. Smooth Landing: Maximum Total Acceleration, Range Total Acceleration, Mean Total Acceleration, Root Mean Square Total Acceleration

Only these selected features were used to build the automatic transfer evaluation system. Random Forest, Support Vector Machine (SVM), Naïve Bayes, Multinomial Logistic Regression were used to build the classifiers, these classifiers are commonly used in the related literature. A leave-one-subject-out cross validation method was used to evaluate the accuracy of the models and test for generalization over unseen users.

For both evaluation items, all classifiers exhibited similar average accuracies across all participants. For the evaluation of the Head-Hip Relationship item average classifier accuracies across all participants were: SVM 75.9% ± 13.5, Random Forest 72.2% ± 15.6, Naïve Bayes 75% ± 13.8, Multinomial Logistic Regression 75.9% ± 14.1. For the evaluation of the Smooth Landing item average classifiers accuracies across all participants were: SVM 79.6% ± 7.4, Random Forest 73.1% ± 13.7, Naïve Bayes 78.7% ± 7.3, Multinomial Logistic Regression 78.7% ± 7.3. SVM were found to be the most accurate classifiers across all participants for the evaluation of both Head-Hip Relationship use and Smoothness of Landing.

The best performance was given by SVM. Table F-3 shows the individual accuracy of SVM classifiers for each participant in respect of both transfer evaluation's items. Table F-4 shows the confusion matrices for the SVM classifier across all participants for the evaluation of Head-Hip Relationship and Smoothness of Landing.

Table F-0-3 Accuracy of SVM classifiers for the evaluation of Head-Hip Relationship and Smooth Landing items across all participants

Participant	SVM Accuracy Head-Hip Relationship	F1 Score	SVM Accuracy Smooth Landing	F1 Score
1	66.7%	.667	75%	.739
2	100%	1.00	83.3%	.838
3	66.7%	.686	83.3%	.829
4	91.7%	.923	75%	.755
5	75%	.750	75%	.739
6	66.7%	.663	66.7%	.667
7	83.3%	.844	83.3%	.829
8	75%	.767	83.3%	.833
9	58.3%	.569	91.7%	.917
Average (std)	75.93% (0.13)		79.62% (0.07)	

F.5 Automatic transfer detection

The second aim of the study was to investigate the possibility to continuously track the transfer events as the person moves around the various activities. This work builds on the work presented in [17] but with the aim of exploring the contribution of the chest worn sensor and to use more ecological settings to address this question. In addition, in contrast to [17], we also aimed to perform continuous tracking rather than discrimination between pre-segmented activities.

Table F-0-4 SVM global confusion matrices showing actual and predicted classes (and their relative percentages) for the evaluation of Head Hip Relationship use (above), and Smoothness of landing (below) for all wheelchair transfer

		Predicted Class	
Actual Class		H-H Relationship	No H-H Relationship
	H-H Relationship	31 (63.3%)	18 (36.7%)
	No H-H Relationship	8 (13.6%)	51 (86.4%)

		Predicted Class	
Actual Class		Smooth Landing	No Smooth Landing
	Smooth Landing	36 (76.6%)	11 (23.4%)
	No Smooth Landing	11 (18.0%)	50 (82.0%)

F.5.1 Features selection

Data from the accelerometer were divided into windows of 25 samples (1s at 25Hz) with a 50% overlap between neighbouring windows. All windows were labelled for transfer occurrence according to the timestamps extracted from the labelled videos. From each window 59 features were extracted according to the procedure illustrated by [21]. Fourteen features were extracted for each accelerometer axis and the total acceleration vector contained: standard deviation, variance, 10th, 25th, 50th, 75th, and 90th percentiles, interquartile range, range between the 10th and the 90th percentiles, and lag-one correlation of the counts in a period of 10 seconds as a measure of temporal dynamics [21,54]. Additionally, we used a two-level wavelet transform, with Daubechies 2 as mother wavelet [21,45] to calculate the Euclidean norm of the detail coefficients of the first and second level of resolution, the approximation coefficient of the second level. Finally, we calculated sample entropy for each axis (tolerance =.3 s.d.; patter length =2) as shown in [21,29] and the cross-correlation between the three axis.

Although wheelchair transfers were only one of the activities classified by [21] the features they used were found to be very informative to discriminate between discrete types of activities undertaken by wheelchair users. Even though these activities were quite different from each other, the use of the same features would allow for the integration of transfer detection within a more general activity detection framework for the wheelchair user.

As for the transfer evaluation study, the Correlation-based Feature Subset Selection method [23] was used for feature selection. This identified 25 relevant features across all participants and the remaining 24 were removed from the classifiers' list of attributes. The complete list of features is shown in Table F-5.

Table F-0-5 List of features calculated for the Automatic Transfer Detection. Features marked with the * were found to be relevant after the optimization procedure

Time Domain Features	Wavelet Transform Features	Others
Variance (X,Y,Z*, Total*)	Euclidean Norm 1st level coefficient (X,Y*,Z, Total)	Sample Entropy (X,Y,Z, Total)
Standard Deviation (X,Y,Z, Total*)	Euclidean Norm 2nd level coefficient (X,Y*,Z*, Total*)	Cross Correlation XY
10th Percentile (X,Y*,Z*, Total*)	Approximation Coefficient of the 2nd level (X,Y,Z*, Total*)	Cross Correlation XZ
25th Percentile (X,Y,Z*, Total)		Cross Correlation YZ
50th Percentile(X,Y,Z, Total*)		
75th Percentile (X,Y,Z, Total*)		
90th Percentile (X,Y,Z*, Total*)		
Interquartile Range (X*,Y*,Z*, Total)		
Range between 10th and 90th Percentiles (X,Y*,Z*, Total*)		
Lag One Correlation (X,Y,Z*, Total*)		

F.5.2 Modelling and results

Classification algorithms used for transfer monitoring were the same as the one used for transfer evaluation. A leave-one-subject-out validation strategy was to evaluate the performance and generalization capabilities of the models. Table F-6 shows the number of 1-second windows labelled as part of either a transfer or no-transfer (i.e., any other activity: pushing the wheelchair, opening the car door, lifting oneself from the chair for pressure relief, etc.). The decision to have participant wearing the accelerometer for the whole duration of the experiment minimized the disruption and resulted in the collection of a more realistic dataset. However, as accelerometer data were recorded continuously for approximately 40 minutes for each participant and only 12 transfers lasting for a couple of seconds each were performed within the timeframe, this resulted in a severe imbalance between the two classes (transfer and no-transfer). To reduce classifiers bias towards the majority class random sampling with a 1:1 transfer/no transfer ratio was used for all participants.

Table F-0-6 Number of instances labelled according the occurrence, non-occurrence of transfers for each participant (and relative percentages)

Participant	Instances with Transfer Occurrence (Relative %)	Instances with No Transfer Occurrence (Relative %)	Total
1	145 (3.1%)	4520 (96.9%)	4665
2	100 (2%)	4937 (98%)	5037
3	105 (1.4%)	7211 (98.6%)	7316
4	108 (2.6%)	4005 (97.4%)	4113
5	109 (2%)	5219 (98%)	5328
6	108 (2.5%)	4273 (97.5%)	4381
7	101 (1.7%)	5787 (98.3%)	5888
8	117 (2.2%)	5104 (97.8%)	5221
9	93 (1%)	9022 (99%)	9115
Sum	986	50078	51064
Absolute percentage	2%	98%	100%

Average classifiers accuracies for automatic transfer detection were: Naïve Bayes 91.9% ± 4.9, Multinomial Logistic Regression 87.8% ± 4.9, SVM 86.8% ± 10.1, Random Forest 83.2% ± 10.1. Overall, Naïve Bayes classifiers obtained higher classification accuracies. However, as shown by the overall confusion matrices presented in Table F-7, Naïve Bayes classifiers displayed a considerably higher relative accuracy for No Transfer

Occurrence instances. On the other hand, Multinomial Logistic Regression classifiers achieved a more balanced relative accuracy between the two classes (See Table F-6). Individual accuracies of each classifier for Automatic Transfer Detection across all participants are displayed in Figure F-5.

Table F-7 Global confusion matrices for Automatic Transfer Detection using Naïve Bayes classifiers (above), and Multinomial Logistic Regression classifiers (below)

		Predicted Class	
Actual Class		Transfer Occurrence	No Transfer Occurrence
	Transfer Occurrence	46160 (92.8%)	3558 (7.2%)
	No Transfer Occurrence	286 (27.5%)	754 (72.5%)

		Predicted Class	
Actual Class		Transfer Occurrence	No Transfer Occurrence
	Transfer Occurrence	44293 (89.1%)	5425 (10.9%)
	No Transfer Occurrence	105 (15.3%)	881 (84.7%)

F.6 Discussion

The first aim of this paper was to be able to determine transfer quality from a single body-worn accelerometer, which could later be incorporated into a more general activity monitoring system. Body-worn sensors are often used to detect movement (i.e. recognition), however, are rarely used to evaluate the quality of body movement in wheelchair users [49]. This is especially true for rehabilitation purposes, as the body-worn system needs to be able to capture clinical expertise in evaluating the movement. We found that when using a single body-worn accelerometer located at the chest, we were able to extract two important elements of the clinically validated TAI: Head-Hip relationship, and Smooth Landing. Head-Hip Relationship and Smooth Landing had accuracy of 75.9% and 79.9 % respectively. These results are comparable to previous studies within the wheelchair user population such as research which classifies wheelchair propulsion [15,35]. Unfortunately, we were unable to perform the automatic valuation for the third item of the TAI we selected, Controlled Flight, as nearly all of our participants were able to control their movement during transferring. The participants in the current study were expert wheelchair users with good upper body strength. However, in a population of non-expert wheelchair users this item could be particularly important as it could help to identify difficulties encountered when transferring and highlight the absence of postural control that can be linked to an increase risk of falling [31].

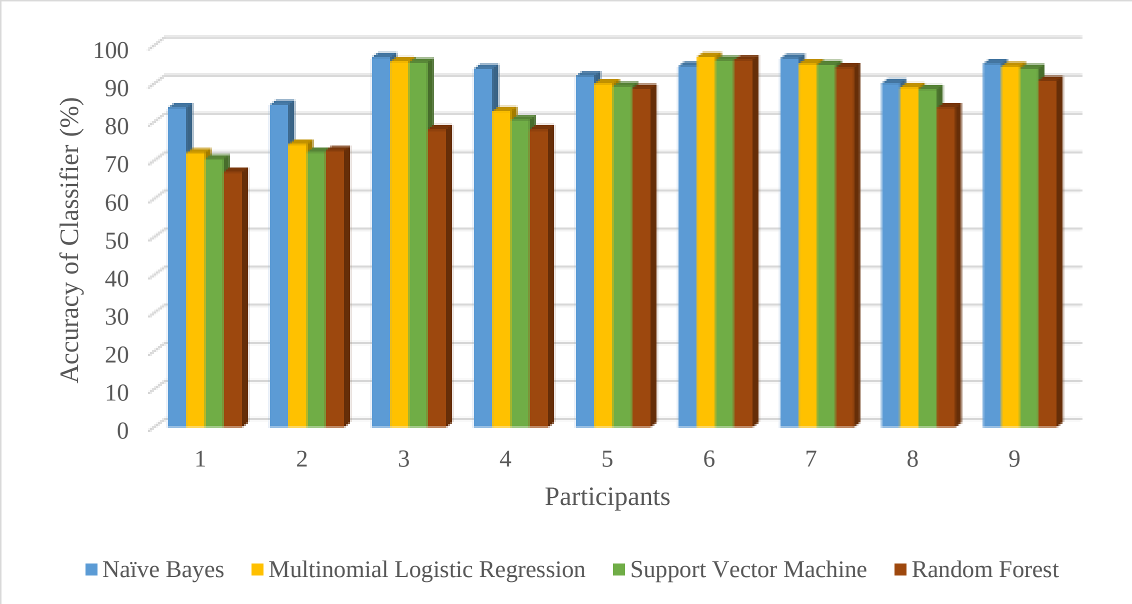

Figure F-5 Classifiers accuracy for Automatic Transfer Detection across all participants

The choice of using a single chest-mounted accelerometer for the automatic evaluation of transfer quality limited our assessment to three items of the TAI. However, such evaluation can have important clinical implications if extended to transfers performed in everyday settings. For example, the use of a Head-Hip relationship during wheelchair transfers has been shown to reduce muscular activity [17], shoulder forces [56] and increase stability [10]. Additionally, while a smooth landing is not necessarily linked with a reduction in the upper limb forces measured during wheelchair transfers, it offers an important indication of safety, as poor control in the final stage of the transfer can lead to an increased risk of falling [36].

Overall, the performance of machine learning classifiers for evaluation of transfer technique shows good potential for future clinical and well-being applications. Despite not reaching 100% accuracy of detection, our results using a single chest-mounted accelerometer were better than those previously reported by [21] when using accelerometers mounted on both wrists. The placement on the chest also allowed for quality of movement to be detected. However, this sensor alone is not sufficient to measure the exact start and end points of a transfer (or other items of TAI). Therefore, future work should investigate the use of an unobtrusive second sensor to aid with accurate detection (e.g. a pressure switch on the wheelchair itself). Furthermore, combining the chest accelerometer with a portable surface EMG system placed on the arm, for example, the low cost Myo Amrband (https://www.myo.com/), which is currently used in various activity detection studies [2,42], or even better a customized low cost EMG-shoulder sensors could allow a more complete picture of the transfer skills to be captures. This information could then be used to provide more detailed exercises and feedback to the MWU to help them train and practice the movement in real contexts.

The larger aim of our project is to develop a wearable capable to continuously tracking and giving real-time feedback to wheelchair users on their transfer ability as they go about their life. We have shown the potential of using a single chest-mounted sensor, a position of sensor, which until now has been under-investigated for transfer tracking. Previous research looked to include the chest sensor as an additional sensor to increase the accuracy of classification, when combined with wrist mounted sensors [21]. However, this previous research failed to investigate the data from the chest alone. Our results show that such a sensor is as powerful as a pair of wrist sensors in detecting transfers compared to results in [21]. It should be noted that even if the data are not the same and hence not directly comparable, our dataset had increased complexity due to its higher ecological variability and to the continuous detection of such events. Indeed, we attempted to replicate a typical pattern of daily activities within a wheelchair user's day by asking the participants to wear the accelerometer whilst travelling and resting between scenario activities. This makes detecting transfers a more difficult task than where transfers are completed cyclically for up to a minute at a time between surfaces of a fixed height, and without any change in scenario. Furthermore, we used extracted features within each second window (in line with [21]) rather than using pre-segmented instances.

The detection of transfer events was more successful for some participants than others. The Naïve Bayes classifiers were the most accurate across all participants. However, it was unbalanced and over-predicted the number of transfers when no-transfer was present. Despite this the Naïve Bayes classifiers were more robust across all participants, ensuring an accuracy of more than 80% for each participant. When the more balanced MLR was used the accuracy for participants 1 and 2 dropped to below 70%. It is unclear why these participants were so affected. Future work should look to replicate our work in the wild and with a larger sample of wheelchair users, which we believe would begin to address these limitations of the current dataset.

Overall, the automatic evaluation of transfer quality is not only important for clinicians but can offer significant benefits to the individual and the MWU population as a whole. A wearable system would allow people to self-monitor their transfers and seek additional medical help as and when required. In addition, the system could be used to provide real time feedback to MWUs, helping them to identify potential weaknesses and providing suggestions for improvements. Finally, if paired with data concerning, for example – the environment, emotional state of the MWU, time of day – a more complex picture of wheelchair transfers can be built, and better feedback and support mechanisms put in place for MWUs. Therefore, future applications could provide MWUs with real-time and long-term feedback on their performance to help them improve their technique to reduce both load on the upper limbs and risk of falling. Being able to easily map transfer difficulties in the built environment could also allow MWUs to share their experiences and provide information about accessibility standards of various establishments (i.e. hotel rooms, restaurant's toilet). This could also be extended to lower and middle income countries, where the majority of disabled people live, who frequently do not have access to rehabilitation programs.

F.7 Conclusions

In this paper, we investigated the use of a low-cost wearable device to support wheelchair users to train their movement skills in real-life situations. The aim is to increase capabilities and reduce injury by leveraging wearable technology, thereby moving rehabilitation into real life. We contributed to this body of work in three ways. We present results from a single chest-mounted accelerometer to detect both the quality and occurrence of wheelchair transfers under three ecological wheelchair transfer settings: Wheelchair–Bed, Wheelchair–Toilet and Wheelchair–Car. We provide the results from nine MWUs, who completed a total of 12 transfers over the three real-life situations. Using features extracted from a chest-mounted accelerometer we were able to improve the accuracy of detection of transfers with respect to the ubiquitous computing literature in this area whilst also detecting key elements of the quality of movement at performance levels observed for other aspect of the movements. Quality of transfer movement was identified using two elements from the clinically validated Transfer Assessment Index: Head-Hip Relationship and Smooth Landing. We were unable to use a third element (Controlled Flight) as there were only three positive incidences of this activity, however we believe this will prove a useful feature when working with non-expert and beginner MWUs.

The most promising classifier for quality was SVM and for detection MLR. We discuss how future work should look to expand from a single chest-mounted sensor, to include additional sensors to improve overall detection rates in particular in real-life activity.

However, we urge future researchers to evolve the work on measuring trunk activity within activity monitoring for MWUs more generally, and to this end we make our data set available to the research community.

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