An Early Intervention Programme (AiMS) for Developing Handwriting Skills in Young Autistic Children

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Declaration

I, [Tugce Cetiner] confirm that the work presented in my thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Abstract

The PhD programme of work was carried out to develop a novel parent-mediated home-based motor skill intervention to support handwriting in young autistic children aged between 4 and 5 – it is called “Autism Early Intervention for Motor Skills (AiMS)”. In Study 1, a systematic review investigated the critical ingredients of existing autism early interventions, with the main finding showing there was only one home-based, parent-mediated motor skill early intervention to support young autistic children. For Study 2, a survey examined parents/caregivers’ beliefs and knowledge about motor skills, and the motor skill activities they used to support young children. The results indicated that parents believed motor skills to be more important than literacy skills. They also had greater knowledge of motor skills compared to literacy and maths skills, but they used fewer motor skill activities. The Study 3 feasibility investigation was developed from Study 1 and 2, with the first part being the development of an AiMS workbook, parent training videos and instruction sheets. AiMS was underpinned by the theoretical principles associated with motor learning and practice-specificity, which formed the AB/BA randomised crossover experimental design. Autistic children performed fifteen tracing activities per day, five days a week for six weeks. Letter writing performance was evaluated in acquisition and transfer. All children improved letter writing performance, but importantly practice-specificity underpinned significantly better motor learning of novel Gokturk letters and the transfer to unpractised English letters. These results are the first to show practice-specificity in young autistic children and confirmed the feasibility of AiMS as a parent-mediated home-based motor skill intervention.

Impact Statement

Autism is a lifelong neurodevelopmental condition with ~80% of autistic individuals showing motor skill difficulties and/or differences, which should be supported by targeted early interventions. The motor skill early interventions that have been developed to support the young autistic children motor skills have mainly been conducted at school by professionals, rather than by parents/caregivers. This difference is important because parents/caregivers are known to play a critical role in child development in the early years (Bronfenbrenner, 1979). The overall findings of the programme of work indicated a need for the development of parent-mediated, home-based motor skill early intervention to support young autistic children's motor skill development. Developing and implementing such an intervention has the potential to not only improve motor skills in young autistic children, but also support stronger parent-child relationships and promote a more holistic environment. Moreover, parent-mediated interventions also provide collaboration between parents and professionals, which encourages open communication, mutual respect, shared decision-making, leading to more effective and sustainable intervention outcomes for young autistic children.

In the early years, parents/caregivers are regarded as the main stakeholders for early interventions meaning that their perceptions, including their beliefs and knowledge, can shape intervention priorities and intervention choice for their young children. The current findings showed that while parents/caregivers believed motor skill to be important, and they have the requisite knowledge, they used fewer motor skills activities at home. The choice of activities used at home may influence how parents/caregivers engage with the available early interventions. This emphasised the decision to develop a tailored, parent-mediated home-based motor skills intervention.

In general, children learn and improve motor skills via practice and instruction. The current AiMS findings showed that young autistic children aged between 4 and 5 learned new motor skills, which transferred to unpractised skills via a period specificity of practice (i.e., blocked followed by random practice). Furthermore, children also improved motor planning processes with practice, which was a significant findings given this process is often regarded as one of the most important reasons for motor skill difficulties in autistic children. The current findings also increased our theoretical understanding of how the contextual interference effect (Shea & Morgan, 1979), and practice variation (i.e., Schema Theory; Schmidt, 1975), modulates motor learning and transfer in young autistic children. Taken together, the findings provide the basis for practical guidance for educators, therapists, and educator, plus researchers that investigate motor skill interventions for children using the principles of motor learning theory.

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Chapter 1: Introduction

Background and Context for the Choice of Research Topic

Autism spectrum disorder (autism) is a lifelong neurodevelopmental condition clinically described as meaning persistent difficulties in social interaction and social communication, repetitive behaviour, limited interests, and hyper- or hypo-reactivity to sensory inputs (DSM-V; American Psychiatric Association, 2013). Autism is one of the most common developmental conditions in the world, and currently, at least 1% of the world population is diagnosed with said condition (Lord et al., 2020). The average age of autism diagnosis is approximately 4.5 years in the UK (Brett et al., 2016), and many recent studies have been conducted on how to reduce the age of diagnosis of autism (Constantino & Charman, 2016; Lord et al., 2020). The primary motivation to decrease the age of diagnosis is to be able to engage in the implementation of early interventions (Constantino & Charman, 2016). Early interventions are important support systems for children with special needs (or likelihood developing special needs) and their families. The general aim of early interventions is to help maximize children's overall potential and provide support for parents with their children's special needs (Baker & Feinfield, 2003). Recent years have seen a number of systematic reviews and meta-analyses conducted on early interventions for autistic children, and the findings suggest that early interventions have a significant positive impact on autistic children's outcomes in language (Virués -Ortega, 2010; Hampton & Kaiser, 2016), adaptive behaviour (Eldevik et al., 2010), and communication (Goldstein, 2002). Therefore, early interventions are suggested to be a priority for young autistic children, specifically being considered most effective in the early years because of increased brain plasticity (Lord et al., 2020).

Brain plasticity refers to the neural processes within the brain related to learning new skills by remembering, forgetting, reorganising, and recovering (Johnston, 2004). Although brain plasticity is present lifelong, it is more prominent in early childhood (Inguaggiato et al., 2017). Therefore, it may be more effective to implement early intervention in early years due to the potential of rapid learning capacity resulting from the increased brain plasticity of children (Inguaggiato et al., 2017).

Parents are important in children's early years as they have an important influence on their children's development (Swanson et al., 2003). Blackman (2002) agrees that parental involvement should be included in early interventions, adding that any early intervention programme that excludes the parent is unlikely to be successful. Due to the importance of parents on children's early years development, parental involvement should increase in early interventions settings. Early intervention can occur in different settings (e.g., school, home, and clinic) (Prata, et al., 2018). In school or clinical settings (a community setting), mainly professionals conduct early intervention. However, in home-based early intervention, parents play a more active role, and parental involvement may be maximized. Home-based early interventions have other advantages when compared to community setting-based intervention. For example, children can easily generalize targeted skills in home-based early interventions (Leaf et al., 2018). Moreover, home-based early interventions are also time- and cost-effective compared to community setting-based early interventions for parents and service providers (Mullan, et al., 2021).

Many forms of early intervention are recommended for young autistic children. In general, these early interventions focus on the main difficulties of autism, such as communication, language, or repetitive behaviours (French & Kennedy, 2018). One area that is frequently overlooked in early interventions is the motor skill difficulties and/or differences of young autistic children (Zampella et al., 2021). Motor skills are a task that requires the voluntary control of the overall body to achieve an action goal (e.g., running fast) or an outcome goal (e.g., holding a cup). Although motor skill difficulties are not currently considered a main defining feature of autism diagnosis in DSM-V criteria, growing evidence showed that autistic children often present with difficulties in these skills such as gait, postural control (Coll et al., 2020), motor coordination (Green et al., 2002), motor planning (Forti et al., 2011), fine and gross motor skills (Green et al., 2009). Motor skill learning/control can be improved with practices, both blocked and random. Blocked practice includes typical drills in which a task is repeated over and over, before another task is performed (e.g., AAA, BBB, CCC). Another practice variation is called random practice, in which different variations of tasks are presented in an unpredictable order across the practice period (e.g., ACB, BCA, AAC) (Merbah & Meulemans, 2011). Study (Battig, 1966; Shea & Morgan, 1979; Magill & Hall, 1990) results show that, while blocked practice provides more promising results for the acquisition of new motor skills, random practice leads to a higher level of performance on a retention or transfer test.

Motor skills are particularly important for young autistic children because these skills could have an important role in the development and maintenance of the other core features of autism (Hannant et al., 2016). For example, motor skill difficulties and/or differences may restrict participation in activities that support the development of social, communication, or behavioural skills (Bhat et al., 2011). These difficulties may also limit the participation in physical activities required for maintaining health and wellness and negatively affect autistic individuals' overall health (Srinivasan et al., 2014). In addition, there is a positive relationship between motor skills and children's academic success. For example, children with more effective fine motor skills were shown to be perform at a higher level in maths (Carlson et al., 2013), and those with more effective locomotor skills had higher-level reading skills (Westendorp et al., 2011). Despite the importance of motor skills for development of young autistic children, there are limited early intervention studies based on targeting sensory-motor processes in young autistic children (Zampella et al., 2021), and the systematic review results show that, none of these studies were designed based on motor learning principles. Due to this research gap, the principal aim of this study was develop a novel early intervention called "Autism Early Intervention for Motor Skills" (AiMS). AiMS was a parent-mediated home-based early intervention and designed to improve the motor learning and control of young autistic children based on motor learning principles by focusing on handwriting (letter writing) activities.

Research Plan

This study adopted a mixed design and unfolded through seven distinct sections: (1) Introduction; (2) Literature Review; (3) Methodology; (4) Systematic Literature Review; (5) Survey; (6) Feasibility of AiMS; and (7) Discussion and Recommendations. As illustrated in Table 1, this PhD research began with the "Introduction." To provide a foundation for the study, a general overview of motor skill, motor control and theoretical frameworks were offered in this section. After the introduction, the literature review explored important topics such as motor skills and learning in autism and the importance of handwriting. Towards the end of this section, research questions were formulated to guide the subsequent investigations. Following this section, the methodology meticulously outlined the research design and rationale behind the chosen methods. Subsequently, the first phase of the research, namely the systematic literature review, was presented. This systematic review focused on existing motor and non- motor early interventions, including motor skill outcomes and design for young autistic children. The second study, a survey, engaged parents of both young autistic and non-autistic children. This survey investigated parents' beliefs, and knowledge regarding motor skills, as well as motor skill activities that they facilitate to their children at home compared to literacy and math skills. Building upon the findings of the initial two studies, an AiMS program was designed and tested with the feasibility study. In the final section, the conclusion and recommendations, results were rigorously discussed, culminating in future recommendations for further research and applications.

Table 1: Illustration of the PhD research plan

Chapter 1: Introduction	**Chapter 2: Literature Review**	**Chapter 3: Methodology**	**Chapter 4: Systematic Literature Review**
Motor skills Motor control Motor skill learning Theoretical frameworks	Motor skill difficulties and/or differences in autism Early signs of autism: motor skill s-difficulties ana/or differences Motor skill difficulties and/or differences in young autistic children in pre-school age A reflection of Motor Skills: Handwriting Handwriting Difficulties in Autism Early Interventions for Young Autistic Children How Autistic Children Handwriting Can be Supported with Motor Early Interventions? Conclusion and Research Questions	Research approach Research design Rationale behind the chosen methods	Review of existing motor and non-motor early interventions designed for young autistic children and included motor skill outcomes

Chapter 6: Survey	Chapter 6: Feasibly of AiMS	Chapter 7: Discussion
Understanding of young children's parents' beliefs and knowledge about motor skills, as well as motor skill activities that they facilitate to their children at home	The feasibly of AiMS program with an AB/BA experimental design	Discussion of results Limitations and future directions Conclusion

Motor Skills

Movement is one of the most crucial parts of human life as it enables essential functions such as eating, survival, and engagement with the world and individuals (Wolpert et al., 2001). Movements are specific patterns of motion among body parts used to achieve action goals, forming part of the acquisition of motor skills (Magill & Anderson, 2010). Motor skills are activities or tasks that require voluntary control over the movements of joints and body segments, aiming to achieve an intended action-goal (e.g., to walk; sit on a chair) or an outcome-goal (e.g., to hold a pen; throw a ball) (Magill & Anderson, 2010). Motor skills may be categorized into one-dimensional or two-dimensional classification systems. In the one-dimensional classification system, motor skills are classified according to common characteristics:

1. Size of primary muscle required [fine motor skill (e.g., turning on the tap) and gross motor skill (e.g., jumping over obstacle)]; and
2. Specificity of where actions begin and end [continuous motor skills (e.g., walking) and discrete motor skills (e.g., hitting a piano key)]; and
3. Stability of the environmental context [open motor skills (e.g., catching a thrown ball) and closed skills (e.g., picking up a cup from the table)].

In the two-dimensional classification system (Gentile's Two-Dimension Taxonomy), motor skills are classified according to their two general characteristics:

1. The environmental context in which the person performs the skill; and
2. The function of the action characterizing the skill (Adams, 1999).

The one-dimensional classification system (especially gross/fine distinction) is commonly used in education and special education settings to evaluate children's motor skills, especially in early years. Several standardised measurement tools [e.g., VABS (Vineland Adaptive Behaviour), MSEL (Mullen Scales of Early Learning) or PEP-R (Psychoeducational Profile Revised)] have been developed to evaluate the motor skills of children along the gross/fine dimension (Magill & Anderson, 2010). Since this PhD focuses on young autistic children, when motor skills were classified, the one-dimensional system, which considers the *size of the primary muscles required*, distinguishing between fine motor skills and gross motor skills were used. Gross motor skills are a type of motor skills that mainly require the use and coordination of large muscle groups such as arms or legs to achieve an intendent task such as running, throwing, or jumping. On the other hand, fine motor skills mainly require the use and coordination of small groups of muscle such as hands or fingers to achieve an intended goal such as picking, grasping, or handwriting (Matheis & Estabillo, 2018). When performing a fine motor skill task (i.e., handwriting), large muscles may contribute to the execution of the skill, but small muscles (i.e., hands and fingers) play a primary role in achieving the goal of the skill (Magill & Anderson, 2010).

Motor Control

Motor control may be considered a process of converting sensory inputs into consequent motor outputs (Wolpert et al., 2001). The central nervous system (CNS) regulates and coordinates the muscular and skeletal systems to perform voluntary movements (e.g., holding a cup). In this PhD, motor control processes are explained based on a model developed by Wolpert et al. (1997) as its comprehensive scope addresses various motor functions and presents distinct computational units that may have potential connections to different cognitive tasks (Gowen & Hamilton, 2013). As illustrated in Figure 1, the motor control process is divided into five stages:

(1) sensory system; (2) state estimation; (3) motor planning; (4) forward model; and (5) motor execution.

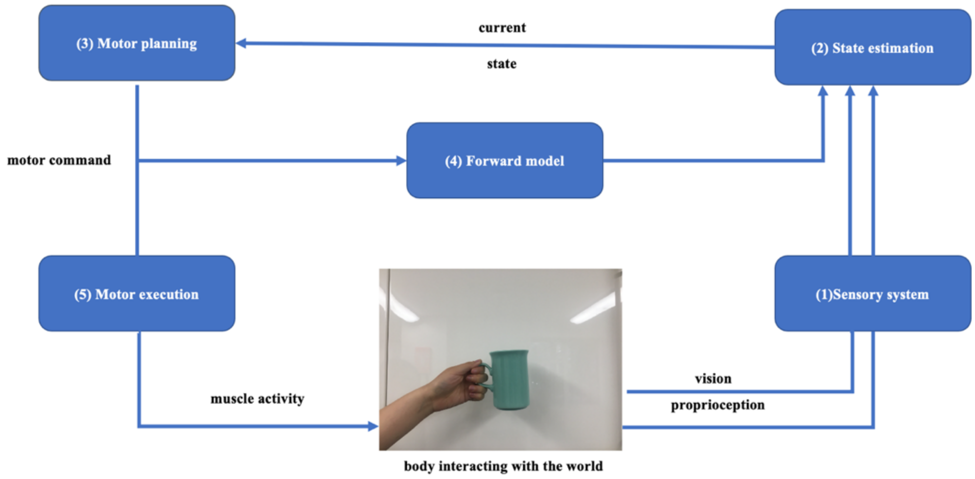


Figure1: Motor control processes engaged whilst performing goal-directed action such as picking up a mug (adapted from Gowen & Hamilton, 2013)

1) Sensory System

Several studies (Keele, 1968; Pew, 1974; Schema 1975) have asserted that, for individuals to perform a motor skill task effectively, they require information about the initial conditions under which muscles are about to move. The initial conditions are comprised of the information received from multiple sensory inputs (e.g., vision, touch, and/or proprioception) that provide information about body and environmental information about the characteristics required to perform a motor skill task. For example, as illustrated in Figure 1, sensory inputs provide environmental information about the initial conditions of the motor skills task (i.e., holding a mug), such as the shape of mug, the location of the mug, as well as information about the body such as hand position. Initially, the brain must receive these sensory inputs with minimal noise or error to subsequently interpret them.

2) State Estimation

Individuals must create or update a motor plan to execute a motor skill task. For this process, individuals require a state estimate of their current location and situation of a particular target (Wolpert 1997). For instance, to hold a cup, the individual must estimate the location of the mug, the location of the hand, and the weight of the mug. During state estimation, different sensory inputs (e.g., vision, touch, and/or proprioception) are integrated to determine the current location of the body and articular target. The integration of these inputs in the state estimation stage is "Multi-Sensory Integration (MSI)" (Gowen & Hamilton, 2013). During MSE, two points are critical. Firstly, when faced with multiple sensory inputs, the following question arises: Which inputs should be integrated (Wolpert 1997)? For instance, should the sound of a metal teaspoon be integrated with the stirring of tea or the ring of the phone (Gowen & Hamilton, 2013)? The solution for this issue may be to integrate sensory inputs that happens close in space or time (Spence et al. 2004). Secondly, different information sources (e.g., vision, touch, and/or proprioception) must be weighted appropriately to use for information. For example, in a dark environment, proprioception may provide more reliable information than vision (Gowen & Hamilton, 2013).

3) Motor Planning

Even for the most basic tasks, such as holding a mug, there exists an infinite number of potential paths through which the hand could hold the mug. Moreover, for each of these paths, there is an unlimited number of possible velocity profiles or trajectories that the hand could follow. Motor planning is a computational process of choosing a singular solution or pattern of behavior across all levels of possibilities, which requires the selection of numerous alternatives that align with the objective of the task (Wolpert 1997). The selection process in motor planning is related to cost of the movement. All movements have a cost, including energy expenditure, time, accuracy, comfort, or efficiency, and the movement with the lowest cost is selected as the plan to perform a task. For example, it is less costly to pick up a pen on the table, on the right side of the body, with the right hand than with the left.

After receiving and integrating sensory inputs, the next stage is motor planning for motor skill execution. Motor planning begins before a motor skill task is initiated, and the inverse model controls movement and correct error during motor skill execution. The inverse model is a system that generates the motor commands required to bring about that desired state (Cooper, 2010). The basic means of assessing motor planning stage is measuring reaction time, which is the common measure demonstrating how long takes to prepare and initiate a motor skill task (Magill & Anderson, 2010). A longer reaction time could be led to slower motor execution (Gowen & Hamilton, 2013).

4) Feedforward Control and Prediction

During the execution of a motor task, it is crucial to control whether the task is progressing according to the plan. If necessary, corrections should be made to address errors that may arise during the performance of the task (Gowen & Hamilton, 2013). In order to control and correct the movement, sensory feedback results from the movement and intended goal (i.e., feedback control) may compare. However, particularly in rapid movements, delays in both sensory and motor systems contribute to slow feedback control (Miall & Wolpert, 1996). In order to deal with these delays, the brain creates a prediction for expected sensory inputs using the feedforward model. The feedforward model is a representation that uses the current states of the motor system and motor command to predict the next stage (Miall & Wolpert, 1996). For rapid correction, firstly, an efference copy (i.e., a copy of motor command) is sent to a feedforward model. This feedforward model quickly produces a prediction of the sensory outcomes of the action (Wolpert & Flanagan 2001). This prediction is then compared with incoming sensory inputs, facilitating the rapid detection of errors (Wolpert et al., 2001).

5) Motor Execution

Motor execution is the last stage of the motor control process. In this stage, based on motor plan, sensory feedback and forward model motor skill tasks are executed (Gowen & Hamilton, 2013).

Theoretical Framework for Motor Control: The Multiple-Process Model of Limb Control

The first theoretical model aiming to ensure the accuracy and control of voluntary movement (henceforth goal-directed aiming movements) (e.g., holding a pen, opening the door, or kicking a ball) was developed by Woodworth (1899). According to this model, goal-directed movements consist of two different phases. The first phase of movement (e.g., holding a pen) is ballistic and, the limb (e.g., the hand) comes closer to the target (e.g., the pen). In the second phase, feedback (e.g., visual, and proprioceptive) is used to decrease discrepancy between the limb and the target position. Woodworth's (1899) two-component model of upper limb control for goal-directed aiming movements has been used commonly, and different variations of this model have been developed by many researchers (Keele, 1968;

Beggs & Howarth, 1970, 1972; Crossman and Goodeve 1983). In general, these models focus on speed-accuracy relations in goal-directed aiming movements (Fitts, 1954; Fitts & Peterson, 1964). However, despite the importance of motor planning and online control on speed and precision of goal-directed aiming movements, it is clear that Woodworth's simple two-component model, and its descendants, cannot fully capture the flexibility and sophistication of skilled upper limb motor control for goal-directed aiming movements (Elliott et al., 2010). Therefore, Elliott et al. developed a new model of upper limb motor control for goal-directed movement called the "Multiple-Process Model of Limb Control." The multiple-process model of limb control consists of two identifiable phases that are planned and corrective. In the planned component, the limb (e.g., hand) gets to the target area (e.g., a mug on the table). As time progresses, the corrective phase of the movement starts, and spatial discrepancy between the limb and target position late in the movement is reduced using sensory inputs. During these two phases, multiple processing events occur. As illustrated in an acceleration profile in Figure 2, the time between the start of trial (1) and signal to move (2) is the "pre-planning" part of the movement. In this stage, based on advanced information [(e.g., instructions for task (e.g., when you see the green light, you should throw the ball on the target as quickly and accurately as possible)] planning of the movement is start. In this part, the performer must determine the maximum speed of the movement to ensure that it hits the target. The time between signal to move (2) and movement initiation (3) is the "reaction time (RA)." RA time is the common measure demonstrating how long it takes to prepare and initiate a motor skill task (Magill & Anderson, 2010). In this part of the movement, the timing of muscular forces is specified, and the internal representation of expected efference and internal representation of expected sensory consequences are formulated. Longer reaction time could be led to slower motor execution. The basic way to assess motor planning stage is measuring RA (Gowen & Hamilton, 2013).

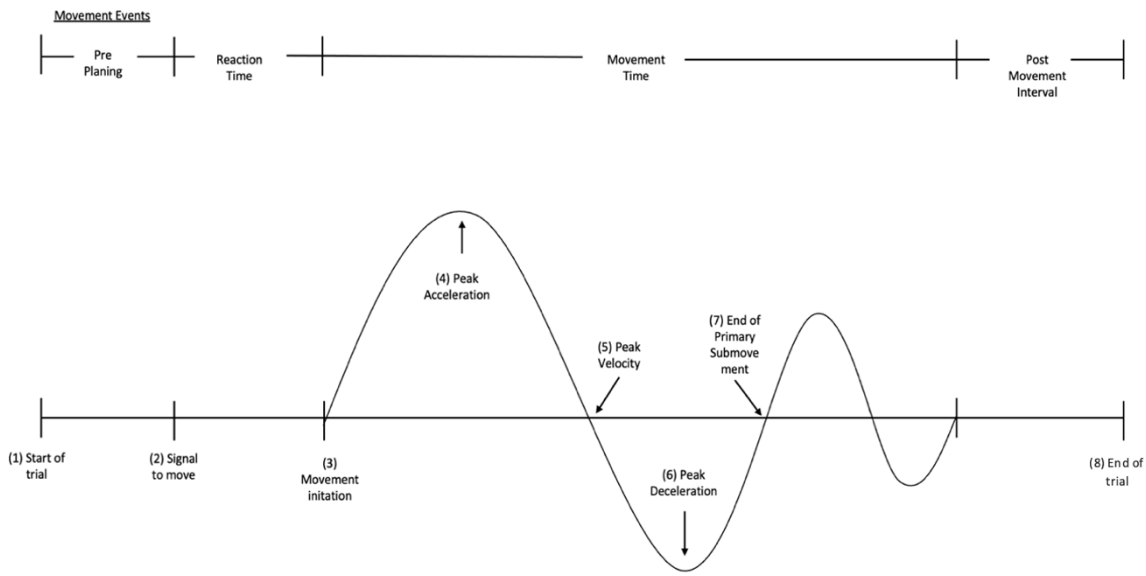


Figure 2: Illustration of specific acceleration profile that include multiple processing events linked to a single goal-directed movement towards a small target (adapted from Elliot et al.,2010)

With the movement initiation at the start, the “movement phase” lasts by end of the movement. The movement phase consists of different kinematic markers, namely peak acceleration, peak deceleration, and peak velocity (see Figure 2). Peak acceleration refers to the highest rate of change in velocity observed during a specific movement. Peak acceleration occurs at the point within the movement at which the acceleration reaches its maximum value. Peak velocity is the highest speed achieved during an execution of specific movement. In contrast to peak acceleration, peak deceleration refers to the highest slowing down during the execution of specific movement and represents a negative change in velocity. Elliott et al. (2010) claim that these kinematic markers would be associated with feedforward and/or feedback processes of motor control. The feedforward model involves making initial adjustments by comparing motor commands with anticipated outputs, a concept that includes efference copy associated with early kinematic markers (i.e., before peak velocity) (Meyer et al., 1982; Elliott et al., 2010; Miall & Wolpert, 1996). The feedback process refers to correction phase in which online sensory processing compares the intended state to the current state associated with later kinematic parameters (i.e., after peak velocity) (Meyer et al., 1982; Elliott et al., 2010). Increased variably in peak acceleration, peak deceleration, or peak velocity is an important indicator of less effective motor control. This variability may be the result of motor planning difficulty related to the accurate specification of forces for movement execution with an internal action model (Wolpert et al., 1995; Foster et al., 2020; Glazebrook et al., 2006).

Motor Skill Learning

Learning is behavioral changes arising from interactions with the environment, differing from maturation, which refers to changes that occur independently from interactions (Wolpert et al., 2001). Motor skill learning relates to the acquisition of new motor skills (e.g., learning to swim) to improve the performance of already acquired motor skills (e.g., scoring a basket in two out of 10 attempts in the first month and eight out of 10 attempts at the end of three months of practice) and/or the reacquisition of motor skills after injury or disease (e.g., learning to walk after a stroke) (Magill & Anderson, 2010). While learning a motor skill may appear to be a unified experience, researchers in motor control and learning have deconstructed the involved processes into several interacting components that contain sensorimotor information on how to plan, key features of the task, execute, and control movements (Schmidt, 1975; Wolpert & Flanagan, 2010).

The process of motor learning is to master and adapt to the numerous sensorimotor control transformations that are available (i.e., redundant degrees of freedom) (Bernstein, 1967) to achieve an intended action goal (Wolpert et al., 2001). Sensorimotor control transformation involves two directions, namely forward and inverse. "Forward" represents causal direction, such as mapping motor commands onto their sensory outcomes. "Inverse" represents the opposite direction, such as converting a desired sensory outcome into the motor commands that would be necessary to accomplish it. These transformations are controlled by the body and environment, and their representations in the central nervous system are the “internal model” (Miall & Wolpert, 1996; Wolpert et al., 2001). The process of motor learning may be considered acquisition of representation of forward and inverse internal models suitable for different motor skill tasks and environments (Wolpert et al., 2001).

Motor skill learning requires relatively enduring, consistent improvement in the execution of a specific motor skill task (Magill & Anderson, 2010). Study findings show that the permanence and stability of motor skill improvement are achieved through practice (Schmidt & McCabe, 1976; Khan et al., 1998; Hansen et al., 2005). Individuals may improve their motor skills with different types of practices, either blocked or random. A blocked-practice trial-order is structured so that **Task A** (i.e., throw the ball to the target) is performed across a consecutive number of practice trials before performing a different **Task B** (i.e., kick the ball to the target) and a different **Task C**. Therefore, a blocked-practice trial-order is typically structured as follows: **AAA; BBB; CCC**. On the other hand, random-practice requires the same three tasks to be practised but in an unpredictable trial-order - therefore, a random-practice trial-order is typically structured as follows: **ACBBCACBA** (Shea & Morgan, 1979). Practice type has differential effects on motor performance, motor learning, and motor transfer (generality) (Battig, 1972; Shea & Morgan, 1979; Magill & Hall, 1990; Raviv et al., 2022). One of the most important theories in the literature explaining the impact of various types of practice on motor skill learning is the schema theory (Schmidt, 1975).

Theoretical Framework for Motor Skill Learning: A Schema Theory of Discrete Motor Skill Learning

Schema theory centres on the acquisition and execution of diverse movements that a human can perform, encompassing the successful execution of new movements (Wulf, 1991). The main distinction of 'schema theory' compared to earlier motor skill learning theories [(e.g., Closed-loop Theory (Adams (1971)] is that it explains the motor skill learning with the flexibility in human movement (Wulf, 1991). Two important components of this theory are generalised motor program and motor schema.

Motor programs are pre-structured sets of muscle commands that are stored in the central nervous system to be used when required for any specific movement or action (Lashley, 1917; Schmidt, 1975). Previous researchers (Henry, 1960) have asserted that each distinct movement necessitates a specific motor program. However, in schema theory, as articulated by Schmidt (1975), this perspective is modified, suggesting that a single motor program could be employed for the execution of related motor skills through the used generalised motor programs (GMPs). For example, using a GMP could be enough to various techniques (e.g., fast, or slow) of kicking a football. It is assumed that, if specific response specifications are provided, GMPs can deliver pre-structured commands for different movements. These specifications may considered parameters to be adjusted before the movement commences, allowing the execution of the program at varying speeds, forces, and other factors. In this context, motor schemata help individuals to organise and adapt motor programs based on the variations and experiences encountered during practice (Schmidt, 1975).

Motor schemata refers to cognitive structures or representations that individuals develop as a result of motor skill learning with practices, highlighting the connection between the motor outcomes obtained from previous attempts and the parameters selected during novel attempts (Schmidt, 1975; Schmidt, 2003). In motor learning perspectives, two types of motor schema are ‘recall schema’ and ‘recognition schema’ Recall schema refer to the generalised motor commands stored in the memory, which can be retrieved and adapted for use in different situations, allowing individuals to recall and execute learned motor skills in a variety of contexts (Schmidt, 1975; Schmidt, 2003). For example, once tennis players master the basic stroke, they develop a recall schema encompassing the key elements of the movement. Subsequently, these individuals can apply these key elements in diverse conditions, (e.g., varied incoming ball speeds). Recognition schema, on the other hand, represent the connection between the previous sensory outcomes produced by executing the program and the results or consequences of that program (Schmidt, 1975; Schmidt, 2003). Recognition schema involve sensory feedback received during the execution of a motor skill. For example, in the process of learning of playing basketball, when the player misses a shot of a ball into a hoop, the recognition schema processes the sensory feedback from the missed shot, comparing the actual outcomes with the expected outcomes for shooting the ball into a hoop. The recognition schema detects the error and provide feedback to the learner. Subsequently, the learner adjusts their shooting technique based on this feedback, making refinements to factors such as the angle and force applied to the ball. Recall and recognition are regarded as key elements of motor skill learning and transfer and may be developed with experience and practice (Schmidt, 2003).

In the schema theory (Schmidt, 1975), motor skill learning, and transfer may be facilitated with random practice rather than blocked practice. Variable practice expands the range of associations that constitute the rule for selecting parameters (i.e., recall schema). This process, in turn, increases the efficiency of the rule for selecting parameters, particularly in transfer situations in which novel parameters are required. In other words, with the help of variability in movements, schemata are formed and strengthened (Merbah & Meulemans, 2011). The suggestion would be to practise with random order in motor movements, which would require individuals to constantly adjust their motor program with each trial. In contrast, blocked practice of the same movement reinforces a specific motor program without promoting adaptability to changing conditions. The argument is that random practice with different movement encourages a more dynamic, adaptable motor learning process compared to the blocked practice of a singular movement (Lee, 1988).

In existing literature, different studies have investigated random versus blocked practice effects on motor skill learning (Shea & Morgan, 1979; Lee & Magill, 1983; Magill & Hall, 1990; Raviv, et al., 2022). Typically, these investigations compare two primary learning conditions, namely the high-variability condition and the low-variability condition. Under the high-variability condition, motor skill tasks are executed following a random practice schedule, introducing variability and unpredictability in the sequencing of trials. In contrast, the low-variability condition involves a blocked practice schedule, where motor skill tasks are performed in a consistent and repetitive sequence. The results of these studies generally reveal that, although the random practice condition results in lower performance during the acquisition phase compared to the blocked practice condition, it leads to superior performance in retention or transfer (Merbah & Meulemans, 2011). This phenomenon is commonly referred to as the "contextual interference effect” (Battig, 1972).

In motor learning literature, the contextual interference effect (CI) on motor learning and transfer via random practice schedule is explained with other theories as. Many researchers (Shea & Morgan,1979; Shea & Zimny, 1983) have claimed that engaging in more elaborate cognitive processing during skill acquisition contributes to the more effective retention and transfer of motor skills (i.e., ‘elaboration hypothesis’; Shea & Zimny, 1983). This engagement allows individuals to identify similarities and differences between movements and provide a more effective memorial representation (Brady, 2008). Given the nature of random practice, participants are required to switch tasks in every trial, providing them with the opportunity to identify similarities and differences among tasks. In contrast, participants followed a blocked schedule engage in just one task during the trials. Consequently, the random practice schedule promotes superior motor skill learning and transfer than a blocked practice schedule (Shea & Morgan, 1979; Shea & Zimny,1983).

Another explanation for CI in motor learning and transfer via random practices was developed by Lee and Magill (1985). Random practice condition requires more effortful processing on each trial because information related to the action plan developed for each individual trial may be forget following the practice of different movements ('action-plan reconstruction hypothesis'; see Cross, Schmitt, & Grafton, 2007). Therefore, in a random practice schedule, participants must reconstruct the action plan before performing the upcoming movement. On the other hand, during the blocked practice schedule, since the upcoming movement is not by chance, the same action plan is used, which minimises reconstructing the action plan. The act of reconstructing the action plan at each trial enhances a learner's capability to generate suitable responses when faced with a new transfer task. In other words, the performance of this transfer task benefits from a learner's adeptness to creating or reconstructing new action plans (Lee & Magill, 1985).

In the literature, although the impact of CI effect via the random practice schedule on motor learning and transfer has been expounded by various theories (Schmidt 1975; Shea & Morgan,1979; Lee & Magill,1985), and numerous studies have consistently affirmed the existence of this effect, some researchers have claimed that the random practice schedule cannot be applied in every context and for all types of participants (Brady, 2008; Merbah & Meulemans, 2011). One of the most important reasons for this limitation is that, compared to blocked practice schedule, random practice schedule is required superior cognitive processing, and it could overload the participant's cognitive system and cancel out the benefit of the random practice schedule (Merbah & Meulemans, 2011). It has been proposed that combination of practice schedules (i.e., blocked practice schedule followed random practice schedule) would be helpful. In this combination, using a blocked practice schedule in the initial phases of motor skill learning could alleviate cognitive load. Subsequently, transitioning to a random practice schedule could enhance motor skill learning and transfer (Brady, 2008 ; Merbah & Meulemans, 2011).

Combined Effects of Practice Schedule on Motor Learning and Transfer Skills: Blocked Followed Random Practice Schedule

In terms of understanding the combined effects of two practice schedules, Lai et al. (2000) conducted an experiment. 40 neurotypical undergraduate participants were randomly assigned to an acquisition condition (i.e., blocked/blocked, blocked/random, random/blocked, random/random). During the experiment, participants were asked press four keys (i.e., 2, 4, 6, 8) on the computer keyboard using their right-hand index finger. Dependent variables were relative timing and absolute timing. Absolute timing represented overall task duration, and relative timing represented coordination and sequencing of components within a movement. Participants completed tasks based on their condition in two phases of acquisition. Participants in the blocked-random schedule condition received blocked practice during the initial half of the acquisition phase and random practice during the latter half. Conversely, participants in the random-blocked schedule condition received random practice in the first half of the acquisition phase and blocked practice during the latter half. Participants completed 108 trials (six blocks of 18 trials) during the acquisition phases. After 24 hours, participants completed a retention and transfer phase with a novel version of the task used during the acquisition phase. The study results show that participants in blocked/random condition show superior performance in acquisition, retention, and transfer than participants in random/blocked condition.

The study results indicate the advantages of using a blocked practice schedule in the early stages of motor skill learning. Providing a blocked practice schedule to participants before the random practices schedule improved their motor skill learning in the acquisition phase. The improved performance observed in the acquisition of new motor skills through the blocked practice schedule is attributed to the use of a greater amount of afferent and efferent sensorimotor information during blocked trials. Afferent information encompasses data transmitted from sensory receptors across various body parts to the central nervous system (i.e., spinal cord) via afferent neurons. On the other hand, efferent information comprises data conveyed from the central nervous system to muscles through efferent neurons (Magill & Anderson, 2010). Throughout and following the execution of motor skills, efferent and afferent information undergo integration and processing, facilitated by feedforward and feedback control mechanisms, supporting the encoding of motor learning (Wolpert et al., 2011). Over repeated trials with blocked practice, based on these efferent and afferent information, an action-representation is developed for specific motor skill and used for each trial. Consequently, motor skills become similar to the observed biological motion characteristics (Foster at al., 2020).

A random practice schedule requires increased cognitive processing, which could potentially overwhelm the participants' cognitive system. This overload may decrease the benefits of a random practice schedule on motor skill learning and transfer. However, as suggested in Lai et al. (2000), introducing the random practice schedule after a blocked practice schedule may eliminate this potential issue.

Conclusion

Results from several studies (Vernazza-Martin et al., 2005; Fort et al., 2011; Fulceri et al., 2015; Craig et al., 2018) consistently show that young autistic children frequently experience difficulties and/or differences in motor skills. These challenges significantly affect their developmental skills, including social-communication, language, and daily life skills (Jasmin et al., 2009; LeBarton & Landa, 2019; Craig et al., 2021). Recognizing the importance of motor skills for autistic children, early interventions aimed at supporting their motor skills are crucial (Lloyd et al., 2013). However, motor skill difficulties and/or differences are not identified as primary diagnostic criteria in the DSM-V. As a result, the focus of current early intervention programs primarily revolves around the main diagnostic criteria of autism, such as social communication, language, and repetitive behaviors. This has led to a limited number of early intervention programs targeting motor skills for young autistic children, highlighting a significant gap in the literature. Addressing this gap, this PhD research was centered on developing an early intervention program to support the motor skills of young autistic children.

As it mentioned before, there are limited motor skill interventions designed to support young autistic children, and these programmes are predominantly offered in community settings such as schools and childcare centers, often by professionals like teachers and therapists. The prevalence of school-based motor skill interventions may be attributed to international policymakers (e.g., Department for Education, 2013; Ontario Ministry of Education, 2015; Society of Health and Physical Educators America, 2016; Youth Sport Trust, 2013) emphasizing the importance of physical activity, and their efforts to promote physical activities and interventions within school environments (e.g., Public Health England, 2020). While schools have many advantages for physical activities [(i.e., fundamental motor skills (e.g., jumping, kicking, or throwing)] suitable places like gardens, or equipment like trampolines, around the world many children cannot access early interventions in schools or special education centres (Lee & Meadan, 2021). In this point, home-based, parent-mediated interventions become crucial as they are more accessible for both children and parents (Leaf et al., 2018). Recognizing the gap in home-based, parent-mediated motor skill interventions for young autistic children, this PhD research focused on developing a home-based, parent-mediated intervention to support motor skills of young autistic children.

In this study, the motor skill task chosen to support young autistic children's motor skills at home through their parents was "handwriting." Handwriting is a crucial fine motor skill that plays a significant role in children's future reading abilities, academic success, and social communication skills (Kushki et al., 2011; McCarroll & Fletcher, 2017). Because of the importance of handwriting and its impact on various developmental areas, this study employed handwriting tasks to enhance young autistic children's motor skills. Moreover, as handwriting is an activity familiar to both children and parents, it lends itself well to home-based, parent-mediated interventions. This familiarity was another important factor in selecting handwriting as the task for the AiMS intervention to support young autistic children's motor skills.

The process of motor skill learning is inherently intricate (Magill & Anderson, 2010). Augmented information, such as the knowledge of results and practice including performing physical movements, or observing movements, facilitates motor skill learning. Two predominant types of practices employed in supporting motor skill learning are blocked and random. Established motor skill learning theories (Schmidt, 1975) and existing literature (Shea & Morgan, 1979) have asserted that, while blocked practice enhances motor skill acquisition, random practice fosters superior retention and transfer of motor skills. In this PhD, to use the advantages of both practice types, an AiMS program was developed based on a combination of practice schedules to support young autistic children's motor skills.

Chapter 2: Literature Review

Motor Skill Difficulties and/or Differences in Autism

Autism is mainly characterized by difficulties in social interaction and social communication, repetitive behaviour, limited interests, and hyper- or hypo-reactivity to sensory inputs (DSM-V; American Psychiatric Association, 2013). Even though motor skill difficulties and/or differences are not explicitly outlined in DSM V diagnostic criteria, these difficulties and/or differences among autistic individuals have been specified since the earliest definition by Kanner (1943). In his definition of autism, Leo Kanner highlighted differences and/or difficulties in autistic individuals' motor skills, such as a clumsy gait or challenges in gross motor performance. Kanner (1943) also reported that parents of autistic children observed that their children could not adjust their body posture in preparation for being picked up, even at 2 or 3 years old (in general, infants aged between 2 to 3 months can prepare their body postures to be picked up). Research in the field of autism, particularly in the last 30 years, have consistently affirmed the findings of Kanner's 1943 study, demonstrating motor skill differences and/or difficulties in autism (e.g., Vernazza-Martin er al., 2005; Lloyd et al., 2013; Libertus et al, 2014; LeBarton & Landa, 2019). The results of these studies have showed that motor skill difficulties and/or differences observed in autism emerge in early childhood, even before core difficulties (e.g., social communication, or social interaction) (Teitelbaum et al., 1998; LeBarton & Landa, 2019). Therefore, it has been suggested that motor skill difficulties and/or differences could be considered as the early signs of autism, aiding in the early diagnosis (Posar & Visconti, 2022).

Early Signs of Autism: Motor Skill Difficulties and/or Differences

Autism is commonly diagnosed around the age of approximately 4 years, since around these age children begin engaging in social environments. If their social communication skills (e.g., limited facial expressions) or behavioral patterns (e.g., repetitive behaviors) do not align with the expectations of social, educational, or other critical life stages, they are deemed likelihood for developing autism (Brett, et al., 2016; Baio et al., 2018). The problem is that observing these social and behavioral patterns during infancy is quite difficult (i.e., 4 – 6 months). In the early stages of life, children's movements are readily observable (Teitelbaum et al., 1998). Therefore, researchers have directed their focus to the early motor skills of autistic children (or those at risk), aiming to diagnose autism before the age of ~4 (Teitelbaum et al., 1998; Baranek, 1999; Teitelbaum et al., 2004; Landa et al., 2006; Ozonoff et al., 2011; Flanagan et al., 2012; Miller et al., 2021). For example, Teitelbaum et al. (1998) compared autistic (n=17) and non-autistic infants (n=15) (aged between 0 and 3 years) motor skills including patterns of lying (prone and supine), righting from their back to their stomach, sitting, crawling, standing, and walking based on their video records. Researcher took video of non-autistic infant's and requested parents of autistic children to send videos records capturing their children's early infancy experiences. Their results have been demonstrated those autistic children, during their infancy term showed difficulties and/or differences in righting, crawling, standing, and walking. The researcher asserted that motor skill difficulties and/or differences could serve as indicators for diagnosing of autism within the initial months of life. In another study (Baranek, 1999), motor skill differences were investigated in three groups of infants: autistic infants, infants with developmental disabilities, and neurotypically developing infants. For the study, parents were asked to send videos capturing their children's early infancy experiences (i.e., before the age of 2). The researchers analysed video records for the 9-12 months infancy period for all three groups of children. The study's findings revealed that infants later diagnosed with autism exhibited unusual postures, atypical orienting, and object-directed behaviors in the 9-12 months infancy period. Researchers proposed that early assessment procedures of autism should encompass sensory processing and sensory-motor functions, in addition to social responses during infancy.

In order to diagnose autism in the early years, studies in the field (e.g., Zwaigenbaum et al., 2005; Landa & Garrett-Mayer, 2006; Ozonoff et al., 2010; Libertus & Landa, 2014) have concentrated on the baby siblings of autistic individuals during early infancy, because it is known that these siblings are observed to have a higher likelihood of being diagnosed with autism (i.e. ~18.7%) compared to the general population (Ozonoff et al., 2011). For example, Landa & Garrett-Mayer, (2006) examined infants' siblings of autistic children (i.e., high risk group) (n=60) and infants who do not have any autism family history (i.e., low risk group) (n=27). Motor skills of participants in both high risk and low risk group assessed using the Mullen Scales of Early Learning (MSEL) at target ages 6, 14,and 24 months. The results of the study indicated that there were no statistically significant differences at 6 months between the groups. However, at 14 and 24 months, siblings of autistic children exhibited poorer performance in both gross (for 14 months M=47.46, SD:12.36; for 24 months p<0.001 M=36.21, SD=9.31 p<0.001) and fine motor skills (for 14 months M=50.52, SD=10.21, p=0.08; for 24 months M=36.71, SD=14.32, p=0.08) compared to the other groups' gross motor (for 14 months M=58.00, SD:10.48; for 24 months M=51.94, SD=11.02) and fine motor (for 14 months M=57.38, SD:7.35, p=0.08; for

24 months *M*=52.58, *SD*=11.07, *p*=0.08) skills. Moreover, the developmental trajectory of siblings of autistic children progressed at a slower rate than that of the other groups and demonstrated a significant decrease in development between the first and second birthdays. Researchers have indicated that motor skills might be crucial for at-risk infants and emphasized the need for further investigation.

Another longitudinal study was conducted by Libertus and colleagues (2014) to investigate the early motor development of infants at high family risk for autism, as well as low-risk infants without any family history of autism. The study comprised two experiments. In the initial experiment, fine motor skills (i.e., grasping skills and object manipulation skills) of 6-month-old infants at high risk for autism (n=107) and low-risk infants (n=22) were assessed using the MSEL tool. Additionally, the researchers observed the grasping skills of these infants during a naturalistic free-play task, providing them with the opportunity to independently explore objects. The first experiment's results showed that participants in high-risk group's fine motor skills (*M*=48.83, *SD*:8.65) significantly lower than participants in low-risk group's fine motor skills (*M*=54.53, *SD*:9.74). Four months later, some of the same infants participated in the second experiment. In this phase, 10-month-old infants at high risk for autism (*n* = 23) and low-risk infants (*n* = 19) were assessed using the same methods employed in the initial experiment. The second experiment's results showed that participants in high-risk group's fine motor skills (*M* = 3.39, *SD* = 1.53) significantly lower than participants in low-risk group's fine motor skills (*M* = 4.79, *SD* = 1.72). In addition, infants in high-risk group displayed less grasping duration time (*M*=63.86, *SD* = 1.53) in a naturalistic free-play context compared to infants with a low risk for autism (*M*=83.76, *SD*:20.85). Libertus and colleagues (2014) claimed that difficulties and /or differences in object manipulation -related motor skills in early infancy might be an indicator of autism.

As indicated above, many studies have been confirmed that motor skill difficulties and/or differences observe in autistic children in the early year's life even before core features of autism. In this point, some researchers have raised questions about whether the motor skill differences observed in the infants who are later diagnosed with autism are more indicative of delays rather than a significant difficulty and/or differences in autism (Ozonoff et al., 2008). In another word, do motor skill difficulties and/or differences disappear as autistic infants grow? Studies results' have shown that these difficulties and/or differences persists through childhood, adolescence, and adulthood (Glazebrook et al., 2008; Nazarali et al., 2009; Travers, et al., 2013; Lyod et al., 2014). Since this PhD targeted to support young autistic children's motor skill, motor skill difficulties of young autistic children in pre-school age (i.e., aged between 3 – 6), in the following section, young autistic children's motor skill difficulties and/or differences were discussed.

Motor Skill Difficulties and/or Differences in Young Autistic Children in Pre-school Age

Motor skill difficulties and/or differences of preschool autistic children's have been investigated by many researchers (e.g., Vernazza-Martin et al., 2005; Fort et al., 2011; Fulceri et al., 2015; Craig et al., 2018; Craig et al., 2021; Chua et al., 2022). For example, Ming and colleagues (2007) conducted a study investigating the prevalence of motor difficulties and/or differences in autism. The research involved an examination of clinical records of 154 autistic individuals, including 81 young autistic children aged between 2 and 6. The results revealed that young autistic children aged between 2 and 6 had motor skill difficulties and/or difference in many areas like hypotonia (63%), apraxia (41%), toe-walking (19%), and gross motor delay (9%). Another study was conducted by Fulceri et al. (2015) to explore locomotion (i.e., a type of gross motor skills) and grasping (i.e., a type of fine motor skills) difficulties and/or differences in young autistic children aged between 30 – 60 months (*n* = 35). They assessed children's skills by using The Peabody Developmental Motor Scales, Second Edition (PDMS- 2), and results revealed that young autistic children's showed substantial impairments in locomotion (*M*=5.14, *SD*:1.11) and grasping skills (*M* = 4.26, *SD*:2.28). Based on PDMS- 2 scoring criteria, their locomotion and grasping skills categorised as "poor," and it indicated that their performance in these areas falls below the expected developmental level for their age group. The researcher recommended assessing motor skills in preschool-aged children and providing support for any motor skill difficulties or differences identified.

Many studies in the literature examined relationship between motor skill difficulties and/or differences in young autistic children and their other skills such as language skill, social skills, or daily living skills (Jasmin et al., 2009; Craig et al., 2021). For example, Jasmin and colleagues (2009) investigated motor skills of young autistic children and their impacts on daily living skills. In the study, they assessed motor skills of 35 young autistic children aged between 3 and 4 by using PDMS- 2, and their daily living skills by using The Functional Independence Measure for children and the Survey Interview Form of the Vineland Adaptive Behavior Scales—Second Edition (VABS-2). The study results indicated that young autistic children showed very poor performance in both gross motor and fine motor skill. Sixty-three (63%) percent of them had a significant gross motor skill delay, 53% a fine motor skill delay, and 57% an overall motor skill delay. Similarly, they showed poor performance in daily living skills, and forty- nine percent (49%) of them scored 2 SD below the mean. The corelation results between motor skills and daily living skills revealed that, young autistic children's fine motor skill score, and total motor composite score of the PDMS-2, as well as the motor skills score of the VABS-2 were significantly correlated with daily living skills. In the study, autistic traits were not used as a covariate. The study results showed that motor skills have an important impact on daily living skills, researchers, therefore, recommended develop early interventions to support the development of motor skills of young autistic children.

In another study, Craig et al. (2021) examined motor skills and social communication skills of young autistic children aged between 3 and 6 in comparison to their non-autistic counterparts. The research involved the assessment of motor skills and social skills in both young autistic (*n* = 43) and non-autistic (*n* = 30) children using the Movement Assessment Battery for Children-Second Edition (MABC-2), the Autism Diagnostic Observation Schedule-Second Version (ADOS-2), and the Psychoeducational Profile-Third Edition (PP-3). The study's results indicated that young autistic children demonstrated poor performance in MABC-2 manual dexterity (*M* = 3.06, *SD*=1.8) and aiming and catching tasks (*M* = 4.2, *SD* = 2.7) in contrast to their non-autistic counterparts' manual dexterity (*M* = 5.5, *SD* = 2.3) and aiming and catching tasks (*M* = 7.9, *SD* = 3.1). Furthermore, the results indicated a correlation between the motor skill difficulties and/or differences observed in autistic children and their compromised social communication skills. Craig and colleagues (2021) proposed that stratifying autistic children with according to their motor and social endophenotypes could offer valuable insights into the neurobiological basis of autism, and with this novel approach may also pave the way for novel intervention strategies tailored to specific subgroups within autism.

As indicated above, many studies' results confirmed motor skill difficulties and/or differences in young autistic children by using standardized measurement tools such as MAB-C, VABS, or PDMS. The use of standardized measurement tools comes with several advantages, such as the provision of meaningful data, ease of implementation with children (often based on observation), and efficiency in terms of cost and time (Gullo, 2005; Downs & Strand, 2006). Despite their widespread utilization, Gowen & Hamilton (2014) highlighted inability of these tools to offer detailed insights into the underlying motor control processes (see in Chapter 1: Introduction, Motor Control) that influence the acquisition of motor skills. To attain a more comprehensive understanding of motor skill difficulties and/or differences in young autistic children, it is recommended to employ advanced methods such as motion capture cameras or tablets during the assessment (Gowen & Hamilton 2014). In the literature, studies (e.g., Vernazza-Martin et al., 2005; Fort et al., 2011; Dowd et al., 2012; Chua et al., 2022) used these advance techniques to assess young autistic children's motor skill difficulties and/or differences. For example, Vernazza-Martin et al. (2005) investigated postural anticipation and multi-joint coordination during locomotion in autistic children (*n* = 9) and non-autistic children (*n* = 6) aged between 4 and 5 by using motion capture technology. During the study, cameras were positioned to ensure comprehensive coverage of children walking, capturing their movements. The task involved children walking to a playhouse and go to the inside of the playhouse situated approximately 5 meters from their initial position. Children were instructed with the request, "Would you please go to the door of the playhouse?". The data showed that approximately 80% of autistic children aged between 4-6 years did not plan the task accurately because they failed to pass through an open door (i.e., the task goal) because either they stopped mid-locomotion, or they executed the wrong trajectory path towards the door. It indicated that in young autistic children during locomotion, the primary components impacted are not necessarily posture or coordination control. Vernazza-Martin and colleagues (2005) suggested a potential impairment in movement planning as the underlying factor influencing these aspects of locomotion in autistic children.

In another study (Forti et al., 2011), researchers examined kinematic markers which are movement time, and velocity in young autistic children aged ~ 3.5 years (*n* = 12) by using a reach and drop task. This group's performance was compared with their non-autistic peers' performance (*n* = 12). The experimental task involved transporting a rubber ball from a support positioned on the table, to a hole into which the ball was to be dropped. The experiment set up on the table, and participants sat on front of the table. Each participants performed blocked 10 trials. Participants' performances were recorded by motion capture cameras. Results revelated that autistic children' MT, nearly twice as long as compared to non-autistic children's *(M* = 1495 ms vs. *M* = 813 ms), but for task accuracy, there were no significant differences between groups ($p > 0.05$). In terms of velocity, there were no significant differences between groups during the initial movement, but in the second phase of the movement (i.e., when the hand was surmounting the box) autistic children showed significantly higher velocity than other group (*M* = 14.2 vs. *M* = 7.8, $p < 0.01$). Additionally, sub movement analysis revealed that during the task, all autistic children actuated corrections at least once, but among non-autistic children, only 5 participants actuated corrections. Researchers claimed that motor difficulties and/or differences in young autistic children could be attributed to either a disruption in motor planning- motor control integration or problems in the planning process.

In the literature many study's results showed that young autistic children show motor skill difficulties and/or differences in motor skills such as fine motor skills (e.g., grasping, or manual dexterity task), gross motor skills (e.g., walking, catching, or throwing), and motor planning. These difficulties and/or differences affect their social skills, daily living skill, and academic skills (Jasmin et al., 2009; Craig et al., 2021; Escolano-Pérez et al., 2020). One of the most important academic skills that autistic children's motor skills difficulties and/or differences might affects is handwriting (Beversdorf et al., 2001; Myles et al., 2003; Johnson et al., 2013; Rosenblum et al., 2016)

A reflection of Motor Skills: Handwriting

Effective gross and fine motor skills are essential for human life because when people sit, walk, throw a baseball, play the piano, dance, or write, they are engaged in the performance of a type of motor skills (Magill & Anderson, 2010). Even in a pre-school classroom setting, research has suggested that children spend a significant portion of the school day (36%–66%) performing a variety of activities that need to performance motor skills, such as eating breakfast, playing with Legos, colouring, and handwriting (Ohl et al., 2013). Handwriting is more than a simple activity, it has an important impact on social and communicative development, building self-esteem, and academic achievement (Kushki et.al., 2011; McCarroll & Fletcher, 2017). Although it is mainly regarded as necessary skill for school aged children, handwriting skills are significant during the pre-school years (Dinehart, 2015). For example, young children's handwriting skills at the end of preschool are linked to early and long-term literacy skills success (Levin et al., 1996; Bindman et al., 2014). Literacy skills are defined as all skills needed for writing and reading and handwriting is one of the important parts of early literacy skills during the pre-school years (Street, 2003). Researchers have suggested that handwriting activities during the early years have an important impact on children's reading skills (Longcamp et al., 2005; James & Engelhardt, 2012; Kiefer et al., 2015). For instance, Longcamp and colleagues (2005) investigated impact of writing practices (typing, or handwriting) on reading performance (letter recognition) of 38 young children aged between 3 and 5. During the research, firstly, children's letter knowledge was measured with a pre-test. In pre-test, twelve letters (B, C, D, E, F, G, J, L, N, P, R, Z) were to be learned during the training were presented on computer screen. There were 4 options (1 correct, 3 distractors) for each letter, and children were asked to index finger the right option. After pre-test, children mainly divided into two groups (handwriting and typing), and each group was separated three groups based on age (younger, middle, older). 3 weeks training were conducted based on group types (handwriting and typing), and end of the training, the same test was performed before training sessions. Based on children's correct response in pre and post-tests, they founded that handwriting training provided better letter recognition than the typing training for young children, especially for older children aged between 4 and 5.

Another study for impact of two modes of writing (handwriting, and typing) on letter recognition, reading and writing performance of young children was conducted by Kiefer et al. (2015). The researcher investigated handwriting and typing impact on reading of 23 neurotypical young children aged between 4 and 5. During the research, children were separated into two training conditions handwriting and typing. Based on their training condition, they received training to learn eight letters of the German alphabet (L, I, O, A, M, S, T, and E) over four weeks (four days in a week, 25 minutes in a session). During the research children's letter-recognition and letter-naming skills were measured before and after training. Letter-recognition skills were measured with the task that ask children to select the right letter among the distractors for eight letters were to be learned during the training. To measure the letter naming skills of children, 26 letters were shown to children and asked them to say letter names when they see a familiar letter. Children's word reading, letter writing, free letter writing, and word writing skills were only assessed after the training session. In order to assess word reading skills, children received three words (OMI, TAL, and TEAS) based on the trained letters, and were asked to read words. For letter writing skill assessment, the trained letters were read to children and were asked to write letters based on their training condition (handwriting or typing). A similar process was followed for assessing word writing, the four words (LILI, OLİ, SALAMI, and TASTE) based on the trained letters were read to children and were asked to write words based on their training condition (handwriting or typing). The study's results indicated that typing group did not show any superior performance compared with the handwriting group in all tasks, but the handwriting group showed better performance in the word writing tasks (p = 0.048, d = 0.76), and, as a tendency, in word reading.

Besides the literacy skills, difficulties in handwriting can area create a barrier to developing other areas such as, self-esteem, classroom participation, and development of social and communication skills (Fuentes et al., 2009). For example, Enstrom, (1965) claimed that poor writing skills put students at a disadvantage in position because these difficulties negatively affect their creative efforts and assignment performance. In this point, autistic individuals may regarded as a disadvantage in position, because studies results indicated that, they showed handwriting difficulties (Beversdorf et al., 2001; Myles et al., 2003; Johnson et al., 2013; Rosenblum et al., 2016).

Handwriting Difficulties in Autism

Handwriting difficulties are a significant challenge for autistic children and individuals (Grace et al., 2017). Research indicates that they often struggle with various attributes such as spacing, alignment, letter formation, variability in letter movements, letter size, legibility, and handwriting speed (Beversdorf et al., 2001; Myles et al., 2003; Johnson et al., 2013; Rosenblum et al., 2016). Traditionally, handwriting studies have focused on school-aged children (e.g., Beversdorf et al., 2001; Johnson et al., 2013; Grace et al., 2018), likely because traditionally handwriting is regarded as an important skill for this age group. However, recent research highlights the importance of handwriting during the preschool period (Dinehart, 2015). Moreover, handwriting (i.e., letter writing) is now included in preschool curricula as a skill to be developed early on [(see "Development Matters Non-statutory curriculum guidance for the early years foundation stage," DfE, 2021)]. Reflecting these developments, recent studies have started to focus on handwriting skills of autistic preschool children. For example, Yamaguchi et al. (2019) compared the handwriting movement trajectory of young autistic children by using "line drawing task". The researchers worked with 17 young autistic and non-autistic children aged between 4 and 6. During the task, two parallel lines conditions (2cm apart in the easy condition and 2mm apart in the difficult condition) were presented to participants. The participants drew a line between the parallel lines [(6 trials in the easy condition (the parallel lines were 2cm apart), 6 trials in the difficult condition (the parallel lines were 2mm apart) by using a pen-type writing pressure gauge. The study results indicated that young autistic children showed significant (p = 0.01) deviation in the difficult condition compared to non-autistic children. The researcher claimed that this deviation reflected poorer motor coordination of autistic children compared to their non-autistic peers, and the larger deviation in autistic children may be related to impaired sensorimotor coordination, especially visuo-motor coordination.

Similar to other motor skill differences and/or difficulties, handwriting differences and/or difficulties persist through childhood, adolescence, and adulthood (Beversdorf et al., 2001; Fuentes et al., 2010; Godde et al., 2018; Li-Tsang et al., 2018). Recognizing the importance of early intervention, addressing handwriting difficulties in the early years provide crucial support that may alleviate future challenges, thereby better preparing autistic children for the demands of school. However, as mentioned earlier, handwriting studies for young autistic children are limited. Therefore, to gain a comprehensive understanding of the specific types of handwriting difficulties that autistic children have, this section also reviews the relevant literature for older autistic children.

The movement trajectory for letter writing has an important impact handwriting quality. Studies have been reported that autistic children are unable to control and regulate their handwriting (Johnson et al. 2013; Grace et al., 2018; Yamaguchi et al., 2019). For instance, Grace et al. (2018) to compare the handwriting movement trajectory of 23 autistic and 20 non-autistic children aged between 8 to 12 years. Participants wrote five cursive letter sequencing conditions (1. eeee, 2. eeel, 3. eeem, 4. elel, 5. emem) on a back-lit, touchscreen, WACOM graphics tablet that can record handwriting movements. The study results indicated that even at a basic level, autistic children showed a breakdown in their ability to control and regulate their handwriting movements. During the tasks, autistic children show greater neuromotor noise. Neuromotor noise is the natural noise within the muscular system and the degree of energy required to produce an overall movement, and greater neuromotor noise indicates atypical visuomotor control. Poor movement planning and recruitment of muscles are reflected as an increase in neuromotor noise. According to researchers, the findings also suggest that poor control of handwriting movements may arise from inhibitory control difficulties in autism.

Letter formation is another important aspect of handwriting, and studies results showed that autistic children show difficulties in this area. In terms of letter formation, Fuentes et al. (2009) examined handwriting samples of 14 autistic and 14 non-autistic children aged between 8 and 13 by using the Minnesota Handwriting Assessment. The researchers also assessed children motor skills with Revised Physical and Neurological Examination for Subtle (Motor) Signs (PANESS). The PANESS consists of several categories, including stressed gaits, balance, and timed movements. Timed movement tasks include repetitive movements (hand patting, finger tapping, foot tapping), and they were specifically linked to handwriting performance. End of the study, they founded those autistic children showed the worst quality of forming letters than non-autistic children. According to researcher's motor skills (motor control) were significantly predictive of poor handwriting performance of autistic children. They suggested that focusing on letter formation training for autistic children may be the best way to improve their handwriting performance. The researcher Fuentes et al. (2010) was conducted similar study with older autistic (*n* = 12) and non-autistic (*n* = 12) children aged between 12 and 16 by using the Minnesota Handwriting Assessment. Like the previous study with younger autistic children [(i.e., Fuentes et al. (2009)], older autistic children showed poorer handwriting quality relative to controls as well. Another study (Cartmill, Rodger & Ziviani, 2009) was also reported low quality of letter formation in autistic children. The study assessed letter formation of autistic (*n*=28) and non-autistic (*n*=28) children aged around 8 years. Researchers developed an "Alphabet to Dictation Test", and during the test children wrote 26 letters of alphabet in random order. These letters were then scored using a protocol based on the Minnesota Handwriting Assessment (Reisman, 1999), which including parameters of letter formation. End of the test, they found that the accuracy of letter formation of autistic children was significantly worse than non-autistic children (t = 3.53; df = 54; p = .001).

Letter size differences are the one of the common aspects of autistic children's handwriting (Beversdorf et al., 2001; Johnson et al., 2013). For example, Beversdorf et al. (2001) compared handwriting size between 10 autistic and 13 (age- and IQ-matched) non-autistic adults aged around 30 years. Participants wrote two upper case letters (C and S), and four lower case letters (t, f, o and a), and the vertical extent of each letter was measured by researchers. They found that autistic participants' handwriting letters were significantly larger (6.8 ± 1.9mm), than non-autistic participants (4.7 ± 1.0mm). The researchers claimed that these findings relate to the motor coordination difficulties of autistic individuals. Similar study was conducted by Johnson et al. (2013) with autistic children aged between 8-13. The researchers compared the size of handwriting letters of 26 autistic children and 17 non-autistic children. Participants wrote four times cursive "l" on a graphics tablet with a stylus. Their results showed that autistic children's' letters' sizes (approximately 14 cm) were significantly larger than non-autistic children's letter size (approximately 4 cm), and autistic children had variable movement trajectory. The researchers claimed that these difficulties can stem from the motor coordination and motor planning difficulties that are commonly observed in autism.

Speed is another important aspect of handwriting, and in general, studies (Rosenblum et al., 2016; Li-Tsang, et al., 2018) reported that autistic children's handwriting speed is lower than non-autistic children. For example, Rosenblum et al. (2016) compared to handwriting performance of autistic children (*n* = 30) and non-autistic (*n* = 30) children aged between 9 and 12 years old. All children performed 3 writing tasks (writing one's own name, paragraph copying and free-style writing) on an electronic tablet, which is part of a computerized handwriting evaluation system (ComPET). The study's results demonstrated that autistic children wrote slower than non-autistic children. Another study was conducted by Li-Tsang, et al. (2018) to compare the handwriting speed of 15 autistic and 174 non-autistic children aged between 12 and 18 by using "The Computerized Handwriting Speed Test System, Version 2 (CHSTS-2)". This test provided information handwriting speed (character per minutes) and SD of writing time per character. All participants copied 130 traditional Chinese characters and 120 English words (participants able to write Traditional Chinese and English) on the surface of a Wacom Intuos Pro L tablet using a wireless electronic pen as eligible and as quickly as possible. The study's results showed that autistic participants showed lower handwriting speed in both Chinese characters and English words compared to non-autistic participants.

Difficulties and /or differences in autistic children's handwriting (e.g., letter formation, movement trajectory, or speed) affects their handwriting qualities. For example, Grace et al. (2017) examined handwriting performance of 23 autistic and 29 non-autistic children aged between 8–12 years by using advanced descriptive measures (WACOM graphics tablet). During the handwriting experiment participants wrote five cursive letter sequencing conditions (1. eeee, 2. eeel, 3. eeem, 4. elel, 5. emem) on tablet. Autistic children demonstrated greater variability in in vertical and horizontal sizing of the letter. Also, autistic children’s peak velocity greater than typical children (U=105, z=−3.04, p=.002, r=−0.046). According to researchers it is lead to overall poor quality of handwriting. Similarly, Godde et al. (2018) conducted an experiment to understand handwriting quality of autistic individuals. They examined the handwriting performance of autistic (n = 21) and non-autistic (n = 21) adults aged between 18 -35. They asked participants to perform a copy paragraph task to assess handwriting quality. Researchers used the French adaptation of the Concise Evaluation Scale for Children’s Handwriting (BHK; Hamstra-Bletz & Blöte, 1993) to assess the handwriting quality and speed of all the participants. This scale consisted in copying out a text for five minutes or until the participant finishes writing the first five sentences. An overall score of handwriting quality was calculated on the basis of 13 criteria reflecting pathological morphokinetic and topokinetic aspects: large letter size, left margin widening, poor word alignment, insufficient word spacing, chaotic writing, irregularities in joining strokes, collision of letters, inconsistent letter size, incorrect relative height of letters, letter distortion, ambiguous letter forms, correction of letter forms, and unsteady writing. They found that the overall handwriting speed and handwriting quality of autistic adults were significantly poorer than non-autistic adults.

The literature for handwriting difficulties/differences in autistic children and individuals demonstrates that they have difficulties/differences in terms of important aspects of quality handwriting, such as letter formation, movement trajectory, or handwriting speed. Given the importance of having good handwriting skills(Graham et al., 1998; Ohl et al., 2013) as well as the high prevalence of handwriting difficulties in autistic children (Kushki et al., 2011; Verma & Lahiri, 2021), it is essential to develop the necessary early interventions to support them.

Early Interventions for Young Autistic Children

Early interventions serve as crucial support systems for children with special needs, or those at risk of developing such needs, along with their families. The primary objective of an early intervention is to maximise children's overall potential while offering support to parents in managing their children's special requirements (Baker & Feinfield, 2003). Early interventions are recommended as a priority for young autistic children, particularly during the early years when brain plasticity is heightened (Lord et al., 2020). Brain plasticity, defined as the neural processes involved in learning new skills through remembering, forgetting, reorganizing, and recovering (Johnston, 2004), is more pronounced in early childhood (Inguaggiato et al., 2017). This increased plasticity during early development suggests that implementing early interventions during this period may capitalize on children's rapid learning capacities (Inguaggiato et al., 2017). Research indicates that early intervention s during the preschool years yield long-term intellectual and academic benefits, potentially enhancing cognitive development and facilitating the transfer of cognitive-academic skills to future educational settings such as school (Campbell & Ramey, 1995; Ceci, 1991). In other words, early interventions in early years can better prepare children for their educational journey

In the literature, many different early interventions [(e.g., Early start Denver Model (ESDM), Treatment and Education of Autistic and Communication Handicapped Children (TEACHH), or Joint Attention Symbolic Play Engagement Regulation (JASPER)] were developed for young autistic children, with a common focus on addressing core difficulties associated with autism, such as communication, language, and repetitive behaviors (French & Kennedy, 2018). These interventions were designed to target specific areas of challenge to support the overall development and well-being of young autistic children and their parents. The findings of current systematic reviews and meta-analysis consistently indicate that early interventions exert a significant positive influence on various outcomes among autistic children, including language (Virués-Ortega, 2010; Hampton & Kaiser, 2016), adaptive behavior (Eldevik et al., 2010), and communication skills (Goldstein, 2002).

Existing Handwriting Interventions for Young Autistic Children

In the literature, early interventions were conducted to support handwriting skills of autistic children in pre -school term as well. For example, Moore et al., (2013) were conducted a study to teach an autistic child (5.5 years old) to write her name (Kiera) by using video modelling technique. The first video only showed how to produce the letter a, and the second video showed how to write "r" (new skill) and "a" (revision). Videos continued until depicted all letters of the name. Kiera was asked to write the letter five times in each session. All sessions were conducted in the child's house by professionals. The child writing was assessed based on the following criteria recognizable letters, (b) correct execution, (c) correct components, (d) all components in the correct place, and (e) correct size. At the end of the study, the child showed improvement in the task of writing the name including letter sequencing, alignment, and letter size.

Another study was done by Smith et al. (2013) to examine the effects of tracing and fading prompts to improve the legibility of two preschool students' writing of their names. One of the participants was autistic aged 4, other had developmental delay aged 5. The children's handwriting was scored based on the size of the letter, the slant of the lines or curves within appropriate letters, and the formation of the letter. During the task, the researcher drew each letter of each participant's name 24 times through 7-9 stages in which the prompts for the participants were faded. The first stage was the letter written with wide, solid lines. The next stage was the whole letter written with thin solid lines. The third stage was the use of wide dots, and the fourth stage was thin dots all to be connected by the participants. After the fourth stage, the number of dots to be connected were faded until the eighth or ninth stage, depending on the complexity of the letter. Next, the participant has presented a full sheet of blank line paper on which to write the letter. The first letter of every page, including the pages designated for the student to write the letter without prompts, had a model of how the final letter should look. All intervention sessions were conducted at school by professionals. The study’s result showed that each individual participant improved in their ability to write his or her name.

Another study for understanding the effectiveness of the tracing method on handwriting (name writing) was conducted by Cosby et al. (2009) with an autistic child aged 5.3 years. During the task session, the participant was given were given a Handwriting Without Tears® worksheet for the specified letters and the instructor used the verbal prompt. For example, specifically, for the letter L, the instructor verbally prompts, “Start at the top, big line down, little line across". Letters were scored based on the two criteria: size and legibility. After completing all letters of the name, the child was presented with the same sheet of paper used in the baseline for increased practice in tracing and coping from a model for each letter set. All intervention sessions were conducted at school by professionals. After the nine sessions the child increased the legibility of handwriting.

Existing Handwriting Interventions for Young Non-Autistic Children

In the literature, early interventions were also conducted to support handwriting skills of non-autistic children in pre -school term. For instance, Lust, & Donica (2011) was conducted an early intervention (i.e., Handwriting Without Tears–Get Set for School) with 32 neurotypical pre-school children aged between 4 and 5. Participants were place in intervention group (n = 17), and control group (n = 15). The intervention group attended sessions three times a week for 5 months, totalling 47 sessions, conducted in schools by professionals. The sessions included activities focused on body awareness skills, directional concepts, and letter-play. These activities progressed to colouring and tracing of capital letters and shapes. Before and after the intervention, participants' pre-writing skills were assessed using the Learning Accomplishment Profile. At the end of the study, the intervention group's pre-writing skills were significantly higher than those of the control group (p = 0.058).

Similarly, another study utilized the Handwriting Without Tears intervention program to support handwriting skills of 5 young children with developmental disabilities aged between 3 and 5 (Delegato et al., 2018). During the intervention, all participants attended 5 to 10 minutes sessions, 2 to 4 days a week across 6 weeks in school by guidance of professionals. In each session, 3 participants were working on tracing over five vertical lines of varying lengths, and 2 participants were working on writing the first four letters of their first and last names (i.e., E, L, H, N, C, R, I, S). Participants' handwriting performance was assessed using criteria developed by the researchers. Before the intervention, in pre-test, Participant 1 received handwriting scores ranging from 0 to 3 points with an average of 2 points, while Participant 2 earned no points. Participant 3's scores ranged from 4 to 8 points with an average of 6.2, and Participant 4 scored between 6 and 7 points, averaging 6.6 points.

Participant 5 received scores ranging from 0 to 1 point with an average of 0.375. After the intervention, Participant 2's scores improved to an average of 3.857 points, Participant 3's scores averaged 6 points, Participant 4's scores increased to an average of 9 points, and Participant 1's score improved to 4.0 points. Additionally, Participant 5's scores rose to an average of 4.166 points following the intervention.

In the literature some early intervention studies used tablet as a tool to support young children’s writing skills. For instance, Neumann (2018) conducted a tablet based handwriting intervention study with 48 neurotypical children aged between 2 and 5. In the study, children were located in iPad group (*n* = 24) and the waitlist control group (*n* = 24). Children in the iPad group received the iPad literacy intervention across 9-weeks, consisting of 30-minute sessions per week, focused on three new alphabet letters each week using three different apps: letter matching, letter tracing, and drawing. All intervention sessions were conducted in schools or special centre by professionals. Before and after the intervention, children's name writing skills and letter writing skills were evaluated. During the pre and post-tests, children were asked to write their name and each of the 26 alphabet letters. The children's name writing performance was scored on a 7-point scale as follows: 0 = no production, 1 = random scribbling, 2 = controlled scribbling (e.g., dots, lines), 3 = random letter-like forms (pseudo-letters), 4 = strings of non-phonetic conventional letters or the first letter of their name, 5 = some correct letters of their name, 6 = generally correct name writing, and 7 = name written and spelled correctly. Their letter writing performance was assessed using criteria based on Schickedanz & Casbergue’s (2009) examples of written letters. After completing the program, children in the iPad group demonstrated significantly greater knowledge of name writing (p = 0.003), then control group but there were no significant differences between the groups in letter writing skills (p = 0.08).

Existing Handwriting Interventions for Older Autistic and Non-Autistic Children

In the literature, early intervention studies were also conducted to support handwriting skills of older autistic children in primary school, or elementary school. For example, Lee (2015) was conducted an early intervention program (i.e., Here's How I Write) with a 7.3-year-old autistic child to support his handwriting. The intervention lasted 1 week, 3 sessions a week, and 40-minute per sessions in school. The program consisted of 24 writing intervention cards designed for the child to conduct a self-assessment and receive support from the teacher in setting personal goals and advancing learning. Initially, the child assessed himself/herself by selecting cards with either positive or negative statements on both sides. The self-assessment score for the autistic child was 56 out of 100, while the teacher's assessment scored 43. Using these scores, the child and the teacher identified three writing tasks (i.e., proper spacing between words, staying on the lines, and correctly copying words). For the first task (i.e., proper spacing between words) the number of proper spaces between words was assessed by dividing the number of positive responses by the total number of spaces and multiplying the resulting fraction by 100. For the second task (i.e., staying on the lines), the number of phonemes that fell within the designated line was divided by the total number of phonemes on the line. The resulting fraction was then multiplied by 100. For the third task (i.e., correctly copying words), the number of correctly copied phonemes was divided by the total number of phonemes and then multiplied by 100. After the program, the child demonstrated improvement in three skills: proper spacing between words improved from 2% to 99.8%, staying on the lines increased from 52.7% to 98.1%, and correct copying from 34.3% to 97.8%.

Another handwriting intervention (i.e., The Write Start Program) study was conducted by Case-Smith et al. (2011) with 1st grade neurotypical children (*n* = 19). The intervention lasted 12 weeks, with all children attending 45-minute sessions twice a week at their school, facilitated by professionals. In each session, the teachers and therapist first modelled letter formation and offered clear, consistent verbal cues for letter formation. Students then copied from the model and engaged in repeated practice. Subsequently, students were grouped in sets of 6 – 7 and rotated through stations that focused on complementary aspects of handwriting and writing. Throughout the sessions, teachers and therapists provided regular feedback, which included correcting errors, encouraging self-evaluation, and praising the students' efforts. Before and after the intervention, children's handwriting performance, including legibility and speed was assessed using the Evaluation of Children's Handwriting Test, Minnesota Handwriting Assessment, and Woodcock–Johnson Fluency and Writing Samples tests. By the end of the study, the students' legibility improved from a mean of 62% to 87%, indicating a change score of 25%. They also made significant improvements in handwriting speed, reducing the time needed to write the alphabet from over 3.0 minutes to 1.5 minutes.

Another study was conducted by Batchelder et al. (2009) with a 14-year-old autistic student to support her/him handwriting skill by using hand-over- hand and dot-to-dot tracing technique. During the 28 sessions of intervention, the participant did practice with one capital, two lover-case letters (i.e., T; e; y) in school. In each session, the researcher provided the student with three worksheets. Each worksheet featured four lines of dotted letters, with each line consisting of five letters. The participant's letter writing performance was assessed by two separate researchers both before and after the intervention, based on criteria set by the researchers. The results showed that the participant's ability to write the letters "T," "y," and "e" improved from 60% to 100%.

In the literature, some studies used “Computer-Assisted Techniques” to support children’s handwriting skills (e.g., Palsbo & Hood-Szivek 2012; Kim et al., 2013). For instance, Palsbo & Hood-Szivek (2012) conducted a study where they developed an assistive robot to guide participants' hands during handwriting tasks. This robot offered mechanical assistance, encouraging participants to learn active control over the movement of each letter. Researchers worked with neurotypical children (n = 6), autistic children (n = 5), children with ADHD (n = 2), pervasive developmental delay (n = 1), intellectual disability (n = 2), auditory processing disorder or deafness (n = 2). In the study, participants aged varied between 5 to 11. All participants received intervention sessions in their school, 3 to 5 times per week for 4 to 6 weeks, amounting to a total of 15 to 20 sessions per child. During the sessions, participants wrote letters and numbers with the help of assistive robot. Researchers conducted pre, post-test before and after the intervention, and they measured children’s handwriting speed, and size. Results showed that compared to pre-test, in post-test, 5 autistic participants increased handwriting speed and wrote letters and numbers in appropriate size.

Another study was conducted by Kim et al. (2013), and in the study, researcher used the "Haptics Assisted Training (HAT) System" to enhance handwriting skills. Within this system children needs to do handwriting on a screen, and the HAT system directs the participant’s hand through the sequence of strokes based on the reference handwriting recorded by an expert or teacher. In the study, Kim et al. (2013) worked with 10 children with learning disabilities, aged between 6 and 12, as well as in 10 neurotypical children of the same age range. They were divided into four groups, with five participants in each group, based on two main categories: by education type (typical and special) and by device type (FalconTM and OmniTM). Children using OmniTM experienced an exact spatial match between the visual display and the haptic workspace. In contrast, children using FalconTM had approximately half the size of the haptic device workspace mapped to the visual display. All participants underwent four intervention sessions in their school, over a two-week period. Each session was integrated into daily activities and lasted approximately twenty minutes. Before and after the intervention, the children's tracing precision was assessed by measuring 'closeness', which averaged the tracing error (distance in millimetres) against the provided expert's reference handwriting. The results indicated that while all children showed improvement over time and became more precise in handwriting (i.e., tracing), only the neurotypical children in the OmniTM group exhibited significant improvement ($p < 0.05$).

Discussion about Existing Handwriting Interventions

As explained above, in the literature, handwriting interventions were conducted to support handwriting skills of autistic or non- autistic children. While most of early interventions improve children's handwriting skills, they have some limitations. Firstly, their sample size, especially early intervention studies for autistic children is too small. Some early intervention studies' participants number are only consist of one or two autistic children (e.g., Batchelder et al., 2009; Moore et al., 2013; Smith et al., 2013). Such a small sample size significantly reduces the generalisability of early intervention's effect (Biau et al., 2008). Another important limitation for existing early intervention studies is lack of control group. In general, they worked with just one group of children, and all children access early interventions (e.g., Batchelder et al., 2009; Cosby, et al., 2009; Case-Smith et al., 2011; Donica, 2011; Moore et al., 2013; Smith et al., 2013; Lee, 2015). In a well-designed early intervention study, all variables apart from the early intervention should be kept constant between the two groups. This means researchers can correctly measure the entire effect of the treatment without any confounding variables (Allen, 2017).

Another significant finding from examination of existing handwriting intervention studies was that many have been conducted in schools by professionals, with limited interventions taking place at home (e.g., Moore et al., 2013). While school-based early interventions offer several advantages, such as a structured environment and the ability to reach more children in one session (Leaf et al., 2018), the results of studies indicate that many children cannot access schools or special centers to receive early interventions (Harrison et al., 2016; Lee & Meadan, 2021). Therefore, there was a need to develop home-based early interventions to support children's handwriting skills and address this gap in the literature.

Further, most early intervention studies focused on handwriting products by using marking scores scales or standardized measurement tools or criteria that they developed by researchers (e.g., Cosby, et al., 2009; Donica, 2011; Moore et al., 2013; Smith et al., 2013). But it is known that handwriting is an important motor skill and one of the most important aspects of handwriting difficulties of autistic children is related to the underlying mechanism of motor skills (e.g., planning, variability of movement trajectory, or low handwriting speed). Evaluation of these processes is possible with kinematic analysis, which quantifies how the movement changes (displacement, velocity, and acceleration) across the position and orientation of the body segments (Magill & Anderson, 2010). Kinematic analysis is based on recording the movement of specific body segments while the person is executing the skill. These recordings are performed by motion capture devices (e.g., a marking pen, special light-reflecting balls, light-emitting diodes (LEDs) (Arslan et al., 2019). To understand changes in underlying mechanism of motor skills in terms of handwriting, before and after the early intervention, children should evaluate with the kinematic analysis technique.

In summary, while there is literature on early intervention studies aimed at supporting autistic and non-autistic children, many of these studies have limitations such as small sample sizes or the absence of control groups. Furthermore, these studies often do not specifically address the motor aspect of handwriting difficulties observed in young autistic children. Therefore, it can be suggested that, supporting young autistic children's handwriting skills with an early intervention program that addresses the motor aspects influencing handwriting can address a significant gap in the literature.

How Autistic Children Handwriting Can be Supported with Motor Early Interventions?

As previously mentioned, handwriting is considered a fine motor skill, and motor skills difficulties and/or differences are identified as one of the main reasons for handwriting challenges in autistic individuals (Fuentes et al., 2009). Therefore, it can be claimed that handwriting difficulties of autistic children can support based on motor skill learning and or improvement principles. Motor skill learning is facilitated or improved by providing learners with augmented information (i.e., knowledge of results) and practice (i.e., performing physical movements; or observing movements). In terms of practice, it is known that practice specificity (i.e., blocked-practice and/or random-practice) has differential effects on motor learning and motor transfer (generality) performance (Battig, 1972; Shea & Morgan, 1979; Magill & Hall, 1990; Raviv, et al., 2022). A blocked-practice trial-order is structured so that a **Task A** (i.e., place a pencil in a cup) is performed across a consecutive number of practice trials before performing a different **Task B** (i.e., pick up a counting block) and a different **Task C** – therefore, a blocked-practice trial-order is typically structured as follows: **AAA, BBB, CCC**. Whereas random-practice requires the same three tasks to be practised but in an unpredictable trial-order - therefore, a random-practice trial-order is typically structured as follows: **ACBBCACBA**. Results from studies learning study (Shea & Morgan, 1979; Wulf & Lee, 1993; Sekiya et al., 1994) indicated that blocked-practice underpinned more accurate motor performance during a practice phase of acquiring a new set of motor skills than random-practice. The data however revealed that random-practice led to better motor performance during periods of retention and transfer, which indicated benefits in the generality of motor learning. In the literature this random practice's effects commonly named as a “Contextual Interference (CI)” effect (see in Chapter 1: Introduction).

In the literature, many laboratory studies have been investigated CI effect on motor skill learning and transfer (e.g., Shea and Morgan; 1979, Lee & Magill, 1983; Lee et al., 1992). Shea and Morgan (1979) conducted the first experiment to understand CI effect on new motor skill learning. During the experiment, they used the Barrier Knock-Down Task. In this task, participants were required to perform three distinct arm movements as quickly as possible as a response to a stimulus light: picking up a tennis ball, knocking over three movable wooden barriers, and returning the ball to a final location. The time between the onset of the stimulus light and the ball's arrival in its last location was the dependent variable. Researcher introduced two conditions by employing both a blocked practice schedule (i.e., low contextual interference), and a random practice schedule (i.e., high contextual interference). In the blocked schedule, participants practiced in consecutive trials for one movement pattern before transitioning to another, whereas in the random schedule, practice trials for each movement pattern were distributed randomly. The results indicated that during the acquisition phase, the blocked schedule group showed better performance than random schedule group, but in the retention phase, the random schedule group greatly outperformed the blocked practice group. Many subsequent studies employing the same paradigm consistently replicated these findings, confirming the existence of the CI (e.g., Lee & Magill, 1983; Lee et al., 1992; Wulf & Lee, 1993; Sekiya et al., 1994).

Many other laboratory studies have been confirmed CI effect on motor skill learning and transfer with the "Anticipating Timing Task" (e.g., Del Rey et al., 1987; Smith & Rudisill 1993; Overdorf et al., 2004). This task consists of two interconnected 16-lamp runways positioned on a table, with the participant situated in front of both runways and a response button. Participants are asked to press the response button when the last lamp on the runway illuminates. In the task, the magnitude and direction of each participant's error in predicting the light's 'arrival' at the end of the runway are the dependent variables. The variability of these errors is influenced by the speed of the light flashes (Merbah & Meulemans, 2011). Studies results that used the "Anticipating Timing Task" have demonstrated that despite participants in the random practice condition demonstrating poorer performance during the acquisition phase compared to those in the blocked practice condition, they exhibited superior performance on subsequent retention or transfer tests (e.g., Del Rey et al., 1987; Smith & Rudisill 1993; Overdorf et al., 2004).

In the literature, CI effect have been investigated by using real world situation such as training baseball, basketball player or handwriting (e.g., Hall et al., 1994; Ste-Marie et al., 2004; Memmert, 2006). In the study (Hall et al., 1994) 30 neurotypical participants randomly assigned to three groups (i.e., blocked group, random group, and control group). The random group (n=10), and blocked group (n =10) received batting- practice sessions two times as a week, across six weeks, whereas control group did not received any practice session. Practise sessions contained 15 fastballs, 15 curve- balls, and 15 change-up pitches. Random group did practice with these pitches with a random order while blocked group did practice 15 of one type, then 15 of the next type, and finally 15 of the last type of pitch based on a blocked practice order. No significant difference was found between blocked and random practice group during the acquisition phase, but the random group outperformed the blocked group during the transfer test. Retention test results revealed that, compare to pre-test, the random practice group improved their ball pitches skills 56.7%, the blocked practice group 24.8%, and the control group only 6.2%.

The research (Ste-Marie et al., 2004) confirmed the impact of CI effect on motor skill learning and transfer skills via handwriting for neurotypical ~ 6-year-old children through different experiments. First experiment consisted of 3 phases: an acquisition phase, an interpolated phase, and a retention test phase. Before starting the experiment, participants were removed from their classroom, and randomly assigned two groups which are blocked (n=22) and random (n=22). During the acquisition phase of the study, participants engaged in a total of 72 drawing trials.

These trials were distributed across three different symbols from English alphabet letters, with each symbol being practiced in 24 drawing trials. While in the blocked group, participants completed all 24 trials of a specific symbol consecutively, in the blocked group, participants completed all 72 trials of three symbols in a random order. Once the participants completed the 72 trials, they returned to their regular classroom setting, and the acquisition phase was completed. When they returned their classroom interpolated phase started. interpolated phase lasted 30 minutes, and during this phase all participants did regular classroom activities. A crucial aspect of this phase was that all participants engaged in cognitively demanding activities after completing the drawing trials. This intentional engagement aimed to prevent mental rehearsal of the preceding symbol handwriting task. After 30 minutes, participants came back to experiment area to participate retention phase of the study. In the retention phase, two acquisition groups, namely the blocked and random groups, underwent additional random subdivision, resulting in four retention groups: (1) blocked acquisition-blocked retention (2) blocked acquisition-random retention, (3) random acquisition-blocked retention, and (4) random acquisition-random retention. In the blocked retention trials groups, participants were instructed to handwrite each of the symbols three consecutive times. On the other hand, in the random retention groups, nine trials were conducted in an unsystematic order, with three repetitions of each symbol. The researchers evaluated participants' handwriting performance in acquisition and retention phases by using a point-scoring system specifically developed by them. Results revealed that the acquisition score of the blocked group was found to be higher (M = 2.42, SD = 0.95) in comparison to the random group (M = 2.26, SD = 0.86), but in retention phase, random group (M = 2.5) showed better performance than blocked group (M = ~2.3)

In the second experiment of the study conducted by Ste-Marie et al. (2004), a cohort of 48 young children, approximately 6 years old, participated. The researchers randomly assigned them to two groups: blocked (*n*=24) and random (*n*=24). In Experiment 2, the researcher followed similar steps to Experiment 1, with some exceptions. Firstly, children in Experiment 2 practiced with three lowercase alphabet letters (i.e., h, a, y), instead of different symbols. Secondly, a transfer test was added immediately following the retention test. During this transfer test, children were required to write three lowercase alphabet letters that were matching the form the letters h, a, and y. Additionally, in Experiment 2, an extra retention test was conducted 24 hours later. The final exception was that during the retention tests, children wrote the letters only in a blocked order. This is because in Experiment 1, the researcher did not find significant differences between blocked and random order letter writing. Acquisition test's results revealed that, in contrast in experiment 1, in acquisition tests, random group showed better performance than blocked group in some trial set. Twenty minutes retention test results indicated that random group showed better performance for letter a (*M* = ~4.7), and letter y (*M* = ~4.1) compared to blocked group performance for letter a (*M* = ~4.2), and letter y (*M* = ~3.7). But for letter h, blocked group showed better performance (*M* = ~4.7), than random group (*M* = ~4.7). In terms of transfer test after the 20 minutes retention, results showed that, across three letters, random group (*M* = 23.8, *SD* = 5.7) showed better performance (i.e., faster) than blocked group (*M* = 28.3, *SD* = 6.2). In terms of 24 hours retention test, researcher did not find significant differences between groups, but in 24 hours transfer test, random group (*M* = 29.8, *SD* = 4.8) showed better performance (i.e., faster) than blocked group (*M* = 28.2, *SD* = 5.5).

In the literature, as indicated in previous paragraphs, while numerous studies have explored the effects of different types of practice (e.g., blocked versus random) on motor skill learning and transfer in neurotypical individuals including children and adults, there has been relatively limited research examining these effects specifically in autistic individuals (Holloway et al., 2023). One of the recent scoping review's findings, which aimed to offer an overview of current motor learning strategies employed to improve the acquisition, retention, transfer, and generalization of motor tasks in autistic children, revealed that only one study in the literature, (Weber & Thorpe, 1992), investigated the effects of practice (i.e., blocked practice versus random practice) on motor learning and transfer skills in autistic children (Holloway et al., 2023). Weber & Thorpe (1992) conducted an intervention study to understand practices effects on acquisition of gross motor skills of autistic children aged between 11 and 15 (*n* = 12). During the study, participants were randomly assigned to either the blocked group (*n* = 6) or the random group (*n* = 6). Each participant engaged in practice sessions involving six gross motor skill tasks, namely ball bounce, throw, kick, roll, vertical jump, and slide, according to their group's practice condition. These practice sessions lasted for 45 minutes per day, five times a week, across six weeks. Before (i.e., pre-test) and after the intervention (i.e., post-test), all participants performed the gross motor skill tasks that used in the study and their performance was recorded. The results of the study showed that although there was no significant difference in the total gross motor skill task scores between the blocked group (*M* = 8.16) and the random group (*M* = 9.16) during the pre-test, the post-test results indicated a significant difference. Specifically, the performance of the random group (*M* = 78.66) was significantly higher than that of the blocked group (*M* = 41.66). The findings of the study were in line with the literature on neurotypical individuals, which suggests that individuals tend to retain and transfer motor skills more effectively when skill acquisition takes place through random practice compared to blocked practice (e.g., Shea and Morgan 1979; Magill and Hall, 1990).

As indicated by Holloway et al. (2023) despite the critical role of practice in motor skill learning and transfer, there has been a notable scarcity of studies investigating its effects specifically in autistic children. The limited literature on this area of interest could be due to the fact that, although motor skill difficulties are significant features of autism, they are not designated as core features in the DSM-V criteria (DSM-V; American Psychiatric Association, 2013). That is, researchers may prioritize studying the core features of autism over motor skills. In other words, the scarcity of studies investigating the effects of random versus blocked practice in autistic individuals may be attributed to the overall lack of motor studies focusing on autistic children.

Although there is limited research on the effects of blocked practice versus random practice on motor learning skills in autistic children, Foster and colleagues (2020a) argued that blocked practice may provide more support for autistic children's motor skill learning compared to random practice. This is because random practice likely involves greater attention-demanding and effortful motor planning processes, which could potentially overload the participant's cognitive system (Li & Wright, 2000). This overload may negate the benefits of the random condition, especially for autistic individuals who already experience motor planning difficulties (Glazebrook et al., 2006; Merbah & Meulemans, 2011; Foster et al., 2020). Therefore, it can be suggested that blocked practice can be more helpful than random practice to support autistic individuals motor learning.

In their study, Foster and colleagues (2020a) showed blocked practices effects on motor skill learning of autistic individuals. The researcher conducted an experiment with autistic and non- autistic individuals aged between 18 and 40, and they investigated whether the imitation of novel atypical biological kinematics by autistic adults is improved when imitating a model in a predictable blocked practice trial order. They measured performance both before and after the blocked practice trials. During the experiment, participants observed a motor task displayed on a screen, involving moving a dot from the home-position red target, and were then instructed to replicate the task using a graphics tablet. Each participant completed a block of 30 imitation trials. The results revealed that after the blocked practice trials, autistic individuals exhibited a significant 17% change in adoption. These findings showed that the motor control system in individuals with autism can be enhanced by blocked practice sessions. Therefore, Foster and colleagues (2020a) suggested that given the notable impact of blocked practice on motor learning and control processes in autistic individuals, autism-specific early motor interventions could incorporate methods based on blocked practice within preschool and educational settings.

Although studies in the literature recognized the challenging effects of random trials on participants, they emphasize the significance of its impact on transferability and suggest that it should be carefully considered (Brady, 2008). In this point, it has been suggested that using both blocked and random practice schedule could be useful to support participants motor skill learning and transfer skills (Merbah & Meulemans, 2011). Employing a blocked schedule during the initial learning stages could alleviate cognitive load, while introducing a random practice schedule later could augment the subject's representation, rendering it deeper and more elaborate. This enhanced storage could subsequently lead to improved retention and transfer

(Merbah & Meulemans, 2011). This claim (i.e., potential advantages of using blocked followed random practice schedule) tested by Lai et al. (2000). In the study they assigned forty neurotypical participants to four combined practice conditions (i.e., blocked/blocked, blocked/random, random/blocked, random/random). During the experiment participants were asked press on four keys (i.e., 2, 4, 6, 8) on the computer keyboard by using their right-hand index finger. The study results showed that, participants in blocked/random condition show superior performance in acquisition, retention, and transfer tests than participants in random/blocked condition [see the Lai et al. (2000), see details in Chapter 1: Introduction].

Conclusion and Research Questions

Autism, a lifelong condition, is primarily characterised by difficulties in social interaction, communication, repetitive behaviors, and sensory sensitivity (DSM-V; American Psychiatric Association, 2013). Although not formally listed as a diagnostic criterion, numerous studies (Landa and Garrett-Mayer, 2006; Ozonoff et al., 2008; Biffi et al., 2018) have highlighted the presence of motor skill difficulties and/or differences in autistic children and adults, encompassing areas such as gait, fine motor abilities, gross motor skills, postural control, and motor planning. These motor difficulties and/or differences typically arise early in life and persist over time. Research findings indicate that these difficulties and/or differences can significantly impact various domains of functioning, including daily life skills, social interactions, and academic performance. Therefore, it has been suggested that autistic children's motor skill difficulties and/or differences should be supported with EIs during the early years.

Handwriting is a critical skill significantly affected by motor skill difficulties in autistic children. While existing literature contains some studies aimed at supporting the handwriting abilities of young autistic children, many of these studies exhibit limitations, such as small sample sizes or the absence of control groups. Furthermore, despite handwriting being recognized as a fundamental fine motor skill, none of the current studies have incorporated early intervention programs based on principles of motor skill learning.

To address this gap in the literature, this PhD targeted to develop a novel early intervention program called AiMS (Autism Intervention Motor Skill). AiMS is a parent-mediated, home-based early intervention program designed to enhance the motor learning and control of young autistic children, focusing specifically on handwriting (i.e., letter writing) activities. In order used advantages of both practice type (i.e., blocked practice and random practice), AiMS was designed based on combine practice condition (i.e., blocked followed random practice versus random followed blocked practice). To develop and understand effectiveness of AiMS the following research questions answered in this PhD programme of the work.

1) What are the critical motor and methodological ingredients needed for the development of AiMS?
2) What are the critical parental considerations needed for the implementation of AiMS?
3) Does the AiMS programme facilitate the acquisition and transfer of motor skills in young autistic children?

Chapter 3: Research Context

Research Approach

A mixed methods approach was adopted to investigate the specified questions set out in this PhD programme of work. A mixed methods approach involves the selection and implementation of certain qualitative and quantitative research methods within a single study or a series of studies (Creswell & Creswell, 2017; Kumar, 2018). This approach is suitable for studies that aim to develop novel interventions because information obtained from qualitative and quantitative approaches complement each other and therefore contribute to the investigation and appraisal of an intervention (Farquhar et al., 2011). For example, qualitative and quantitative approaches play a critical a role in describing the context, justifying the intervention, and contributing to the design, testing, redesign, and formal evaluation (Farquhar et al., 2011). Specifically, qualitative methods are interviews, parent feedback statements and literature reviews and are selected to explore and identify reasons for successful methods used in interventions and establishing the successful outcomes of interventions. Quantitative methods can be randomised control trials, quasi-experimental design methods, pre- and post-test designs and are employed to test hypotheses related to the outcomes of these methods (Nastasi et al., 2007). Given the primary goal of this PhD programme of work was to develop a novel parent-mediated, home-based motor skill intervention for young autistic children, a mixed methods approach was deemed the most appropriate method as it allowed a comprehensive exploration of the factors contributing to the development and implementation of the intervention, while also testing the effectiveness of the intervention for training handwriting in young autistic children.

Research Design

The research design implemented within the programme of work was an embedded design (see Figure 3). This design is suitable when different types of data (i.e., qualitative, and quantitative) are required to answer distinct research questions (Clark & Creswell, 2008). As illustrated in Figure 3, a key characteristic of this type of design is that both types of data sets are crucial at different stages of intervention development. One of the most common applications of embedded designs involves the utilisation of qualitative data to support and supplement the outcomes of quantitative methods (e.g., experimental studies) (Creswell et al., 2003). For example, qualitative methods and data are often used before an intervention to shape design (e.g., dosage), during the intervention to examine the processes (e.g., interview with participants, or parents of participants about the process), and after the intervention to evaluate the outcomes. In such cases, qualitative research methods like focus groups, interviews, or literature reviews are employed to complement quantitative research methods. Therefore, in the PhD programme of work (see in Figure 3) an embedded design was implemented as the research design.

In this PhD programme of work, three main studies (i.e., systematic review, survey, and feasibility study) were conducted. Initially, a systematic review was conducted to examine existing EIs, providing insights into their effectiveness in improving motor skills among young autistic children (i.e., quantitative data), as well as their methodological characteristics such as settings, instructors, and assessment methods (i.e., qualitative data). This informed the design of methodological features for the AiMS intervention in this thesis, such as the selection of assessment methods, instructor, or intervention settings. Following the systematic review, a survey was conducted with parents of young children, as well as classroom observations and meetings with parents and teachers. The survey yielded quantitative data reflecting parental perspectives on motor skills, while observations and meetings provided qualitative data on children's activities, routines, and needs. This data guided the design of AiMS activities, materials, and parent training components. Subsequently, based on both qualitative and quantitative data obtained from the systematic review, survey, observations, and meetings, the AiMS program was developed and implemented using an experimental design to assess its effectiveness in improving handwriting skills among young autistic children (quantitative data). Post-intervention, qualitative data were collected from parents via questionnaires to evaluate the AiMS processes and materials, providing insights into the program's applicability. In the following subsections, detailed explanations for choosing these methods (i.e., systematic review, survey, and feasibility study) were provided.

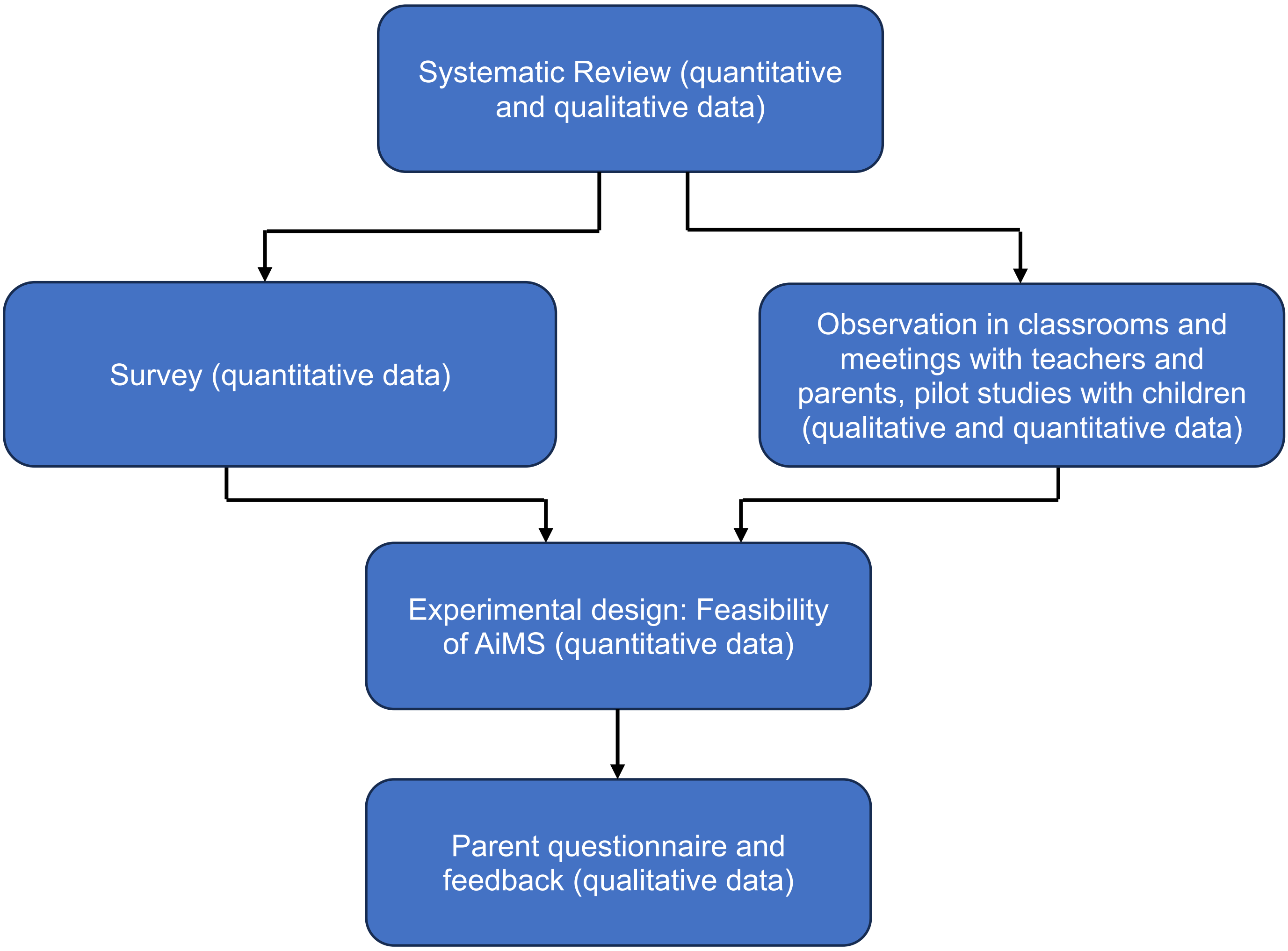


Figure 3: Illustrates the embedded research design used in the PhD programme of work.

Systematic Review: What are the critical motor and methodological ingredients needed for the development of AiMS?

Interventions are multifaceted processes with many complementary components such as different groups, settings, and outcomes (Craig et al., 2010). Developing a novel intervention requires a comprehensive understanding of how these components interact and as such it is suggested that the initial step is to identify and understand components from existing interventions (Craig et al., 2008).

A method typically adopted to explore a set of interacting components is a systematic review (Craig et al., 2008). A systematic review is a methodology that captures existing studies, selects and evaluates contributions, analyses and synthesises data, and reports the evidence so that conclusions can be reached about what is and is not known (Denyer & Tranfield, 2009). This method aids in identifying gaps, limitations, and strengths in current evidence, thereby informing future research directions (Munn et al., 2018). Consequently, when starting on the development of an intervention, it is essential to identify evidence from existing interventions through high-quality systematic reviews. In cases where there are no recent, high-quality systematic reviews available in the specific area of interest, it is recommended that a new systematic review is conducted to appraise the landscape associated with existing interventions (Craig et al., 2008).

Over the last decade, there has been several systematic reviews exploring interventions for motor skill difficulties in autistic children (e.g., Bremer et al., 2016; Dillon et al., 2017; Colombo-Dougovito & Block, 2019; Ruggeri et al., 2020). Whilst these have provided important information, none of these reviews were specifically focused on EIs that were designed for training motor skills in young autistic children. Additionally, there has been a lack of focus on reviewing non-motor skill EIs for young autistic children, which is an important gap given many incorporate motor skill tasks such as drawing, painting, or playing with Lego and as such are likely to indirectly support motor skills in young autistic children. To address these gaps, and to obtain a comprehensive understanding of both motor and non-motor EIs, a novel systematic review was conducted to answer the first research question posed in this thesis. This systematic review therefore synthesised information via a narrative synthesis technique, which will appraise and discuss information from the selected papers to contribute to the developmental design of the novel AiMS intervention.

Survey: What are the critical parental considerations needed for the implementation of AiMS?

The results from Study 1 (the systematic review) have indicated that typically the main focus of existing interventions is to support the core (e.g., social interaction; language) and associated features of autism. For these interventions, parents/caregivers are often required to identify, select, and implement the interventions for their autistic children. Moreover, it is suggested that the underpinning knowledge and beliefs that parents/caregivers have of particular aspects of autism, or the methods used in interventions, can influence whether interventions are indeed chosen and/or implemented (Al Anbar et al., 2010; Mire et al., 2017).

Given that AiMS will be a novel EI program focused on developing motor skills in the home, and that parents/caregivers are integral to the effectiveness of an intervention, the rationale for Study 2 is to understand parents' perceptions about motor skills in young autistic children. For example, if parents believe that motor skills are not important for the development young autistic children, they may not choose a motor skills intervention or be reluctant to participate in the delivery of a motor skill intervention. In these cases, it would be necessary to provide instructional information prior to a motor skills intervention that outlines the key benefits of how motor skills may facilitate development and learning in young autistic children in terms of school attainment (e.g., handwriting), physical well-being (e.g., engaging in physical activity) and/or daily life skills (e.g., cleaning teeth). This instructional method should help to ensure that parents/caregivers are informed about the importance of motor skills and thus support their engagement and commitment to the intervention process. Therefore, measuring parents/caregivers' perceptions of motor skills before designing the AiMS program is important to shape the overall AiMS intervention design and implementation. In addition to their perceptions of motor skills, it is also important to gather an understanding of the types and frequency of home activities that parents do with their children on a daily and weekly basis. This information is instrumental for the effective design of the AiMS activities and importantly how the task instructions and prior training is presented.

To obtain an understanding of parents/caregivers' perceptions about motor skills, and the activities they do with their children at home, a novel survey was designed and conducted as it is an effective method to garner the views, attitudes, and perceptions of a particular group (i.e., sample) of people (Fink, 2003). Specifically, surveys offer researchers a time effective process of accessing information from a diverse and large sample of the selected population, compared to interviews and focus groups,. Due to the methodological and practical advantages of surveys, and in alignment with the research aim of understanding parents' perceptions about the motor skills of young autistic children, a survey was chosen as one of the research methods to answer the second research question.

Feasibility of AiMS: Does the AiMS programme facilitate the acquisition and transfer of motor skills in young autistic children?

There are different types of study designs that are utilised for investigating interventions based on specific goals and questions – *feasibility* studies, *mechanistic* studies, plus *efficacy and effectiveness* studies (Green et al., 2019). For example, *mechanistic* studies are suggested to focus on testing a hypothesis based on a clear theoretical framework for an intervention; an *efficacy* study is implemented to investigate the nature of improvements in cognitive processing following an intervention. It is therefore important to consider the aim of the study when selecting and adopting a type of intervention study (Green et al., 2019).

In the current PhD, a *feasibility* study was selected to help develop the novel parent-mediated EI intervention, AiMS. The main purpose of a *feasibility* study is to test the viability of a given paradigm or project in real-life settings and to understand the appropriateness of an intervention for further development and testing (Green et al., 2019). These types of studies enable researchers to assess whether the ideas and findings can be refined to be relevant and sustainable (Bowen et al., 2009) and thus are carried out before a large-scale trial is conducted to evaluate all the intervention components such as materials, dosages, and instructions (Whitehead et al., 2014). While *feasibility* studies mainly focus on viability, tolerability, or safety of interventions, they also answer “Does the new idea, program, process, or measure show promise of being successful with the intended population, even in a highly controlled setting?” (Bowen et al., 2009, p. 454).

Based on Bowen et al., (2009), it is important to note that AiMS is a novel home-based, parent-led EI program that will be designed to investigate the effects of practice schedule and type on the acquisition and transfer of handwriting letters in young autistic children. Therefore, before examining the effectiveness of AiMS via a larger scale trial, several critical components first need to be examined, such as “Can AiMS be applied in a home environment?”; “What is the impact of a specific practice schedule and type (i.e., blocked-followed-by-random practice) on motor learning in young autistic children? To address these questions, and to assess the feasibility of AiMS, a feasibility study was designed and conducted in Study 3.

Observations in the classrooms, pilot studies with children and meeting with parents and teachers

As specified previously, in this PhD, a mixed-method approach was adopted to construct an efficacious early intervention programme tailored for autistic children. Central to this approach, alongside the main studies, was the undertaking of 150 hours of observations within autism reception classrooms. According to Nock & Steven (2005), such observations offer a comprehensive understanding of the unique needs, behaviours, and challenges encountered by children. In this PhD, these observations served as one of the most important foundations for the development of AiMS tasks, which were designed based on the identified needs and behaviours of young autistic children. Subsequently, these tasks underwent piloting with young autistic children to assess their suitability and applicability within the intervention framework. Additionally, meetings with teachers and parents were conducted to solicit their insights and expertise in tailoring the AiMS intervention to align with the unique requirements of children.

Parent Questionnaire and Feedback

AiMS, a new developed intervention conducted at children's homes by parents, underscores the significance of parental opinion regarding the AiMS intervention. Hence, following the AiMS intervention, a questionnaire was administered, and parental feedback during the AiMS implementation was gathered. Questionnaires and parental feedback are commonly employed in the literature for the development of new early interventions to capture parental perspectives on intervention implementation (e.g., Stieber et al., 2011; Vismara et al., 2013; Young et al., 2021). In this PhD, the aim of the questionnaire and parental feedback was to identify potential issues in the AiMS intervention protocol, along with any encountered implementation challenges during AiMS implementation. Additionally, by utilizing questionnaires and feedback, the aim of soliciting parental suggestions was to obtain information about the feasibility and efficacy of intervention strategies within home contexts. This collaborative process facilitated informed decision-making regarding potential AiMS intervention modifications, ensuring alignment with the evolving needs of both children and their parents. Ultimately, the incorporation of parental feedback served to enhance the intervention's potential for meaningful impact by fostering a mutually beneficial partnership between researchers and parents.

Chapter 4: Isolating the critical ingredients used for training motor skills within early intervention studies for young autistic children: A systematic review

As indicated in the previous chapter (i.e., Literature Review), young autistic children in pre-school term (age range: six months to six - seven years) have difficulties, or delays, in motor skills such as gait, fine motor, gross motor, postural control and motor planning (Landa & Garrett-Mayer, 2006; Ozonoff et al., 2008; Biffi et al., 2018). Since these delays or difficulties may have a negative impact on other crucial skills, such as language skills, academic skills or daily living skills, it has been suggested that motor skills of young autistic children should be supported with early interventions. In order to examine how motor skills in young autistic children can be supported a systematic review was carried out of all interventions that included motor skills outcomes.

Previous systematic reviews that examined early intervention program to support autistic children motor skills have shown that, whilst most early intervention programmes focus on the core areas of social communication, language, or repetitive behaviours (Zampella et al., 2021), some have focused on motor skills, fundamental motor skills, and exercise interventions and are synthesised across various systematic reviews (see Lang et al., 2010; Bremer et al., 2016; Dillon et al., 2017; Colombo-Dougovito & Block, 2019; Ruggeri et al., 2020). Three reviews examined the effects of exercise interventions (e.g., dance, or swimming) on core autistic characteristics such as social and behavioral outcome measures (Lang et al., 2010; Bremer, et al., 2016; Dillon, et al., 2017). Two systematic reviews examined the effects of performing fundamental motor skills (FMS) (e.g., kicking, catching, or walking) and motor learning interventions on motor behaviour outcomes (Colombo-

Dougovito & Block, 2019; Ruggeri et al., 2020). The findings indicated that autistic children generally improved many targeted outcomes (i.e., motor competency; stereotypy; social responsiveness; language) after engaging in the early intervention programmes. There were however several limitations related to the quality of studies, such as lack of a comparison/control group, inadequate power, or small sample sizes. It was therefore recommended that future early interventions research should address these areas by conducting high-quality studies that are underpinned by a strong experimental design (e.g., a random control trail). Moreover, and in terms of early interventions that specifically targeted motor skill outcomes, it was suggested that dosage should be investigated and quantified specifically for early interventions that target motor skill outcomes, given that specific intensities facilitate different motor skill outcomes of children (Ruggeri et al., 2020).

Overall, within the previous systematic reviews that examined motor based early interventions the one (Ruggeri et al., 2020) that conducted analyses on motor skill outcomes in autistic children and adults aged between three – 19 years did not sub-section the results to gain an understanding of the effects on young autistic children. It has been known that many existing non-motor skill early interventions programs [e.g., Early Start Denver Model (ESDM)] that aimed to support core features of autism (e.g., social communication, repetitive behaviour, or language skills) often incorporate activities involving motor skills. For example, activities that include colouring or drawing which require using fine motor skills are often important components of non-motor early intervention programs (MacDonald et al., 2013). It is conceivable that as well as motor skill early intervention programs, non-motor skill early interventions programs could enhance the motor skills of young autistic children with these activities (Baranek, 2002). Therefore, all types of early interventions that included motor skill outcomes should be examined within a systematic review to understand which early interventions can benefit motor skill development of young autistic children. As far as the authors known, none of the systematic review in the field have not been examined all types of early interventions that included motor skill outcomes to understand the early interventions impacts on motor skill outcomes.

To this end, and based on the gaps in the literature, the current systematic literature review aimed to isolate the critical ingredients used for training motor skills within all types of early intervention studies that include motor skill outcome for young autistic children (i.e., birth to first year of primary school). This review answered the following research questions.

1. What is the theoretical framework underpinning the early interventions?
2. What types of motor skills (e.g., fine motor; gross motor; motor imitation) are included in early interventions for young autistic children?
3. What are the methodological characteristics used for training motor skills in early interventions for young autistic children?
    a. Task used to train motor skills (e.g. draw; throw; bounce; cut)
    b. Training frequency, intensity, and duration (e.g., six minutes on task; two x per week, across 10 weeks)
    c. Setting (e.g. home; school; clinic)
    d. Instructor (e.g. parent; clinician; teacher)
    e. Movement Measurement Tool (e.g., MABC-2; BOT; VABS or kinematic analysis)
    f. The effectiveness ('effect size') of the early interventions

Methods

This systematic review was organised according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses standards for systematic review (PRISMA; Moher et al., 2015) and was preregistered on the Open Science Framework (https://osf.io/f4tcv).

Search strategies

Search terms (see below for details) were developed and defined based on the literature regarding early interventions, autism, motor skills and the aims outlined in the systematic review. The search terms were pilot tested across selected search engines and then refined to ensure that a wide range of literature was captured for evaluation. The final search terms were: (autism OR autistic OR ASD OR ASC OR Asperger) AND (“early years” OR “young children” OR preschool* OR kindergarten* OR infant* OR toddler*) AND (intervention OR treatment) AND (motor OR sensorimotor OR sensory-motor OR “motor imitation” OR “fundamental motor skill” OR “fine motor” OR “gross motor”). Given that a vast majority of early interventions developed for autistic children were published since 1990 (Thompson, 2013), the literature search range was January 1990 to March 2021. The following data bases were used: PubMed, PsycINFO, ERIC, Scopus, Science Citation Index (SC)-Expanded, Social Science Citation Index (SSCI), Arts & Humanities Citation Index (A&HCI), Emerging Sources Citation Index, and Google Scholar. In addition, grey literature was searched using ProQuest, OpenGrey, Open Science Framework Preprints and PsyArXiv Preprints. Finally, a comprehensive manual search of the reference lists associated with all included studies was conducted to ensure the main search sweeps did not miss related published work.

Selection criteria

Selection criteria were based on the research aims of this systematic review. For 'motor-skill-outcome' criteria, studies were included when an early intervention evaluated a minimum of one motor skill outcome and reported quantitative results relating to the performance of the motor skill (e.g., results from a fine or gross motor skill task like accuracy) that were measured before and after an early intervention. For 'population' criteria early interventions were selected when they were designed for young autistic children in the early years, which is generally defined as the period of time (Pascal et al., 2019) before the start of formal primary school education. Due to countries having different time periods, studies were selected based on participants early intervention within an age range from birth to the first year of primary school. We included early interventions with children that had a formal diagnosis of autism, and those at-risk of autism, given the age of a typical formal diagnosis being ~4 and motor skills difficulties in both groups (Bradshaw et al., 2015). We did not place a restriction on the nature of the comparison group (e.g., no treatment group; waiting list control group; number of participants). Early intervention studies, including RCTs and N-RCTs that met the above criteria and published in 'English', were included. Finally, systematic literature reviews, literature reviews, and meta-analyses were not included. Early interventions that focused on pharmacological, dietary, aquatic, and animal-assisted interventions were also not included as they did not align with current research aims.

Study selection and data extraction

Study selection was performed by Tugce Cetiner and consisted of first removing all duplications. The remaining articles were selected for a full-text review using information from the title and abstract. A second independent researcher (PY) then processed and coded 10% of the selected studies to quantify the reliability of study selection, which returned an inter-rater reliability score of 95%. Following confirmation that the selection criteria was reliable, a full-text review of all included studies was conducted to process and capture the information required for data extraction. PY then conducted a full-text review of 10% of the selected studies and the results were compared and discussed, with four studies requiring a resolution discussion with SH.

To meet the aims of the systematic review, the following data were extracted from each article to generate a textual narrative synthesis: focus of early intervention, study design, population for intervention group (number of participants, age range, diagnosis condition), population for control group (number of participants, age range, diagnosis condition), length of early intervention, intensity of early intervention, setting of early intervention, and instructor for early intervention. After that the following motor skill outcomes measures were extracted: motor skill outcome, measurement tool for motor skill outcome, pre and post-test mean and SD scores for effect size calculation of motor skill outcome, motor skill task, and frequency of motor skill task.

Quality of study

The quality of included studies was assessed using the ‘Standard Quality Assessment Criteria for Evaluating Primary Research Papers from a Variety of Fields’ (Kmet et al., 2004). The assessment is important because it provides a systematic, reproducible, and quantitative means of assessing the quality of research across a broad range of study designs. The outcome of the process assists in the exploration of variation across studies and underpins the synthesis and interpretation of research findings (Kmet et al., 2004). Each selected study was scored using a 0 (No), 1 (Partial), 2 (Yes) or non-applicable (N/A) on 14 quality criteria. To calculate an overall 'quality score' for each study, a '*total sum*' score was calculated using the following formula: [(number of "yes" * 2) + (number of "partials" * 1)]. Second, a '*total possible sum*' was calculated using: [28 – (number of "N/A" * 2)]. Because not all 14 items applied to all studies, an individual quality score was calculated by dividing the '*total sum*' by '*total possible sum*'. A 'quality score' for each individual study ranged between 0 and 1, with < 0.5 indicating limited quality, 0.5 – 0.6 adequate quality, 0.7 – 0.8 good quality, and > 0.8 early interventions indicative of strong quality (Kmet et al., 2004). To ensure rigour within the scoring process, a quality assessment for 10% of included studies was completed by a second independent coder (PY), which resulted in an inter-rater reliability score of 83%.

The Overall Quality of Evidence

The overall body of evidence for motor skill outcomes (e.g., fine motor skills, gross motor skills) was planned to assess using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) framework (Goldet & Howick, 2013). GRADE is a well-developed framework that used by systematic reviewers to assesses the quality of evidence of intervention studies (Goldet & Howick, 2013). In the framework, each different outcome in intervention studies assesses separately based on GRADE criteria. According to the GRADE criteria, firstly, all RCTs should be assigned a "high grade", and all N-RCTs are assigned a "low grade". After that, based on downgrade criteria (risk of bias, inconsistency, indirectness, imprecision, publication bias) and upgrade criteria (large magnitude of effect, dose-response, plausible confounding factors), the quality of evidence is classified as “high”, “moderate”, “low”, and “very low”.

In this review, all motor skill outcomes (e.g., fine motor skills, gross motor skills) which identified in early intervention studies were planned to be assessed with GRADE. However, after the review was completed, it was noticed that, although the included studies comprised 33 different motor skill outcomes, most of these outcomes (e.g., dribble, visuomotor coordination skills, or balance skills) were found in a very small number of studies (e.g., only one early intervention included dribble outcomes). Moreover, many early intervention studies (*n* = 30) utilized a composite "motor skill" outcome, which combined fine and gross motor skills as defined in standardized motor skills measurement tools such as the Mullen Scales of Early Learning (MSEL). In these early interventions fine and gross motor skill outcomes could not be assessed separately. Therefore, due to the very small number of studies providing evidence for most motor skill outcomes and the inability to separate fine motor and gross motor skill outcomes in many early intervention studies, in this review, GRADE assessment could not be conducted across motor skill outcomes.

Effect size for motor skill outcomes

To provide an indication of the magnitude of difference between selected means, standardised within-subject effect sizes were calculated. Standardised between-subject effect sizes were calculated based on comparing the effect of an intervention on motor skill outcomes between an intervention group and a control group. In cases where an early intervention included multiple motor skill outcomes, individual effect sizes were calculated for each motor skill outcome, and then, an overall motor skill outcome effect size score was quantified by averaging the individual effect size scores. The effect size used was Hedge's *g* because it is suggested to provide an accurate estimate of effect size for small sample sizes, which is advisable for use in systematic reviews that encompasses studies with large and small samples (Turner & Bernard, 2006).

Results

As illustrated in the Prisma flow diagram (see Figure 4), the initial search accessed 2239 articles. After removing duplications, 1835 articles were evaluated based on the title and abstract, which led to the exclusion of 1493 articles. The remaining 342 articles were retrieved for full text review, and based on the inclusion criteria, 65 articles were selected for the final review.

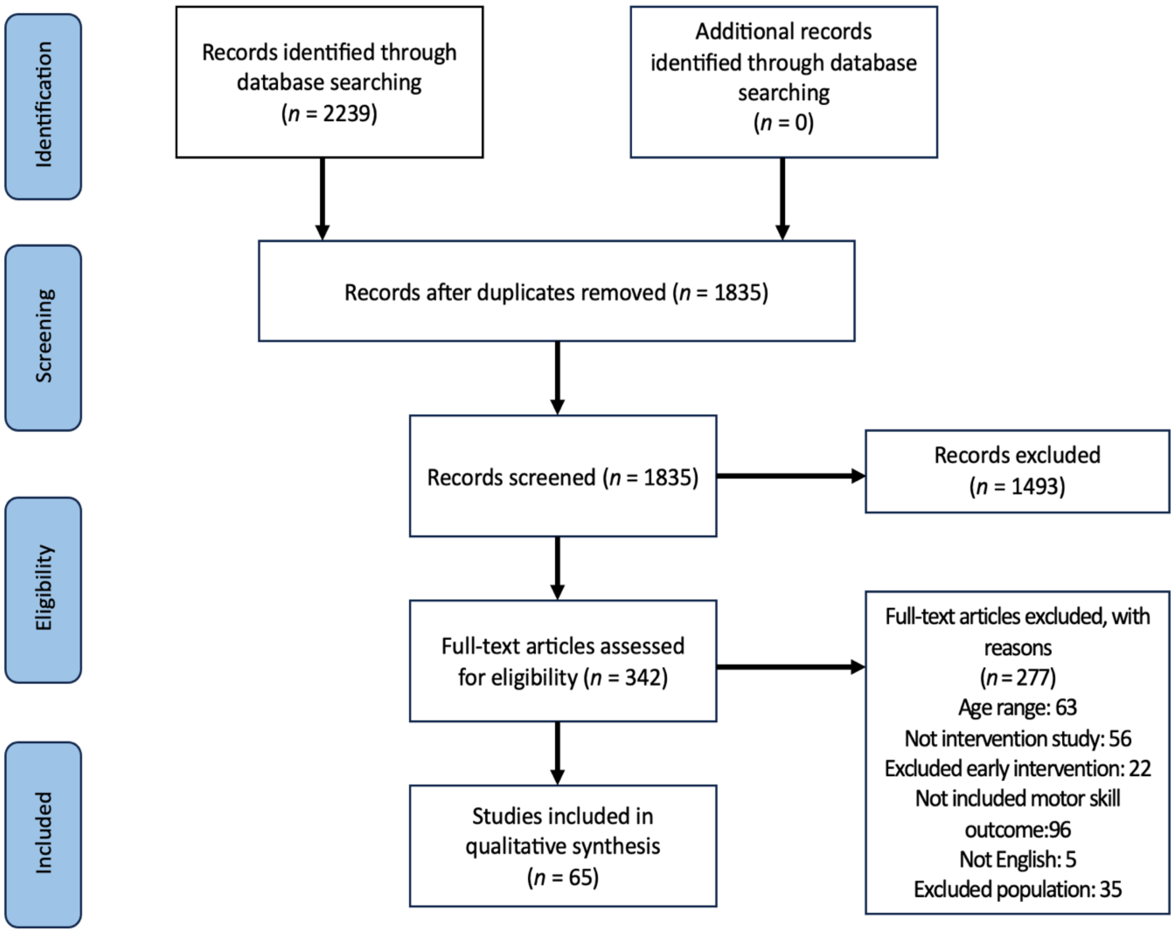


Figure 4: Prisma flow diagram

R.Q1. What is the theoretical framework underpinning the early interventions?

Included early interventions (*n* = 65) used different intervention model to support young autistic children motor skills such as Early Start Denver Model (ESDM), Fundamental Motor Skill (FMS) Intervention model, or Inclusive School-Based model. Ten early interventions focused specifically on improving motor skill outcomes (e.g., fine motor or gross motor), and whilst motor skill outcomes were targeted in the other 55 early interventions (85%), these were principally focused on improving other behavioural (e.g., repetitive behaviour), cognitive (e.g., language), or social-communication skill outcomes (see Table 2 and 3). In these 55 studies, four studies compare two different early interventions. Therefore, the number of early interventions that principally focused on improving other skills calculated as 59.

To answer the other research questions and to evaluate the critical ingredients of early interventions within these two types of interventions, the results are structured into two sections: 1) Motor Skill Early Interventions 2) Non-Motor Skill Early Interventions.

Motor Skill Early Interventions

Description of Motor Skill Early Intervention Studies

A total of ten (15%) motor skill early intervention programs specifically targeted motor skill outcomes. Seven studies used experimental designs that did not contain a control group and three studies implemented single case subject designs. The age of children included in the motor early interventions ranged between three to 72 months (i.e., birth to 6 years). Most of the included early interventions (*n* = 8) worked with autistic children, one worked with children categorised as being at risk of autism (Libertus & Landa, 2014), and one worked with both autistic children and children categorised as early intervention at risk of autism (Bremer & Lloyd, 2016). Ninety percent of the motor early interventions (*n* = 9) evaluated one early interventions program for young autistic children, and one study (Bremer et al., 2015) compared the effects of two different dosages and lengths within the same early interventions program on motor skill outcomes. The 'study quality' of articles reviewed were 'good' (*n* = 5) or adequate (*n* = 3), and two having 'limited quality' (see Table 2).

Table 2: Summary of results for motor skill early interventions

Study	***Model (Focus)***	***Study Design***	***Sample size Intervention Group (n, age)***	***Sample size Control Group (n, age)***	***Length***	***Intensity***	***Setting (instructor)***	***Motor skill outcome (measurement tool)***	***Within subject effect size motor skill outcome***	***Between subject effect size motor skill outcome***	***Motor skill task (frequency)***	***Quality of Study***
Jung et al. (2006)	FMS	N-RCT	autistic (12, 60 -72 months)	non-autistic (20, 60 -72 months)	N.I	N.I	community settings (professional)	visuomotor coordination (TVCAAP)	N.I	N.I	N.I	0.50 (limited)
Libertus & Landa (2014)	fine motor skills	N-RCT	at - risk for autism (17, 3 months)	at - risk for autism (72, 3 months)	2 weeks	70 minutes per week	home (parents)	grasping (video analysing)	N.I	N.I	grasping of toys (10 minutes per day)	0.77 (good)
								fine Motor (EMQ)	0.70	N.I		
								gross Motor (EMQ)	0.58	N.I		
Bremer et al. (2015)	FMS	RCT	autistic (5, 48 months)	autistic (4, 48 months)	Group 1 – 12 weeks Group 2 – 6 weeks	Group 1 - 60 minutes per week Group 2: 120 minutes per week	community settings (professional)	stationary (PDMS-2)	0.29	0.5	Activities with TGMD – 3 skills (N.A)	0.71 (good)
								locomotor (PDMS-2)	0.61	0.47		
								object Manipulation (PDMS-2)	0.87	0.15		
								grasping (PDMS-2)	0.76	-0.01		
								visual-motor integration (PDMS-2)	0.54	-0.41		
								fine motor (PDMS-2)	0.33	0.28		
								gross Motor (PDMS-2)	0.47	-0.35		

Karim & Mohammed (2015)	FMS	N-RCT	autistic (24, 40- 65 months)	N.A	24 weeks	N.I	community setting (professionals)	stationary (PDMS-2)	N.I	N.A	tactile tasks (e.g., finger painting) (N.I)	0.50 (limited)
								locomotor (PDMS-2)	N.I	N.A	vestibular tasks (e.g., swings) (N.I)	
								object manipulation (PDMS-2)	N.I	N.A	proprioceptive tasks (e.g., stress balls) (N.I)	
								grasping (PDMS-2)	N.I	N.A		
								visual-motor Integration (PDMS-2)	N.I	N.A	fine motor tasks (e.g., drawing) (N.I)	
								fine motor (PDMS-2)	N.I	N.A	heavy work activities (pulling, lifting) (N.I)	
								gross motor (PDMS-2)	N.I	N.A		
Bremer & Lloyd (2016)	FMS	N-RCT	autistic or at-risk for autism (5, 36 – 72 months)	N.A	12 weeks	135 minutes per week	community settings (professionals)	balance (visual analyses)	N.I	N.A	Activities with TGMD – 3 skills (30 minutes)	0.72 (good)
								running (visual analyses)	N.I	N.A		
								underhand rolling (visual analyses)	N.I	N.A		
								galloping and leaping (visual analyses)	N.I	N.A		
								underhand throwing (visual analyses)	N.I	N.A		
								jumping (visual analyses)				

								dribbling/bouncing (visual analyses)	N.I	N.A		
								overhand throwing (visual analyses)	N.I	N.A		
								catching (visual analyses)	N.I	N.A		
								hopping (visual analyses)	N.I	N.A		
								kicking (visual analyses)	N.I	N.A		
								striking (visual analyses)	N.I	N.A		
Ketcheson et al. (2017)	FMS	N-RCT	autistic 11 (48 – 72 months)	autistic 9, 48 – 72 months)	8 weeks	1200 minutes per week	community settings (professionals)	locomotor (TGMD -3)	2.22	N.I	TGMD – 3 tasks (N.I)	0.67 (adequate)
								object control (TGMD -3)	3.39	N.I		
Hadadi (2018)	FMS	RCT	autistic (13, 36 – 60 months)	autistic (13, 36 – 60 months)	12 weeks	120 minutes per week	community settings (professionals)	catching rubric sheets that created by researcher)	N.I	N.I	catching a ball (15 minutes)	0.60 (adequate)
								throwing (rubric sheets that created by researcher)	N.I	N.I	throwing a small hacky sack to a smiley-face target on the wall (15 minutes)	
											standing with one foot	

								standing (rubric sheets that created by researcher)	N.I	N.I	immediately behind the other foot (15 minutes)	
								walking balance (rubric sheets that created by researcher)	N.I	N.I	walking with steps by placing right foot in front of left, placing the heel of foot directly in front of the toe of the other foot (15 minutes)	
Weisblatt et al. (2019)	FMS	N-RCT	autistic (7, 40 – 74 months)	N.A	4 weeks	300 minutes per week	community settings	locomotor skill (TGMD-3)	N.I	N.A	N.A	0.63 (adequate)
								ball skill (TGMD-3)	N.I	N.A	N.A	
Felzer-Kim (2020)	FMS model (FMS skills)	RCT	autistic (8, 53 months)	autistic (6, 53 months)	20 weeks	1800 minutes per week	community settings (professionals)	locomotor skill (TGMD-3)	1.16	0.79	TGMD – 3 tasks (10 trial block for each task)	0.75 (good)
								ball skill (TGMD-3)	1.44	1.20	Active social recess game (5 minutes)	
Ketcheson et al. (2021)	FMS	N-RCT	autistic (25, 36 -60 months)	N.A	12 weeks	60 minutes per week	community settings (professionals)	locomotor skill (TGMD-3)	0.3	N.I	Small and large group activities that included TGMD – 3 locomotor skill tasks (15 minutes)	0.72 (good)
								ball skill (TGMD-3)	0.43	N.I	Small and large group activities that	

						included TGMD – 3 ball skill tasks (15 minutes)

N.I: No Information; N.A: Not Applicable; EMQ: Early Motor Questionnaire; MSEL: FMS: Fundamental Motor Skills; Mullen Scales of Early Learning; PDMS: The Peabody Developmental Motor Scales; TGMD: The Test of Gross Motor Development; TVCAAP: The Visuomotor Coordination Ability Assessment Program; VABS: Vineland Adaptive Behavior Scales; SIT: Sensory Integration Therapy

R.Q2. What types of motor skills (e.g., fine motor; gross motor; motor imitation) are included in motor skill early interventions for young autistic children?

The included motor skill early interventions (*n* = 10), included twenty-one different motor skill outcomes (see Table 2): locomotor (*n* = 5), fine motor (*n* = 3), grasping (*n* = 3), gross motor (*n* = 3), stationary (*n* = 2), throwing (*n* = 3), balance (*n* = 2), ball skills (*n* = 2), catching (*n* = 2), object control (*n* = 1), object manipulation (*n* = 1), visual-motor integration (*n* = 2), dribbling/bouncing (*n* = 1), galloping and leaping (*n* = 1), hopping (*n* = 1), kicking (*n* = 1), running (*n* = 1), standing (*n* = 1), striking, (*n* = 1), visuomotor coordination (*n* = 1), and walking (*n* = 1).

R.Q3. What are the methodological characteristics used for training motor skills in motor skill early interventions for young autistic children?

Motor Skill Task, Training Frequency, Intensity, and Duration

Among included early interventions, five studies (Bremer et al., 2015; Bremer & Lloyd, 2016; Ketcheson et al., 2017; Felzer-Kim, 2020; Ketcheson et al., 2021) focused on improving FMS in children using tasks from The Test of Gross Motor Development 2 - 3 (TGMD 2 – 3) (e.g., rolling a ball, or walking on balance beam). In two studies (Bremer et al., 2016; Ketcheson et al., 2021), the early interventions were split into two parts with children engaging in performing motor skills for 30 minutes followed by a second 30-minute session related to general physical activity, a review of previously learned motor skill, an introduction to the new motor skills, and a clean-up. While in the intervention program (Bremer et al., 2015) children performed the tasks across 12 weeks, and 135 minutes per week, in other program (Ketcheson et al., 2021) children performed the tasks across 12 weeks, and 60 minutes per week. In a multi-domain FMS study (Felzer-Kim, 2020), the children performed 10 blocks of each FMS task across 20 weeks, and 1800 minutes per week. The remaining two FMS studies (Bremer et al., 2015; Ketcheson et al., 2017) provided no information on task frequency or number of task trials, but they provided information about intensity and duration of early interventions. In the study Bremer and colleagues (2015) worked with intervention and control group. While the children in intervention group received the intervention across 12 weeks and 60 minutes per week, children in control group received the intervention across six weeks, and 120 minutes per week. Ketcheson et al. (2017) worked with two groups, but just children in the intervention group received the intervention across 8 weeks, a 1200 minutes per week.

One early intervention study (Libertus & Landa, 2014), used a grasping task to support motor skill of children. In the study, infants first learned in a sticky condition where they wore Velcro-covered mittens and grasped Velcro-covered toys, and then transferred to grasping in a non-sticky mitten and toy condition. The frequency of both grasping tasks was 10 minutes, and children performed the task across two weeks, and 70 minutes per week. During a multi-skill early intervention (Hadadi, 2018), children performed catching, throwing, standing, and walking skills. They used two hands to catch balls propelled a distance of 10 feet. They threw small hacky sacks to a target located on a wall. They stood with one foot placed directly behind the other foot. They walked by placing the right foot in front of the left foot with the constraint to place the heel of the right foot in front of the toe of the left foot.

All four skills had a frequency duration of 15 minutes, and children performed the tasks across 12 weeks, and 120 minutes per week.

A sensory integration study (Karim & Mohammed 2015) conducted an early intervention across 24 weeks and provided information that children engaged in tactile tasks (e.g., finger painting), vestibular tasks (e.g., swings), proprioceptive tasks, fine motor tasks (e.g., drawing), and heavy work activities (pulling, lifting), but did specify information on task frequencies. The early intervention study (Weisblatt et al., 2019) provided no information on the motor skill tasks or frequency but provided information about duration of early intervention (i.e., 4 weeks/300 minutes per week). The remaining study (Jung et al., 2006) did not provided any information about motor skill tasks, frequency, or duration of the early intervention (see Table 2).

Setting and Instructor

In terms of setting and instructor, eighty percent (*n* = 8) of the early interventions were conducted in community settings (e.g., schools; childcare centres) by professionals (e.g., teachers; therapists), with one early intervention (Libertus & Landa, 2014) conducted at home by parents, and one conducted in both a community and home setting (see Table 2).

Movement Measurement

In terms of movement measurement, motor skill outcomes were typically quantified using standardised motor behaviour measurement tools (*n* = 9), such as The Peabody Developmental Motor Scales – 2 (PDMS-2), TGMD, and The Vineland Adaptive Behavior Scales (VABS), with the remaining early intervention using a researcher developed motor rubric (*n* = 1) (see Table 2).

The Effectiveness ('effect size') of Motor Skill Early Interventions

Among the 10 included motor early interventions studies (see Table 2), within-subject effect sizes were calculated for five early interventions, with the remaining four not providing the required mean and SD data. The within-subject results indicated large effects sizes for two early interventions (Felzer-Kim, 2020; Ketcheson et al., 2017), medium effects sizes for two early interventions (Libertus & Landa, 2014; Bremer et al., 2015), and a small effect size for one early intervention (Ketcheson et al., 2021). For the between-subject effect size calculations, one early intervention (*n* = 1) reported a large effect size (Felzer-Kim, 2020), with the remaining nine studies not providing the required mean and SD data to calculate an effect size (see Table 2).

Non-Motor Skill Early Interventions

Description of Non-Motor Skill Early Intervention Studies

The 59 early interventions which were identified in 55 study were selected from non-motor early interventions that were principally designed to target core autistic behaviours (e.g., social communication and interaction skills; language; cognitive skills) but also contained motor skill outcomes. Thirty studies used experimental designs that did not have a control group and twenty-five studies were single-subject study design. The sample size range was between four and 117 and the age of children ranged from nine to 72 months (i.e., around birth to six years). Fifty-one early interventions investigated autistic children, three investigated children categorised as being at risk of autism (Beaudoin et al., 2019; Whitehouse, et al., 2019; Yoder et al., 2021) and one worked with both autistic children and children categorised as being at risk of autism (Remington et al., 2007). Most of the studies (*n* = 51) evaluated one type of early interventions program for young autistic children and the remaining 4 compared 2 different early interventions (Howard et al., 2005; Zachor & Itzchak, 2010; Fava et al., 2011; Wetherby et al., 2014). Therefore, although The ‘study quality’ of articles reviewed were ‘good’ (*n* = 24) or adequate (*n* = 22), six having “strong” and three having ‘limited quality’ (see Table 3).

Table 3: Summary of results for non-motor skill early interventions

Study	*Model (Focus)*	*Study Design*	*Sample for Intervention Group (n, age)*	*Sample Control Group (n, age)*	*Length*	*Intensity*	*Setting (instructor)*	*Motor skill outcome (measurement tool)*	*Within Effect size for motor skill outcome*	*Between effect size for motor skill outcome*	*Motor skill task (frequency)*	*Quality of Study*
Ozonoff & Cathcart (1998)	social communication skills and behavioural skills (TEACHH)	N-RCT	autistic (11, 24-72 months)	autistic (11, 24 – 72 months)	16 weeks	210 minutes per week	home (parents)	fine motor (PEP-R)	0.82	0.45	N.I	0.60 (adequate)
								gross motor (PEP-R)	00.76	0.02	N.I	
								eye-hand integration (PEP-R)	0.70	-0.14	N.I	
Luiselli et al. (2000)	behavioural (N.I)	N-RCT	autistic (16, 26 - 57 months)	N.A	under 3 years old: 46 weeks	under 3 years old: 708 minutes per week	home (professionals)	fine motor (ELAP/LAP)	N.I	N.A	N.I	0.68 (adequate)
								gross motor (ELAP/LAP)	N.I	N.A	N.I	
					over 3 years old: 28 weeks	over 3 years old: 936 minutes per week		fine motor (ELAP/LAP)	N.I	N.A	N.I	
								gross motor (ELAP/LAP)	N.I	N.A	N.I	
Salt et al. (2002)	social communication skills (Scottish Early Intervention Program)	N-RCT	autistic (12 37, 42 months)	autistic (5 37, 42 months)	40 weeks	240 minutes per week	community settings (professionals and parents)	motor skills (VABS)	0	0.2	N.I	0.67 (adequate)
Luce (2003)	behavioural skills (Sensory-therapy Program)	N-RCT	autistic 14 (39 - 67 months)	N.A	24 weeks	N.I	community settings (professionals)	motor skills (VABS)	-0.12	N.A	N.I	0.75 (good)
		N-RCT			14 weeks				N.I	N.I	N.I	

Mukaddes et al. (2004)	cognitive skills (Psychoeducation Program)		autistic (10, 24 – 66 months)	children with reactive attachment disorder (11, 24 – 66 months)		45 minutes per week	home and community settings (parents, and professionals)	fine motor (ADSI) gross motor (ADSI)	N.I	N.I	N.I	0.68 (adequate)
Schwartz et al. (2004)	cognitive skills and social skills (Project DATA)	N-RCT	autistic 48 (36 – 72 months)	N.A	64 weeks	1200 minutes per week	home and community settings (parents, and professionals)	fine motor (AEPS)	N.I	N.A	N.I	0.63 (adequate)
								gross motor (AEPS)	N.I	N.A	N.I	
								motor imitation (AEPS)	N.I	N.A	N.I	
Howard et al. (2005)	cognitive skills (N.I)	N-RCT	autistic 29 (30, 37 months)	control group-1: autistic (16 (30, 37 months) control	56 weeks	intervention group : 1800 minutes per week	home and community settings (parents, and professionals)	motor skills (VABS)	0.25	intervention group and Control Group-1: 0.80	N.I	0.75 (good)
						control group-1: : 1800 minutes per week	community settings (professionals)	motor skills (VABS)	-0.42	intervention group and control Group-2: 0.75	N.I	
				control group-2: autistic 16 (30, 37		control group-2: 900 minutes per week	community settings (professionals)	motor skills (VABS)	-0.21)			
Paleo (2005)	behavioural skills (PARC Preschool Program)	N-RCT	autistic (50, 24 – 68 month)	N.A	N.A (2 community settings year)	2100 minutes per week	community settings (professionals)	fine motor (VABS ELAP/LAP)	N.I	N.A	N.I	0.72 (good)
								gross motor (VABS ELAP/LAP)	N.I	N.A	N.I	

								total motor (VABS ELAP/LAP)	N.I	N.A	N.I	
Boulware et al. (2006)	cognitive skills and social skills (Project DATA)	N-RCT	autistic (8, 18-29 month)	N.A	36 weeks	960 minutes per week	community settings (professionals)	motor imitation (AEPS)	N.I	N.A	N.I	0.46 (limited)
Ingersoll & Schreibman (2006)	cognitive skills (RIT)	N-RCT	autistic (5, 29 - 45 months)	N.A	10 weeks	80 minutes per week	community settings (professionals)	object imitation (MIS)	1.67	N.A	modelling of actions (3 times)	0.75 (good)
Goin-Kochel et al. (2007)	cognitive skills and social skills (N.I)	N – RCT	autistic (29, 29 - 61 months	N.A	24 weeks	N.I	home and community settings (professionals, and parents)	motor skills (ABLLS)	N.I	N.A	N.I	0.72 (adequate)
Remington et al. (2007)	cognitive skills and social skills (N.I)	N-RCT	autistic or at-risk of autism (23, 30 – 42 months)	autistic or at-risk of autism (21, 30 – 42 months)	96 weeks	1500 minutes week	home (parents and professionals)	motor skills (VABS)	2.10	0.41	N.I	0.71 (good)
Anan et al. (2008)	behavioral skills and social skills (GIFT Program)	N-RCT (quantitative case series)	autistic (72, 25 – 68 months)	N.A	12 weeks	300 minutes per week	home and community settings(parents)	fine motor (VABS) motor skills (MSEL)	0.49	N.A	N.I	0.70 (good)
Hayward et al. (2009)	cognitive skills, behavioral skills and social skills (UCLA ABA Program)	N-RCT	autistic (23, 24 – 42 months)	autistic (21, 24 – 42 months)	48 weeks	2160 minutes per week	intervention group: community settings (professionals) control group: home (parents)	motor skills (VABS)	N.I	N.I	N.I	0.71 (good)
Ingersoll (2010)	cognitive skills (RIT)	Pilot RCT	autistic (11, 27 – 47 months)	autistic (10, 27 – 47 months)	10 weeks	180 minutes per week	community setting(professionals)	object imitation (MIS)	N.I	N.I	modelling (3 times, 1 minute per times)	0.75 (good)

Smith et al. (2010)	social-communication skills (N.I)	N-RCT	autistic (50 months	autistic (28, 50 months	intervention group: 48 weeks	600 minutes per week	home and community settings(parents)	Motor skills (VABS II)	N.I	N.I	N.I	0.90 (strong)
					Intervention group: 24 weeks		home and community settings(parents)	Motor skills (VABS II)	N.I	N.I	N.I	
Freeman & Perry (2010)	cognitive skills, behavioral skills (N.I)	N-RCT	autistic (81, 20 – 83 months)	N.A	24 weeks	N.I	N.I	motor skills (VABS)	-0.08	N.A	N.I	0.65 (adequate)
McConkey et al. (2010)	social-communication skills (Keyhole Program)	N-RCT	autistic (35, 32 – 40 months)	autistic (26, 32 – 40 months)	36 weeks	N.I	home (parents)	fine motor (PEP-R)	0.94	N.A	N.I	0.71 (good)
								gross motor (PEP-R)	1.22	N.A	N.I	
								eye-hand coordination (PEP-R)	0.96	N.A	N.I	
								motor skills (VABS)	0.13	0.27	N.I	
Wong & Kwan (2010)	social-communication skills(Autism 1-2-3 program)	RCT	autistic (9, 17 – 36 months)	autistic (9, 17 – 36 months)	2 weeks	150 minutes per week	home and community settings(parents, and professionals)	sensory motor behaviour (RFRLRS)	N.A	N.A	N.I	0.78 (good)
Dawson et al. (2010)	cognitive skills, and social skills (ESDM)	RCT	autistic (24, 18 – 30 months)	autistic 24 (18 – 30 months)	96 weeks	1200 minutes per week	home (parents, and professionals)	fine motor (VABS)	-0.3	0.47	N.I	0.75 (good)
								motor skills (MSEL)	0.44	0.78	N.I	
		N-RCT		N.A	10 weeks				1.38	N.A		0.72 (good)

Ingersoll & Lalonde (2010)	cognitive skills (RIT)		autistic (4, 35 – 47 months)			180 minutes per week	community setting (professionals)	motor imitation (MIS)			Modelling (3 times, 1 minute per times)	
Zachor & Itzchak (2010)	Social communicatio n skills and behavioural skills (N.I)	N-RCT	autistic (45, 15 – 35 months)	autistic (33, 15 – 35 months)	48 weeks	Intervention group: 1200 minutes per week	community settings (professionals)	fine motor (VABS)	0.0	-0.32	N.I	0.75 (good)
								motor skills (MSEL)	-1.21	-0.1	N.I	
						control group: 1680 minutes per week		fine motor (VABS)	-0.87	N.I	N.I	
								motor skills (MSEL)	0.26	N.I	N.I	
Cardon & Wilcox (2011)	cognitive skills (RIT)	N-RCT	autistic (3, 20 – 40 months)	autistic (3, 20 – 40 months)	5 weeks	90 minutes per week	community settings (professionals)	motor imitation (MIS)	N.I	N.I	imitation of behaviours of the child (3 times)	0.68 (adequate)
Strain & Bovey (2011)	cognitive skills (LEAP)	RCT	autistic (117, 50 months)	autistic (117, 50 months)	96 weeks	900 minutes per week	community settings (professionals)	fine motor (MSEL)	1.95	0.69	N.I	0.75 (good)
Fava et al. (2011)	cognitive skills, behavioral skills (N.I)	N-RCT	autistic (12, 26 – 81 months)	autistic (10, 26 – 81 months)	24 weeks	intervention group: 840 minutes per week	community settings (professionals)	motor skills (VABS)	0.60	0.51	N.I	0.60 (adequate)
								locomotor skills (GMDS-ER 2–8)	N.I	N.I	N.I	
								eye-hand coordination (VABS)	N.I	N.I	N.I	
						control group: 720 minutes per week	home (parents)	motor skills (VABS)	1.30	N.I	N.I	
								locomotor skills (GMDS-ER 2–8)				

										N.I	N.I	
								eye-hand coordination (VABS)	N.I			
									N.A	N.I	N.I	
Waligórska et al. (2012)	behavioral skills (AutsimPro)	N-RCT	autistic (9, 36 – 84 months)	N.A	24 weeks	600 minutes per week	home (parents)	fine motor (PEP-R)	0.77	N.A	N.I	0.65 (adequate)
								gross motor (PEP-R)	1.02	N.A	N.I	
								eye-hand coordination (PEP-R)	0.76	N.A	N.I	
Cardon (2012)	cognitive skills (VMIT)	N-RCT	autistic (4, 24 – 50 months)	N.A	4 weeks	120 minutes per week	home (parents)	motor imitation (MIS)	N.I	N.A	modelling of actions (3 times)	0.68 (adequate)
Eikeseth et al. (2012)	behavioral skills (N.I)	N-RCT	autistic (35, 25 – 76 months)	autistic (24, 25 -76 months)	48 weeks	1380 minutes per-week	community settings (professionals)	motor skills (VABS)	0.40	0.72	N.I	0.67 (adequate)
Fornasari et al. (2012)	social communication skills and behavioural skills (TEACHH)	N-RCT	autistic (28, 23 – 97 months)	N.A	48 weeks	90 minutes per week	community settings (professionals)	fine motor (PEP-R)	1.59	N.A	N.I	0.65 (adequate)
								gross motor (PEP-R)	1.41	N.A	N.I	
								eye-hand coordination (PEP-R)	1.12	N.A	N.I	
Eapen, Črnčec & Walter (2013)	cognitive skills, and social skills (ESDM)	N-RCT	autistic (26, 36 - 58 months)	N.A	40 weeks	1200 minutes per week.	community settings (professionals)	fine motor (MSEL)	0.14	N.A	N.I	0.73 (good)
								fine motor (VABS II)	0.12	N.A	N.I	
								gross motor (VABS II)	0.86	N.A	N.I	
								motor skills (MSEL)	0.45	N.A	N.I	

Reitzel et al. (2013)	behavioural skills (FBST)	RCT	autistic (14, 38 – 82 months)	autistic (12, 38 82 months)	16 weeks	120 minutes per week	community settings (parents and professionals)	motor skills (VABS II)	-0.19	0.60	N.I	0.75 (good)
Vivanti et al. (2013)	cognitive skills, and social skills (ESDM)	N-RCT	autistic (21, 22 – 58 months)	N.A	a full calendar year (N.S)	900 to 1500 minutes per week	community settings (professionals	fine motor (MSEL)	N.O	N.A	N.I	0.69 (adequate)
Virues-Ortega et al. (2013)	cognitive skills, behavioral skills (N.I)	N-RCT	autistic (24, 50 months)	N.A	87 weeks	1912 minutes per week	Home (parents, and professionals)	fine motor (E-LAP, LAP-D 3)	N.I	N.A	N.I	0.77 (good)
								gross motor (E-LAP, LAP-D 3)	N.I	N.A	N.I	
D'Elia et al. (2014)	cognitive skills, behavioral skills (TEACH)	N-RCT	autistic (15, 24 - 83 months)	autistic (15, 24 – 83 months)	96 weeks	240 minutes per week	home and community settings (parents, and professionals)	motor skills (VABS)	2.26	0.27	N.I	0.67 (adequate)
								fine motor (PEP-3)	1.42	N.I	N.I	
								gross motor (PEP-3)	0.86	N.I	N.I	
								visual-motor imitation (PEP-3)	0.83	N.I	N.I	
								characteristic motor behaviour (PEP-3)	1.16	N.I	N.I	
Ben-Itzchak et al. (2014)	cognitive skills, behavioral skills (N.I)	N-RCT	autistic (46, 17 – 33 months)	N.A	96 weeks	1200 minutes per week	community settings (parents and professionals)	motor skills (VABS)	-0.64	N.A	N.A	0.68 (adequate)
								fine motor (MSEL)	-0.4	N.A	N.I	
		N-RCT		N.A	10 weeks		home (parents)		0.16	N.A	N.I	0.72 (good)

Liao et al. (2014)	behavioral skills (DIR/Floortime)		autistic (11, 45 - 69 months)			600 minutes per week		motor skills (VABS II)				
Wetherby et al. (2014)	Social-communication skills (N.I)	RCT	autistic (42, 16 – 20 months)	autistic (42 - 16 – 20 months)	36 weeks	1500 minutes per week	home (parents)	motor skills (VABS II)	N.I	N.I	N.I	0.85 (strong)
							community settings (parents)	fine motor (MSEL)	N.I	N.I	N.I	
								motor skills (VABS II)	N.I	N.I	N.I	
								fine motor (MSEL)	N.I	N.I	N.I	
Iwanaga et al. (2014)	behavioral skills (SIT)	N-RCT	autistic (8, 33 – 84 months)	autistic (12, 33 – 84 months)	32 – 40 weeks	60 minutes per week	community (professionals)	coordination (JMAP)	N.I	N.I	N.I	0.53 (limited)
Fulton et al. (2014)	cognitive skills, behavioral skills (ESDM)	N-RCT	autistic (38, 24 – 72 months)	N.A	12 weeks	90 to 1200 minutes per week	community (professionals)	motor skills (VABS II)	-0.18	N.A	N.I	0.68 (adequate)
								fine motor (MSEL)	0.19	N.A	N.I	
Paynter et al. (2015)	cognitive skills, behavioral skills (Australian Autism Specific Program)	N-RCT	autistic (59, 30 – 71 months)	N.A	48 weeks	1500 minutes per week	community (professionals)	motor skills (VABS II)	0.11	N.A	N.I	0.63 (adequate)
								fine motor (MSEL)	-0.3	N.A	N.I	
Chang et al. (2016)	social-communication skills (JASPER)	RCT	autistic (38, 24 – 60 months)	autistic (28, 24 – 60 months)	12 weeks	N.I	community settings (professionals)	fine motor (MSEL)	N.I	N.I	N.I	0.78 (good)
Krishnan et al. (2016)	behavioral skills (N.I)	N-RCT	autistic (77, 42 months)	N.A	12 weeks	1200 minutes per week	community (parents)	fine motor (PEP-R)	0.88	N.A	N.I	0.77 (good)

								gross motor (PEP-R)	0.71	N.A	N.I	
								eye-hand coordination (PEP-R)	0.55	N.A	N.I	
								fine motor (PEP-R)	0.98	N.A	N.I	
								gross motor (PEP-R)	0.93	N.A	N.I	
								eye-hand coordination (PEP-R)	0.87	N.A	N.I	
Boccanfuso et al. (2017)	cognitive skills (Robot – Assisted Intervention)	N-RCT	autistic (5, 36 – 72 months)	autistic (3, 36 – 72 months)	6 – 12 weeks	60 min per week	community (professionals)	motor imitation (MIS)	N.I	N.I	imitation games (30 minutes)	0.64 (adequate)
Whitehouse et al. (2017)	cognitive skills, social-communication skills (TOBY)	RCT	autistic (39, 40 months)	autistic (36, 40 months)	24 weeks	1400 minutes per week	home (parents)	fine motor (VABS II)	N.I	N.I	N.I	0.67 (adequate)
								motor skills (MSEL)	N.I	N.I	N.I	
Zachor et al. (2017)	behavioral skills, social-communication skills (Outdoor Adventure Program)	N-RCT	autistic (30, 40 – 88 months)	autistic (21, 40 – 88 months)	13 weeks	30 min. per week	community settings (professionals)	motor skills (VABS)	0.24	N.I	a two-way climbing rope ladder (N.A) rope elevator(N.A) rope bridge (N.A) hammock (N.A) rope swing (N.A)	0.57 (limited)
Alquraini et al. (2018)	social-communication skills (N.I)	RCT	autistic (13, 36 – 60 months)	autistic (15' 36 – 60 months)	24 weeks	60 minutes per week	home and community settings	fine motor (DDTS II)	0.61	N.I	N.I	0.75 (good)
									0.21	N.I	N.I	

							(parents, and professionals)	gross motor (DDTS II)				
Parsons et al. (2019)	cognitive skills, social-communication skills (TOBY)	RCT	autistic (30, 24 – 72 months)	autistic (29, 24 – 72 months)	12 weeks	1400 minutes per week	home (parents)	fine motor (MSEL)	0.39	-0.7	playing game with a tablet (20 minutes)	0.85 (strong)
Töret & Özmen (2019)	cognitive skills (RIT)	N-RCT	autistic (3, 26, 42 months)	N.A	5 weeks	90 minutes per week	community (professionals)	motor imitation (MIS)	N.I	N.A	imitation of (1,5 minutes) modelling of actions (1,5 minutes)	0.68 (adequate)
Beaudoin et al. (2019)	behavioral skills (N.I)	RCT	at-risk for autism (9, 12 – 30 months)	at-risk for autism (9, 12 – 30 months)	12 weeks	45 to 90 minutes week	home (parents, and professionals)	fine motor (BSID – 3)	N.I	N.I	N.I	0.75 (good)
								gross motor (BSID – 3)	N.I	N.I	N.I	
								motor skills (BSID – 3)	N.I	N.I	N.I	
Whitehouse, et al. (2019)	social-communication skills (iBASIS-VIPP)	RCT	at-risk for autism (51, 9 – 14 months)	at-risk for autism (53, 9 – 14 months)	12 weeks	N.I	home (professionals)	fine motor (MSEL)	3.04	0.33	N.I	0.85 (strong)
Vietze & Lax (2020)	behavioral skills (N.I)	N-RCT	autistic (106, 20 – 40 months)	N.A	N.I	2600 minutes per week	community settings (professionals)	motor skills (BSID – 2)	0.54	N.A	N.I	0.81 (strong)
Sinai-Gavrilov, Gev et al. (2020)	cognitive skills, behavioral skills (ESDM)	N-RCT	autistic (26, 43 – 45 months)	autistic (25, 43 – 45 months)	32 weeks	2640 minutes per week	community settings (professionals)	motor skills (VABS II)/parents report	-0.11	0.22	N.I	0.75 (good)
								motor skills (VABS II)/teacher report	0.07	-0.23	N.I	

								fine motor (MSEL)	0.56	0.56	N.I	
Lin et al. (2020)	cognitive skills, behavioral skills (ESDM)	N-RCT	autistic (16, 25 – 46 months)	N.A	24 weeks	480 minutes per week	community settings (professionals)	fine motor (MSEL)	0.19	N.A	N.I	0.72 (good)
Lau at al. (2021)	behavioral skills (N.I)	N-RCT	autistic (9, 48 – 84 months)	autistic (9, 48 – 84 months)	10 weeks	60 minutes per week	N.I (professionals)	characteristic motor behaviour (CPEP-3)	1.34	0.63	tabletop activities like drawing (N.A) dancing (N.A)	0.64 (adequate)
Yoder et al. (2021)	social-communicatio n skills (Community Based Activity Programme)	RCT	at-risk for autism (47, 12 – 18 months)	at-risk for autism (44, 12 – 18 months)	12 weeks	300 minutes per week	home (parents)	motor imitation (SSIS – ALIT)	N.I	N.I	0.03	0.85 (strong)

AEPS: Assessment, Evaluation, and Programming System; BSID: Bayley Scales of Infant Development; CPEP: Chinese Psychoeducational Profile; DDTS: Denver Developmental Screening Test; E-LAP: Early Learning Accomplishment Profile; ESDM: Early Start Denver Model; FBST: Functional Behavior Skills Training; GIFT: Group Intensive Family Training; EMQ: Early Motor Questioner; IBI: Intensive Behavioural Intervention; JMAP: Japanese version of the Miller Assessment for Preschoolers; LAP-D: Learning Accomplishment Profile-Diagnostic; LAP: Learning Accomplishments Profile; MIS: Motor Imitation Scale; MSEL: Mullen Scales of Early Learning; N.A: Not Applicable ; N-RCT: Non-Random Control Trail; N.I: No Information; PDMS The Peabody Developmental Motor Scale; PEP-R: The Psychoeducational Profile-Revised; Project DATA: Development Appropriate Treatment for Autism; PARC: Putnam Associated Resource Centre; RCT: Random Control Trail; RFRLRS: Ritvo-Freeman Real Life Rating Scale;

RIT: Reciprocal Imitation Training; SSIS: Semi-Structured Imitation Scale; ST: Sensory Therapy; TEACHH: Teaching and Educating Autistic and Related Communication Handicapped Children; TOBY: Therapy Outcomes By You; UCLA ABA: University of California at Los Angeles Applied Behavior Analysis; VABS: Vineland Adaptive Behaviour Scales

RQ. 2. What types of motor skills (e.g., fine motor; gross motor; motor imitation) are included in non-motor skill early interventions for young autistic children?

Across 59 early interventions which were identified in 55 study (see Table 3), there were 11 different motor skill outcomes included within the early intervention programs (e.g., characteristic motor behaviour; eye-hand coordination; fine motor skill, motor imitation; locomotor skills; visuomotor skill). These early interventions focused mainly on fine motor skills (*n*= 32), gross motor skills (*n* = 14) and a combination of fine and gross motor skills as defined in standardised motor skills measurement tools (*n* = 30), such as VABS, or Mullen Scales of Early Learning (MSEL). There was less focused on imitation (*n* = 10) and hand-eye coordination skills (*n* = 6).

RQ.3. What are the methodological characteristics used for training motor skills in non-motor skill early interventions for young autistic children?

Motor Skill Task, Training Frequency, Intensity, and Duration

Across the 59 early interventions which were identified in 55 study, 50 early intervention studies provided no specific information regarding the motor skill tasks, and intensity of delivery, used to support autistic children. From the remaining nine studies, six (Ingersoll & Schreibman, 2006; Ingersoll, 2010; Ingersoll & Lalonde, 2010; Cardon & Wilcox, 2011; Cardon, 2012; Töret & Özmen, 2019) used a variety of tasks relating to motor imitation, object imitation, video modelling, and verbal and non-verbal imitation. For frequency, most required children to make three imitation attempts (e.g., Cardon, 2012; Ingersoll, 2010) for a duration of one-minute (Ingersoll & Lalonde, 2010) or 5-

minutes (Beaudoin et al., 2019). The remaining non-imitation early intervention presented information about the motor tasks used such as climbing a two-way rope ladder, using a rope elevator, walking a rope bridge, swinging between trees (Lau et al., 2021) or drawing and dancing (Zachor et al., 2017), but no information was provided about task frequency.

Although most of not-motor skill early interventions did not provide information about frequency of motor skill task, they provided information about overall duration and intensity of early interventions. As indicated in Table 2, the duration of the early programs ranged between two - 12 weeks (*n* = 21), 13 - 24 weeks (*n* = 13), 25 - 48 weeks (*n* = 14) and 48 - 96 weeks (*n* = 8), with only three studies (Paleo, 2005; Vivanti et al., 2013; Vietze & Lax, 2020) not providing information on the length of the early intervention programs (see Table 2). For intensity, the dosage ranged between 30 - 150 minutes (*n* = 14), 151 - 300 minutes (*n* = 8), 301 - 600 minutes (*n* = 4), 601 - 1200 minutes (*n* = 11), 1201 - 2400 minutes (*n* = 14) and 2401 - 2640 minutes (*n* = 2), with six studies (Luce, 2003; Goin-Kochel et al., 2007; Freeman & Perry, 2010; McConkey et al., 2010; Chang et al., 2016; Whitehouse et al., 2019) not providing information on the intensity of the early intervention (see Table 3).

Setting and Instructor

In terms of setting and instructor, the early interventions were performed at home (*n* = 16), community settings (e.g., schools; childcare centres) (*n* = 33) and both home and community settings (*n* = 10). These early interventions were conducted by parents (*n* = 15), professionals (e.g., teachers; therapists) (*n* = 30), and both parents and professionals (*n* = 14) (see Table 3).

Movement Measurement

In terms of measurement tools, all 59 early interventions used standardised and validated measurement tools (e.g., VABS or MSEL) for quantifying motor skill outcomes (see Table 3).

The effectiveness ('effect size') of Non-Motor Skill Early Interventions

Among the 59 included non-motor skill early intervention programs, within subject-effect sizes were calculated for 36 early intervention programs (see Table 3), whereas the remaining 23 early interventions did not provide mean and SD scores from pre- and post-tests. The results indicated the effect sizes were reported to be large for 11 early interventions, medium for four early interventions, small for 12 early interventions, seven provided negative scores and two early interventions did not provide within-subject effects after the early interventions program. For the between-subject comparisons, effect sizes were calculated for 17studies with the remaining 38 studies not providing mean and SD data. The results indicated the effect sizes were reported to be medium for six early interventions, small for 8 early interventions, and negative for two early interventions (see Table 3).

Exploratory Analysis 1

After the systematic review was completed, it was observed that out of the reviewed early interventions, 10 were directly aimed at improving motor skills, while 59 early interventions were not specifically designed to improve motor skill but included motor skill outcomes. To explore the differences between their effectiveness on motor skill outcomes, an exploratory analysis was undertaken by comparing motor skill and non-motor skill early intervention by using *Welch's unequal variances t-test*. The *Welch's unequal variances t-test* was used as the sample sizes for the groups were unequal (Delacre et al., 2017). The *t*-test indicated there was no significant difference [t (4.56) = 0.77, p = 0.477] between the two motor skill outcomes.

Exploratory Analysis 2

After completing the systematic review, it was noted that many early intervention studies have small sample sizes. Small sample sizes can lead to publication bias because studies with a large sample size are likely to be published regardless of the significance of the results, studies with a small sample size are at risk of not being published if their results are non-significant. This implies that studies with a small sample size can only be published if they have statistically significant results. Therefore, the small sample size effect is regarded as one of the most common reasons for publication bias (Harrer et al., 2021).

An exploratory analysis was conducted across included motor skill and non-motor skill early intervention studies that provided data to calculate effect sizes and standard error (n = 41). A funnel plot was created to assess the potential publication bias stemming from these small sample sizes in the studies. A funnel plot is a graphical representation for observed effect sizes of studies and are plotted on the x-axis against a measure of standard error on the y-axis (Simmonds, 2015). Typically, the y-axis in funnel plots is reversed, and "higher" values on the y-axis correspond to lower standard errors. Studies with large sample sizes and low standard errors cluster in the top part of the funnel, closely around the pooled effect size. Conversely, studies with high standard errors and low sample sizes are positioned at the bottom of the plot and are distant from the pooled effect size (Harrer et al., 2021). If there is no publication bias, the data points form a symmetrical pattern, but the interpretation of a funnel plot as "symmetric" or "asymmetric" lacks a clear rule and is suggested to be subjective (Egger, 1997). Therefore, to provide a quantitative measure of potential publication bias an Egger’s regression test was used to measure asymmetry in the funnel plot (Freeman & Sutton, 2020; Harrer et al., 2021).

As illustrated in the Funnel Plot (see Figure 5), there is an asymmetrical pattern of the studies in respect to effect size (x axis) and standard error (y axis) where most studies are positioned in the top-left of the funnel plot. The top left hand of the funnel represents studies that have low standard error scores and small effects sizes, which suggests high precision. Although the observation is asymmetrical, the *Egger’s Regression* test indicated the plot was not significant [i.e., $p = 0.70$) indicating no evidence for publication bias among early interventions. To further test the Egger's outcome (Simmonds, 2015), a *Cochran's Q statistic* was conducted that indicated significant heterogeneity across studies [i.e., (Q (40)= 309.53, $p < 0.0001$)]. Given the heterogeneity, visual examination of the funnel plot was carried out, which inferred a bias in the included studies related to small sample size effect.

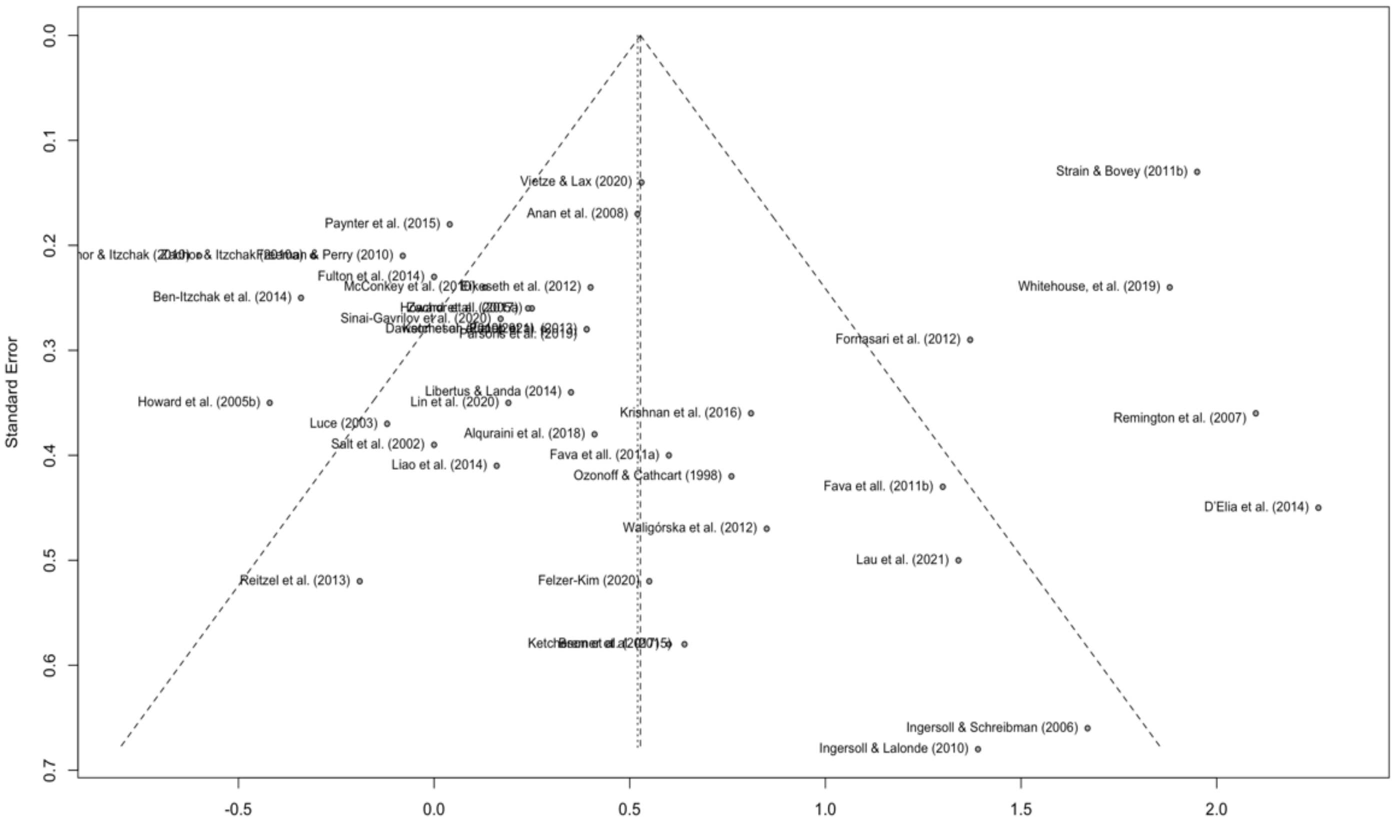


Figure 5: Illustrates a Funnel Plot to visual publication bias across early intervention studies. Effect size is plotted on the x-axis and standard error on the y-axis.

Discussion

The current systematic review examined the critical ingredients of early interventions that included motor skill outcomes. Results showed that, while 10 early interventions mainly focused on improving motor skills of young autistic children, most early intervention program (*n* = 59) principally focused on improving other behavioural (e.g., repetitive behaviour), cognitive (e.g., language), or social-communication skill outcomes.

In terms of the study quality, the general level of study quality across the 65 included studies was good based on the ‘standard quality assessment criteria' (Kmet, 2004), with seven early interventions demonstrating 'strong quality' and nearly half (*n* = 30) rated as 'good' quality. Although these findings are positive, and consistent with previous systematic reviews (e.g., Colombo-Dougovito & Block, 2019), the main methodological concern across motor early interventions and non-motor early interventions were the small sample sizes. Small sample sizes need to be appraised with a level consideration as these samples may inflate effect sizes and therefore lead to the findings not being generalisable to a target population (Kadam & Bhalerao 2010; Button et al., 2013). Moreover, small sample size may lead to publication bias (Harrer et al., 2021). The results of exploratory analysis indicated that, there was a publication bias. Small sample sizes increased the standard error, which is the standard deviation of the sampling distribution. That is, as the sample size increases, the standard error decreases, resulting in a more precise estimate of the true population mean for the study (Harrer et al., 2021). Hence, future early intervention studies that aim to improve the motor skills of young autistic children can work with a large sample size to eliminate small study effects on publication bias.

In addition to the sample size consideration, 70% of the motor early interventions and nearly half of the non-motor early interventions did not use an active control group, which was not exposed to the intervention treatment within the experimental design. Therefore, it is suggested that future early interventions that are designed to facilitate motor outcomes should compare the effects of an early interventions against an active control group, in order to quantify that the motor improvements are based on the treatment effect and not other factors (e.g., impact of families; new learning environment) (Cuijpers et al., 2017).

What types of motor skills (e.g., fine motor; gross motor; motor imitation) are included in motor and non-motor skill early interventions for young autistic children?

Identified motor and non-motor skill early interventions included 32 different motor skill outcomes, but they mostly contained FMS, fine and gross motor skills outcomes as in previous literature review (Colombo-Dougovito & Block, 2019). FMS, fine and gross motor skills are very critical in the early years, because children use these skills to explore and interact with their environment (Herrero-Nivela & Losada, 2020). This exploration allows the child to develop cognitive, and social skills (Veldman, et al., 2016). The importance of these motor skills in the early years may be one reason why early interventions focused on especially FMS, fine and gross motor skills.

What are the methodological characteristics used for training motor skills in motor and non-motor skill early interventions for young autistic children?

Although frequency of tasks showed differences across early interventions, they improved motor skill outcomes of young autistic children. However, to understand effectiveness of early intervention, effect size could calculated for just 5 of the early intervention studies that focused on motor skills. Hence, the findings should be interpreted with care. Regarding non-motor skill early intervention, the specific motor tasks employed, and the number of trials (including dosage) performed by autistic children during task practice remain largely unknown for most early intervention. This lack of dosage information related to the motor activities may stem from the primary focus of non-motor skill early intervention, which is typically directed at enhancing core features of autism rather than specifically targeting motor skill outcomes. Information related to motor skill tasks and their frequency can be elucidated through examination of early interventions' manuals. Therefore, for a comprehensive understanding of motor skill tasks and their frequency in non-motor skill early interventions, future research efforts can be directed towards a detailed analysis of the manuals associated with these early interventions.

Setting and Instructor in motor and non-motor skill early interventions

Most motor skill early interventions were conducted in community settings by professionals as showed in previous reviews (e.g., Colombo-Dougovito & Block, 2019). Conducting early interventions in community settings offers several advantages, such as utilizing a structured environment with easily accessible materials and being less time-consuming for trainers who do not have to visit different children's homes (Leaf et al., 2018). However, it is important to acknowledge that not every child may have access to community settings. For instance, some children's immediate neighbourhood might lack a community centre for early intervention and travel to centres in remote areas could be financially challenging for parents (Leaf et al., 2018). In such cases, there may be advantages to conducting early interventions at home by families. As only 1 motor-specific early intervention was conducted at the home, it is suggested that future research in the motor skill early interventions field can focus on developing early interventions that can be applied in the home environment and implemented by families. In terms of non-motor skill early interventions, setting and instruction showed heterogeneity because of different early interventions and it made difficult to draw a meaningful conclusion.

Measurement tools in motor and non-motor skill early interventions

In terms of measurement of movement, most included both motor and non-motor skill early interventions used standardized measurement tools (e.g., VABS, MABC, or TGMD), and none of them used kinematic analysis as indicated in previous systematic review (e.g., Colombo-Dougovito & Block, 2019). Kinematic analysis is based on recording the movement of specific body segments while the person is executing the skill. These recordings are performed by motion capture devices (e.g., a marking pen, special light-reflecting balls, light-emitting diodes (LEDs) (Arslan et al., 2019). The reason for not using this method may be that kinematic analysis is more difficult, costly and time consuming to apply to children than the standard measurement tools. Although standardised measurement tools have many advantages (e.g., providing meaningful data, being easy to implement, low-cost, and time efficient, they do not provide detailed information on how the underlying motor control processes underpin motor skill acquisition (Downs & Strand, 2006; Gowen & Hamilton, 2014). There are five motor control processing stages that underpin acquisition: (1) sensory system, (2) state estimation, (3) inverse model, (4) forward model, and (5) motor execution. These specific stages should be evaluated before and after the interventions to understand motor skill improvement in children (Gowen & Hamilton, 2014). Evaluation of these processes is only possible with kinematic analysis, which quantifies how the movement changes (displacement, velocity, and acceleration) across the position and orientation of the body segments (Magill & Anderson, 2010). Hence, future early intervention studies can use kinematic analysis methods alongside standardised measurement tools to comprehend improvements in motor skill outcomes.

The effectiveness ('effect size') of motor and non-motor skill early interventions

The results of the effect size calculations revealed that both motor and non-motor early interventions improved motor skill outcomes of young autistic children. But it is worth to note that sample size among early interventions was small, and only 15 early interventions studies used relatively big sample size (i.e., >50). For example, the only study (Felzer-Kim, 2020) that provided both within and between subject effect on motor skill outcomes was conducted with just fourteen participants. As it stated before, small sample size limits generalisability of the results which is unfortunately often the case across early intervention studies. Future research can focus on strategies that how sample size can improve in early intervention studies. Furthermore, it's crucial to highlight that effect sizes for motor skill outcomes could not be calculated for 25 early interventions due to insufficient information provided in the associated studies. This has made it difficult to draw a clear conclusion of the effects of early interventions on motor skill outcomes. As in suggested in one of previous content analysis study (Outhwaite et al., 2022), future research can address these issues by improving the reporting standards of their results for supporting the analysis and synthesis of evidence which plays a critical role in advancing the field.

Another key issue to understand effectiveness of early intervention on motor skill outcomes was heterogeneity among early intervention studies. Due to the heterogeneity across motor skill outcomes, outcome measures, as well as early interventions, doing meaningful comparison and meta-analysis were a challenge as in previous reviews (e.g., French & Kennedy, 2018; Ruggeri et al., 2020). In order to address this issue, future studies might focus on specific early interventions that identified in this review (e.g., ESDM) to perform meta-analyses across motor skill outcomes. Alternatively, based on the results of the current review, researchers may choose to explore early interventions, that have similar motor skill outcome measures and conduct meaningful comparisons through subgroup analysis for motor skill outcomes. This targeted approach could help address the challenges associated with heterogeneity and enhance the precision of analyses in the early intervention literature.

As indicated before, exploratory analysis' results showed that there were no significant differences in the effects of motor and non-motor skill early interventions on motor skill outcomes. In other word, non-motor skill early interventions were just as effective as motor skill early interventions in supporting the motor skill outcomes of young autistic children. These findings can be explained with different motor skill tasks that used in current non-motor skill early intervention program such as drawing, colouring, or cutting. As hypothesised in previous studies (e.g., MacDonald et al., 2013), these motor skill tasks may contribute to the improvement of motor skill outcomes of young autistic children. Therefore, it can be claimed that, to support autistic children's motor skill development, existing non-motor skill early interventions can be effectively utilized. Future studies in the field can focus on improving motor skill tasks in existing early interventions and exploring strategies for supporting motor skills development of young autistic with them. Adaptation of motor skill tasks found in existing non-motor skill early interventions based on motor learning principles would be a good starting point for future research.

Gaps in the Literature

The current review has identified several significant gaps in this research area, particularly in relation to methodological aspects of early interventions. Firstly, among the included early interventions, only a few studies were rated as having strong quality. Additionally, publication bias was observed due to small sample sizes across studies. These methodological considerations could impact the interpretation of results. Furthermore, both motor and non-motor early interventions demonstrated the potential to improve motor skill outcomes in young autistic children. However, the effect size for 25 early interventions could not be calculated due to insufficient information, posing a challenge for generalising the results.

There were some important gaps in critical ingredients of early interventions. For instance, while motor skill outcomes, settings, and instructors varied across non-motor early interventions, motor early interventions predominantly focused on FMS, and conducted by professionals in community settings. Only 1 early intervention conducted by parents at home and focused on fine motor skills. Moreover, despite the kinematic analysis technique being recognized as providing the most reliable data for understanding the underlying mechanisms of motor skill difficulties and improvements (Gowen & Hamilton, 2014), none of the motor and non-motor early interventions incorporated this technique. Consequently, it is challenging to ascertain how early interventions influenced the motor control processes essential for acquiring motor skill outcomes.

Conclusion and Future Direction

This review thoroughly isolated the critical ingredients of existing early interventions that include motor skill outcomes for young autistic children. The findings of the review suggest that both motor and non-motor early interventions show promise in improving motor skill outcomes for autistic children. However, in the future, there is a clear need for methodologically robust early intervention studies with larger sample sizes to provide more reliable and conclusive evidence in this area. Furthermore, the review findings highlighted a scarcity of motor skill early interventions specifically targeting fine motor skills, primarily conducted at home by parents. To address this gap, there is potential for developing new home-based, parent-mediated motor skill early interventions or adapting existing early interventions based on principles of motor skill learning. These early interventions should incorporate kinematic analysis as well as standardised measurement tools to quantify improvements in motor skills outcomes of young autistic children. This becomes crucial for comprehending the underlying motor mechanisms linked to motor skill difficulties or differences in this population. It provides an opportunity to develop new early interventions or adapt existing ones to specifically support the motor skills of young autistic children.

How the Findings of the Systematic Review Informed the Subsequent Studies

As previously indicated, the results of the review demonstrated that while both motor and non-motor skill early interventions improved motor skill outcomes among young autistic children, they had some limitations such as small sample sizes and the absence of control groups. Consequently, the generalizability of their findings was limited. Notably, all motor and non-motor skill early interventions employed standardized measurement tools to assess improvements in motor skill outcomes rather than kinematic analysis methods. Thus, it remained unclear whether these interventions addressed the underlying mechanisms of motor skills improvement in young autistic children, which necessitated evaluation both before and after the interventions to comprehend the motor skill enhancements in children (Gowen & Hamilton, 2014). Additionally, existing motor and non-motor interventions had not focused on the types of practice (i.e., blocked versus random) that were seen as one of the foundations of the motor learning process.

The systematic review's findings shaped AiMS intervention. Based on these findings, the decision was made to develop a motor skill early intervention program (i.e., AiMS) to support young autistic children's motor skills based on the specificity of practice (i.e., blocked versus random). In AiMS intervention, the kinematic analysis method was used as an assessment tool to understand impact of AiMS to underlying motor mechanism of young autistic children. To increase the reliability and generality of the AiMS intervention study, a control group was used, and the participant number of the study was determined based on power analysis.

Another significant finding from the systematic review was that 90 percent of early motor skill interventions were conducted in schools by professionals. This highlighted a gap in home-based, parent-mediated interventions for supporting young autistic children's motor skills. To address this gap, AiMS was designed as a home-based, parent-mediated intervention. The findings from the review also shaped the second study because parents became the main stakeholders in the AiMS intervention. Based on these findings, the second study, a survey, focused on understanding parents' perceptions of their young children's motor skills.

The AiMS intervention aimed to fill a gap in the literature regarding motor skill early interventions for young autistic children based on motor learning principles by using kinematic analysis method. Considering that non-motor early intervention can enhance the motor skills of young autistic children, the AiMS intervention and analysis method could be integrated with existing non-motor skill early interventions (e.g., ESDM), because none of these interventions used this method. Alternatively, since AiMS intervention tasks were developed based on motor learning principles, the motor tasks within existing non motor skill early interventions could be adapted or modified based on the principles and logic underlying the tasks within the AiMS intervention.

Chapter 5: Survey for parental perceptions about motor skills and motor skills activities in the home: autistic and non-autistic young children

The previous systematic review chapter's results indicated that, while motor skill intervention to support young autistic children mostly conducted at community centre (i.e., school), by professionals (i.e., teacher), limited early intervention conducted by parents at home. To address this gap, AiMS was developed home based, parent-mediated early intervention program. When developing new early interventions, especially parent-mediated early interventions, parents can be regarded as one of the most important stakeholders because they have the main responsibility for the process of seeking, choosing, or conducting early interventions for their children (Mire et al., 2017). Research has shown that parental perceptions (including their knowledge and beliefs) directly affect their early intervention chose for their children (Al Anbar et al., 2010; Mire et al., 2017). As such, to develop new early interventions that can successfully support young autistic children's motor skills in the early years, it is critical to understand parents' perceptions towards motor skills.

In terms of the motor skills of young autistic children, a limited number of studies have focused on parental perceptions, and no studies, as far as known by the authors, have focused specifically on parents' knowledge or beliefs about the motor skills of young autistic children. For example, two studies (Petrina et al., 2015; Ma et al., 2023) investigated parental perceptions of the importance of friendship development in contrast to physical and motor development, social skills, intellectual and academic skills, creativity, and emotional capacity. In these studies, parents of autistic children aged between 3 – 12 years were asked to rate and rank the importance of these outcomes. These studies' results showed that while parents ranked social and emotional skills as the most important outcome, physical and motor development were only ranked as fifth (Petrina et al., 2015) and third (Ma et al., 2023) for autistic children. Two other studies (Pituch et al., 2010; Ghanadzadea et al., 2018) investigated parents' perceptions about intervention priorities for their autistic children aged between 2 – 21 years old. In these studies, parents were asked to rate their top ten intervention priorities among 10 main categories (i.e., motor skills, self-care skills, domestic living skills, community living skills, job skills, recreational skills, social skills, communication skills, academic skills, and problem behaviour). The results showed that parents' top treatment priorities consisted of social and communication skills, academic skills, or community living skills. In these studies, parents did not rank any motor skills in the top ten priorities.

In another study (Rios & Scharoun Benson, 2020), the researcher conducted semi-structured interviews to explore caregivers' perspectives on social and motor skills in autistic children aged 5 to 9 years old and the impact on participation in social activities. Parents reported social skills difficulties to be a greater obstacle to participation in social activities than motor skills difficulties. Another study (Must et al., 2015) investigated the perceptions of parents of autistic and non-autistic children aged between 3 - 11 years about barriers to participating in physical activities. They found that parents of autistic children reported more barriers than parents of non-autistic children, such as poor motor skills, behaviour and learning problems, and the need for supervision. As far as the authors know, no studies directly focus on motor skill activities that parents do with their young autistic children. Therefore, how parents support their children's motor skills is not known.

In terms of non-autistic children, again studies about parental beliefs on motor skills are scarce but few studies have focused on the importance of physical activities for children. For example, Agard and colleagues (2021) conducted a semi-structured survey with 26 parents of non-autistic preschool children and showed that parents are not aware of the importance of physical activities. Another survey (Lopez-Dicastillo et al., 2010) was conducted with 47 parents of non-autistic young children (aged between 5 - 7) found that parents did not rate physical activities to be important as many considered that their children are active already and that physical activities are unnecessary.

Current Study

To date, limited research has explored parental beliefs and knowledge concerning the significance of motor skills and abilities in young autistic and non-autistic children. Additionally, as far as it is known, no studies have focused on activities that parents do with their children to support their motor skills. This study addressed these gaps by investigating parental perceptions of motor skills in comparison to literacy and math skills, both for parents of young autistic children and parents of non-autistic children in the UK. This study also investigated the frequency of motor skill activities that parents do with their children at home compared to literacy and math activities.

Specifically, this study focused on three key areas. First, it examined parental beliefs regarding the importance of motor skills in young children's daily life, future academic success, and overall skill development, compared to their beliefs about literacy skills. Drawing on existing literature (e.g., Ghanadzadea et al., 2018; Agard et al., 2021), it was hypothesised that parents, irrespective of their child's neurodevelopmental condition, believe that literacy skills are more important than motor skills. This study also explored parental knowledge concerning motor skills development compared to literacy and math skill development. In line with previous research (e.g., Agard et al., 2021), it was hypothesised that parents, regardless of their child's neurodevelopmental status, have greater knowledge about literacy skills compared to maths and motor skills development. Finally, this study investigated the frequency of motor skills, literacy skills and maths skills activities that children engaged in with their parents at home. Drawing on prior research findings (e.g., LeFevre et al., 2009; Lopez-Dicastillo, 2010; Ranzato et al., 2021), it was hypothesised that children would engage in more literacy and maths activities than motor skills activities.

Methods

Design

The study was a between-groups design where parents/caregivers of young autistic (parent-autism) and non-autistic (parent-non-autism) children aged between 0 and 5 completed an online survey in the UK using Qualtrics[XM] (www.qualtrics.com/uk/). Qualtrics was selected as it is an effective software platform for online survey creation, data collection, analysis, and reporting and was used to distribute the survey to target audience. The survey was designed to examine group differences between parents/caregivers' *knowledge* about motor skills of their children, *beliefs* about the importance of motor skills for their children's development, and the frequency and types of motor skills *activities* they do with their children at home. Within each group, the domain of motor skills was compared to *knowledge*, *beliefs*, and frequency and types of *activities* of the two control domains literacy skills and maths skills.

Data Cleaning

The online survey was viewed by a total of 447 people, with 239 not completing any of survey items including the consent form, and 23 only completing the consent form. The remaining responses were checked in detail and those that were incomplete (*n* = 50) because responders only answered a few items, did not live in the UK (*n* = 1), did not state whether a child had special educational needs (*n* = 14) and their child was older than 6 years (*n* = 6) were excluded from the final analysis leaving a total of 114 participants.

Participants

The 114 participants were recruited via opportunity sampling from existing professional networks (e.g., schools) and social media platforms (e.g., Twitter/X; Facebook). Of the total, there were 55 parents/caregivers of autistic children and 59 parents/caregivers of non-autistic children. The parents/caregivers of the non-autistic children reported that their children did not have any other special educational needs or neurodevelopmental conditions. The age ranges of the children within the total sample were 0 – 3 years old (n = 63) and 4 - 5 years old (n = 51). The total sample consisted of mothers (84%), fathers (13%) and caregivers (3%). The age ranges of parents/caregivers were 18 - 29 (10%), 30 - 39 (68%), 40 - 49 (21%) and > 60 (1%). In terms of education, 60% had a bachelor's degree and a higher educational award and came from a range of ethnic backgrounds including white (40%), black (6%), Asian (17%), or other ethnic backgrounds (37%). Around 90% of parents have access to green spaces, but about 8% lack any such access (see Table 4). Regarding the types of green spaces, approximately 28% of parents did not specify the kinds they utilize. However, among those who did, parks, gardens, and playgrounds emerged as the most commonly mentioned types.

Table 4: Illustration of autistic, and non-autistic parents (caregivers), and their children's demographic information

Demographic Information		Parents (caregivers) of autistic and non- autistic children *(%)*
Relationship with the child		
	Mother	84.2
	Father	13.2
	Caregivers	2.6
Age		
	18 - 29	9.6
	30 - 39	68.4
	40 – 49	21.1
	>60	0.9
Gender		
	Male	14.9
	Female	82.5
	Non-binary/third gender	1.8
	Prefer to not to say	0.9
Relationship Status		
	Married	80.7
	Widowed	0.9
	Divorced	2.6
	Separated	1.8
	Single	8.8
	In a domestic partnership or civil union	0.9
	Other	0.9
Education level		
	Bachelor's degree and above	60.4

	Other qualification	39.6
Employment status		
	Employed full-time	26.3
	Employed part-time	24.6
	Freelance-Contractor	2.6
	Self-employed	6.1
	Unemployed	27.2
	Student	6.1
	Retired	0.9
	Other	6.1
Ethnicity		
	White	39.5
	Black	6.1
	Asian	17.5
	Mixes or multiple ethnic groups	36.9
Country		
	England	96.5
	Wales	0.9
	Northern Ireland	2.6
Living Area		
	Urban	69.5
	Suburban	23.7
	Rural	3.4
	Not specified	3.4
Accessing Green Space		
	Yes	89.8
	No	8.5

Not specified	1.7
Parents' children number	
1	52.5
2	28.8
3	15.3
4	1.7
>4	1.7
Parents' young children's age	
0 -3	55.3
4 -5	44.7
Parents' young children's gender	
Male	60.5
Female	39.5

Procedure

Before completing the survey, all participants were provided with a participant information sheet outlining the study and GDPR requirements for data processing. They were asked to read the information sheet carefully and then make an informed decision as to whether they wanted to consent to participate in the survey. The study was designed in accordance with the

Declaration of Helsinki (2013) and received full ethical approval from IOE, Institute of Education and Society, University College London.

Development of Survey Material

The survey was structured into three main sections: (1) Parents/caregivers' beliefs about motor skills of young children, (2) Parents/caregivers' Knowledge about Motor Skills of Young Children, and (3) Activities that parents/caregivers do with their young children. To develop the first section, which focused on parents/caregivers' beliefs about motor skills of young children, existing literature emphasizing the importance of motor skills and literacy skills for young children was reviewed (e.g., Brown, 2014; Adolph & Hoch, 2020). Subsequently, the section's items were formulated by the main researcher (Tugce Cetiner) and underwent discussion with supervisors and reception class teachers.

The second section, pertaining to Parents/caregivers' Knowledge about Motor Skills of Young Children, was developed by initially examining "Development Matters Non-statutory curriculum guidance for the early years foundation stage (DfE, 2021)" and relevant literature detailing the stages of motor skills, literacy skills, and maths skills in young children (e.g., Hadders-Algra, 2010; Berk, 2015; Horowitz-Kraus et al., 2017; Newell, 2020; Clements & Sarama, 2020). The items in this section (i.e., correct age range where children are able to perform a particular skill) were crafted by the main researcher

(Tugce Cetiner) and underwent review by supervisors and reception class teachers.

The third section focused on activities that parents/caregivers engage in with their young children. Motor skill activities were developed based on observations in an autistic reception class at an autism school, along with discussions with reception and year 1 class teachers, parents of young children, and supervisors. For maths and literacy sections, all maths and five literacy activities were drawn from studies involving early years maths activities (Cost et al., 2021; Ranzato et al., 2021). Remaining three literacy activities were developed based on classroom observations, discussions with reception class teachers, and input from one young children's parent (see details of items in Table 5).

In terms of maths and literacy sections, all maths activities and five literacy activies drawn from studies that included early years maths activities (Cost et al., 2021; Ranzato et al., 2021). Remaining three activities for literacy skills were developed based on classroom observations, discussion with reception class teachers, and one young children’s parent [i.e., (1) Play literacy games that involve reading or recognising letters and sounds (e.g., on the computer, iPad, or on paper, (2) Activities that name the alphabet letters with singing songs or rhymes (e.g., singing A, B, C, D alphabet song), (3) Using educational software or apps, focused on letters and sounds]. It was important to note that studies Cost et al. (2021) and Ranzato et al. (2021) were originally conducted with early years practitioners and parents of primary school of children with Down syndrome and Williams syndrome. However, discussions with parents and reception class teachers indicated that these activities were suitable for both young autistic and non-autistic children in home environments, hence they included to the survey.

Before finalising the survey material, one reception schoolteacher and one nursery schoolteacher helped to shape and refine the terminology that formed the questions via a round table discussion. Following this stage, the survey material was piloted with three parents/caregivers of young children to gain their feedback on the style of the questions and the general procedure of the survey. Based on the feedback, some of the question items were reworded and one new question was added. The final survey consisted of 14 questions associated with demographic information of the parents/caregivers and their children (e.g., age of parents/caregivers; educational level; does their child have special needs). The main survey had 64 questions that were grouped into 3 sections; (1) *beliefs* about the importance of motor skills and literacy skills of young children (2) *knowledge* about the development of motor, literacy, and maths skills of young children, and (3) frequency and type of *activities* that parents/caregivers do with their young children regarding motor, maths, and literacy skills (see the final version of the survey in Appendix 1).

Section 1: Parents/Caregivers' Beliefs about Motor Skills of Young Children

Parents/caregivers rated their *beliefs* about the importance of motor skills and literacy skills on young children's daily life, future academic success, and overall development using a 5-point Likert scale ranging from 1 (strongly disagree), 2 (disagree), 3 (undecided), 4 (agree) and 5 (strongly agree). They rated 6 items for the domains of motor skills and literacy skills and 6 distractor (or filler) items related to social communication skills, children health development, and overall educational outcome were added to minimise response bias, maintain survey integrity, improve data quality, and enhance statistical analysis. Based on beliefs, a mean score was calculated for each participant for each domain (motor; literacy; distractor), with the maximum mean score being 5.

Section 2: Parents/Caregivers' Knowledge about Motor Skills of Young Children

Parents/caregivers were provided with a total of 18 questions that were split into 6 questions for each of the 3 domains (motor; literacy; maths). They were asked to select what they thought was the correct age range where children are able to perform a particular skill (note; there was only one correct answer). In terms of the age of acquiring skills, there was an equivalent spread of ages across three domains. The age ranges were: 1 (under 1 year); 2 (under 2 years); 3 (under 3 years); 4 (under 4 years); 5 (older than 4 years) and 6 (I don't know). Example question types: motor (e.g., children can sit independently), literacy skills (e.g., children can combine and use two words), and maths skills (e.g., children can show 'finger numbers' up to 5). Based on knowledge, a percentage accuracy score of the correct responses was calculated for each participant for each domain (motor; literacy; distractor), with the maximum percentage accuracy score being 100%.

Furthermore, to gain deeper insights into parents/caregivers' knowledge about motor skills, two additional questions regarding motor skill development were included. In one question, parents/caregivers were asked, "When do you believe motor skill development begins in young children?" with six options provided: (1) starts before birth, (2) starts at birth, (3) starts at 6 months, (4) starts at 8 months, (5) starts at 1 year, (6) starts after 1 year, and (7) I don't know. Percentage score of the correct answers were calculated for two groups of parents/caregivers. In another question, parents/caregivers were asked to write five motor skills that they consider important for young their children. Frequency of parents/caregivers' responses were used for analysing.

Section 3: Activities that Parents/Caregivers Do with Their Young Children

Parents/caregivers provided the frequency of activities they carried out with their children across 8 motor skill activities (e.g., dancing), 8 literacy skills activities (e.g., name the alphabet letters with singing songs or rhymes) and 8 maths skill activities (e.g., using number activity books). The frequency of activities was measured using a five-point (0 to 5) rating scale. A score of 0 was given for 'not at all' and 'not age appropriate', a score of 1 was for 'monthly or rarely', a score of 2 for 'once a week', a score of 3 for 'several times a week', a score of 4 for 'once a day', and a score of 5 for 'several times a day'. Based on the frequency of activities, a mean score was calculated for each participant for each domain (motor; literacy; maths), with the maximum mean score being 5.

At the end of the survey, another question aimed to understand parents/caregivers' priorities in supporting motor skills. The question presented was: "Motor skill activities like cutting paper shapes (like a square) and copying words (like a child's own name) can also help children perform other skills such as eating food and doing maths. From the below options which set of skills do you think is most important for helping your child move into primary school (year 1)?". Parents/caregivers were offered two options: (1) Daily life skills (e.g., dressing, eating, or using the toilet), (2) School-related skills (e.g., math, reading, or writing). Mean score of the answers were calculated for two groups of parents/caregivers.

Handling Missing Data

One of the most common issues in survey research is missing data (Brick & Kalton, 1996). In the present study, there was less than 5% of missing data (e.g., nonresponse; a survey question was accidentally missed) in each section. Since the mean score of two each section and percentage accuracy score of one section were used for analysing, this amount of missing data did not affect the results.

Results

Reliability analyses were conducted using Cronbach's alpha (α) to assess the internal consistency of the survey questions in terms of whether they are measuring the same construct (Hays & Revicki 2005). As summarised in Table 1, the Cronbach's α outcomes revealed high internal consistency across all survey sections. Normality testing using a Shapiro-Wilk test revealed that all but one variable was normally distributed ($p > .05$), with the parent/caregiver responses for the non-autistic children in the 'beliefs' section deviating from normality [$W(55) = .86$, $p < .001$] (see Table 5). It is important to note the sample size was small (n = 54) for the parent/caregiver responses for the non-autistic children and thus the non-normality was treated with some caution given that the power of normality tests (e.g., Shapiro-Wilk, Kolmogorov-Smirnov, or Lilliefors) is suggested to be low for small sample sizes (Razali & Wah, 2011). Moreover, parametric tests, like ANOVA, are robust to these violations (Blanca Mena et al., 2017), and along with the visual examination of QQ plots, parametric testing was conducted on all the data. Finally, analyses were completed with and without outliers to check if outliers affected the outcome of the results. Since there were no significant differences in results, outliers were included analysis.

Table 5: Cronbach's alfa and Shapiro-wilk scores of each survey section

Survey Sections	**Cronbach's Alfa**	**Shapiro-Wilk**
Believing	.84	Autistic children's parents/caregivers: < .001 Neurotypically developing children's parents/caregivers: .071
Knowing	.87	Autistic children's parents/caregivers: .36 Neurotypically developing children's parents/caregivers: .362
Doing	.86	Autistic children's parents/caregivers: .531 Neurotypically developing children's parents/caregivers:.107

Section 1: Parents/Caregivers' Beliefs about Motor Skills of Young Children

To understand parents/caregivers' beliefs, a mixed-design repeated measures ANOVA was conducted with *parent/caregiver-group* (i.e., *parent/caregiver* -autistic, parent-not-autistic) as between-group factor and *domain* (i.e., motor, literacy, distractor) as the within-group repeated measures factor. ANOVA revealed no significant main effect for *group*, F (1, 110) = 0.82, p = 0.366, η_p^2 = 0.0007, but significant effects were revealed for *domain*, F (2, 220) = 9.78, p < .001, η_p^2 = 0.08, and a *domain* x *parent/caregiver-group* interaction, F (2, 220) = 3.32, p = 0.040, = 0.0002. As illustrated in Figure 6, and confirmed using Bonferroni post-hoc testing, *parents/caregivers* showed significantly (p < 0.001, Cohen's d = 0.34) greater beliefs about motor skills (M = 4.08; SD = 0.03) than literacy skills (M = 3.85; SD = 0.03) and (p < 0.001, Cohen's d = 0.29) distractors (M = 3.88 ; SD = 0.07). The difference in beliefs between literacy and distractors was not significant (p > 0.05). For the *domain* x *parent/caregiver-group* interaction, the findings showed that parents of non-autistic children believed motor skills to be significantly more important than literacy skills (p < 0.001, Cohen's d = 0.55) and distractors (p < 0.001, Cohen's d = 0.43). Whereas there were no significant differences (ps > 0.05) in beliefs between the three domains for the parents/caregivers of autistic children.

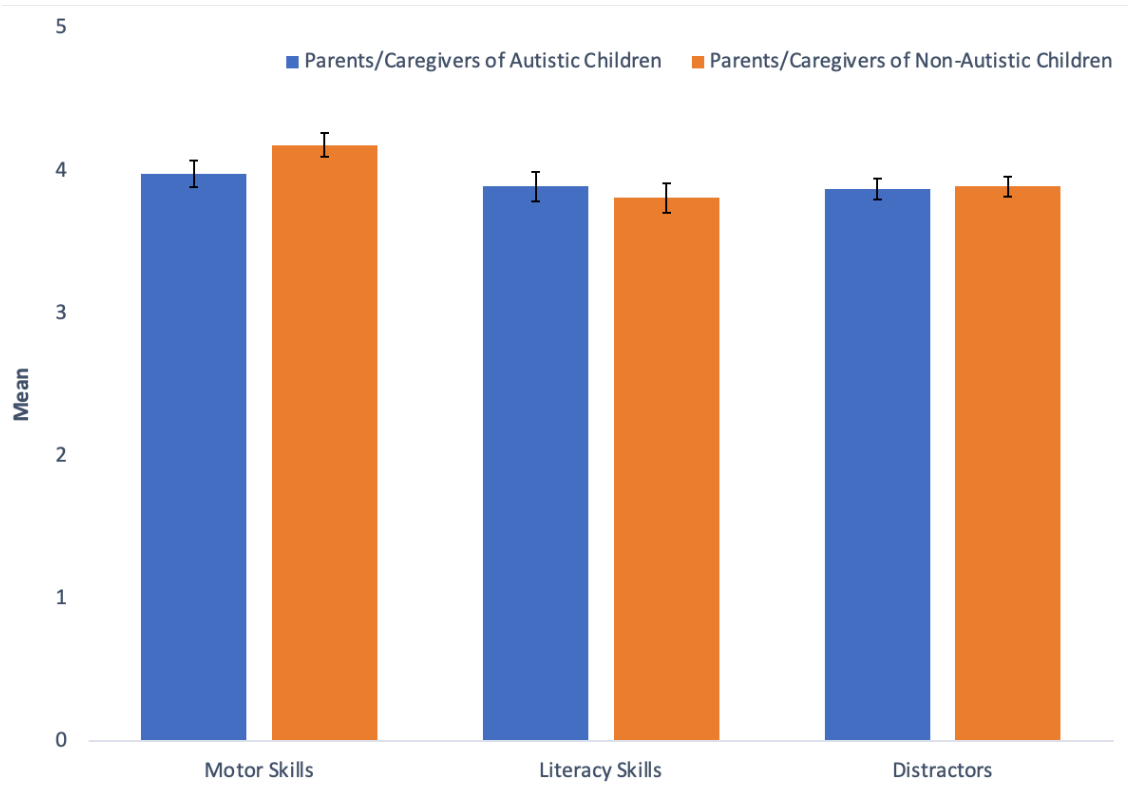


Figure 6: Mean (and standard error of the mean represented by error bars) scores of autistic and non-autistic children's parents/caregivers' beliefs about the importance of motor skills, literacy skills and distractors.

Section 2: Parents/Caregivers' Knowledge about Motor Skills of Young Children

To understand parents/caregivers' knowledge, a mixed-design repeated measures ANOVA was conducted with *parent-group* (i.e., autistic; non-autistic) as between-group factor and *domain* (i.e., motor, literacy, maths) as the within-group repeated measures factor. The ANOVA revealed no significant effects *for parent/caregiver-group*, $F(1, 111) = 1.11$, $p = .29$, $\eta_p^2 = .010$ or *domain* x *parent/caregiver-group* interaction $F(2, 220) = .33$, $p = .71$, $\eta_p^2 = .003$, but the effect for *domain* was significant $F(2, 220) = 38.70$, $p < .001$, $\eta_p^2 = .259$. As illustrated in Figure 7, and confirmed using Bonferroni post-hoc testing, parents/caregivers showed significantly ($p < 0.001$, Cohen's $d = .51$) greater knowledge about motor skills ($M = 47.64$; $SD = 18.35$) than literacy skills ($M = 37.91$; $SD = 21.62$) and ($p < 0.001$, Cohen's $d = 1.09$) maths skills ($M = 26.99$; $SD = 16.41$). The difference in knowledge between literacy skills ($M = 37.91$;

SD = 21.62) and maths skills (*M* = 26.99 ; *SD* = 16.41) was also significant ($p < 0.001$, Cohen's *d* = .57).

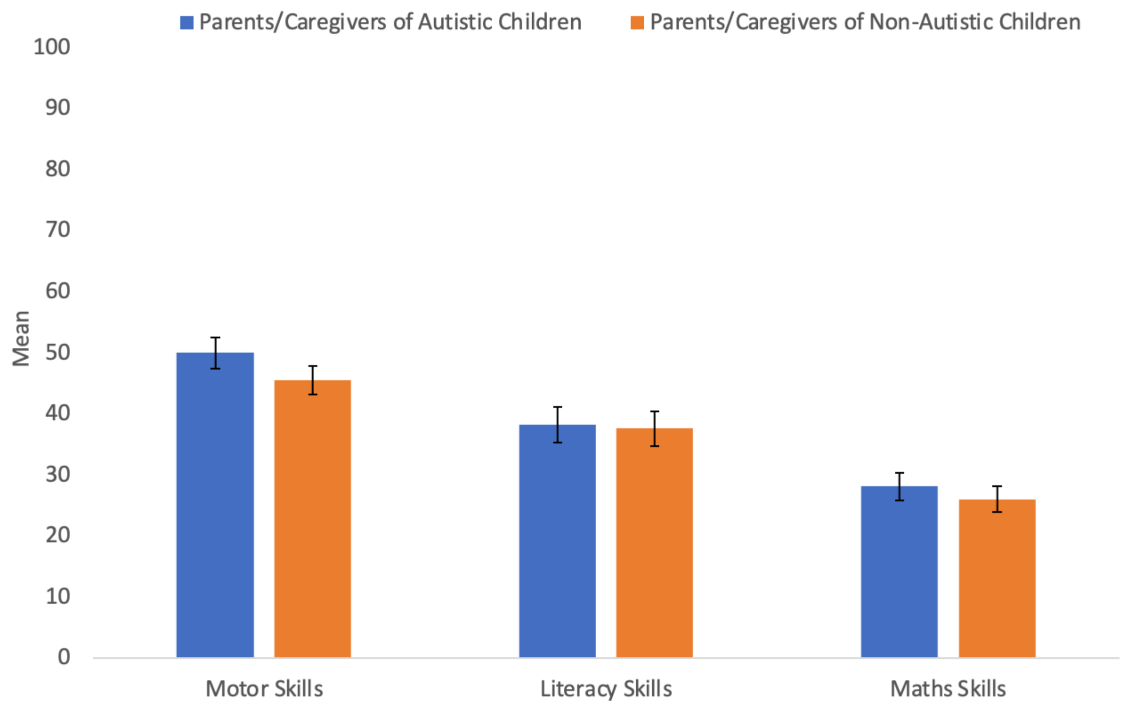


Figure 7: Mean (and standard error of the mean represented by error bars) scores of parents/caregivers' knowledges about motor skills, literacy skills and math skills

It was important to note that in addressing missing data for this section, percentage accuracy scores were employed for result analysis. However, utilizing percentage scores in ANOVA data analysis can carry notable implications because dataset cannot adhere to a normal distribution due to their confinement within a range of 0% minimum to 100% maximum. While in theory, it can be demonstrated that such data are unlikely to conform to a normal distribution, even if this conclusion is not directly derived from the available dataset (Quicke et al., 2020; Childs et al., 2021). Handling this issue, often necessitates the application of mathematical functions to transform the data, ensuring alignment with the assumptions of the model (Childs et al., 2021). Therefore, to ensure there were not any potential impact of percentage data on the results, percentage accuracy scores for each section were transformed using the arcsine square root transformation, recommended for percentage or proportional data (Fernandez, 1992; Childs et al., 2021). Subsequently, the analysis was re-run, revealing no significant differences in results between ANOVA with percentage scores and ANOVA with transformed scores.

To assess parents/caregivers' knowledge about when motor skill development starts, the percentage scores of correct answers for both groups of parents were calculated. The results showed that 34.55% of parents/caregivers of autistic children (n = 19) gave the correct response, while 49.09% of parents/caregivers of non-autistic children (n = 27) provided the correct response. Following that , a Chi-Square test was conducted to examine the differences in correct response rates between the two groups of parents/caregivers. The results indicated no significant difference between the groups' correct response, [($\chi^2(1) = 1.48$, $p = 0.22$].

To analyse the question about important motor skills for children, parents/caregivers' answers were initially categorized into similar skills to identify common themes. Based on parents/caregivers' responses, six themes were identified: (1) Walking/running, (2) Jumping, (3) Climbing, (4) Handwriting skills (e.g., pen holding, writing, or drawing), (5) Self-care skills (e.g., dressing up, using the toilet, or brushing teeth), and (6) Eating (e.g., using fork, using cutlery, or feeding themselves). Subsequently, frequency analysis was conducted to count the number of times each theme was mentioned in the responses. Due to the relatively small number of responses received from both parents of autistic children (*n* = 33) and non-autistic children (*n* = 32), the analysis was performed using Excel rather than any statistical software packages. Results indicated that parents/caregivers of autistic children consider the five most important motor skills for their children to be handwriting skills (*n* = 14), walking/running (*n* = 11), self-care skills (*n* = 11), jumping (*n* = 11), and eating (*n* = 10). In terms of parents/caregivers of non-autistic children, they consider the five most important motor skills for their children to be walking/running (*n* =15), handwriting skills (*n* = 13), Self-care skills (*n* = 12), eating (*n* = 11), and climbing (*n* = 9).

Section 3: Activities that Parents/Caregivers Do with Their Young Children

A mixed-design ANOVA was conducted with *parent/caregiver-group* (i.e., autistic; non-autistic) as the between-group factor and *domain* (i.e., motor, literacy, maths) as the within-group repeated measures factor was carried to examine the frequency of activities that parents/caregivers use in the domains of motor skills, literacy skills and maths skills. ANOVA revealed no significant effects *for parent/caregiver-group,* F (1, 108) = 0.001, p = 0.979, η_p^2 <.001 and *domain* x *parent/caregiver-group* interaction, F (2, 195) = 0.929, p = 0.39, η^2 <.001, but the effect for *domain* was significant, F (2, 195) = 53.29, p < 0.001, η_p^2 = 0.008. As illustrated in Figure 8, and confirmed using Bonferroni post-hoc testing, parents/caregivers employed a significantly (p < 0.001, Cohen's d = 50) greater frequency of literacy skills (M = 3.05 ; SD = 0.98) than maths skills (M = 2.81; SD = 0.99) and motor skills (M = 2.27 ; SD = 0.79). The difference between maths skills (*M* = 2.81; *SD* = 0.99) and motor skills (*M* = 2.27; *SD* = 0.79) was also significant ($p < 0.001$, Cohen's $d = 0.50$).

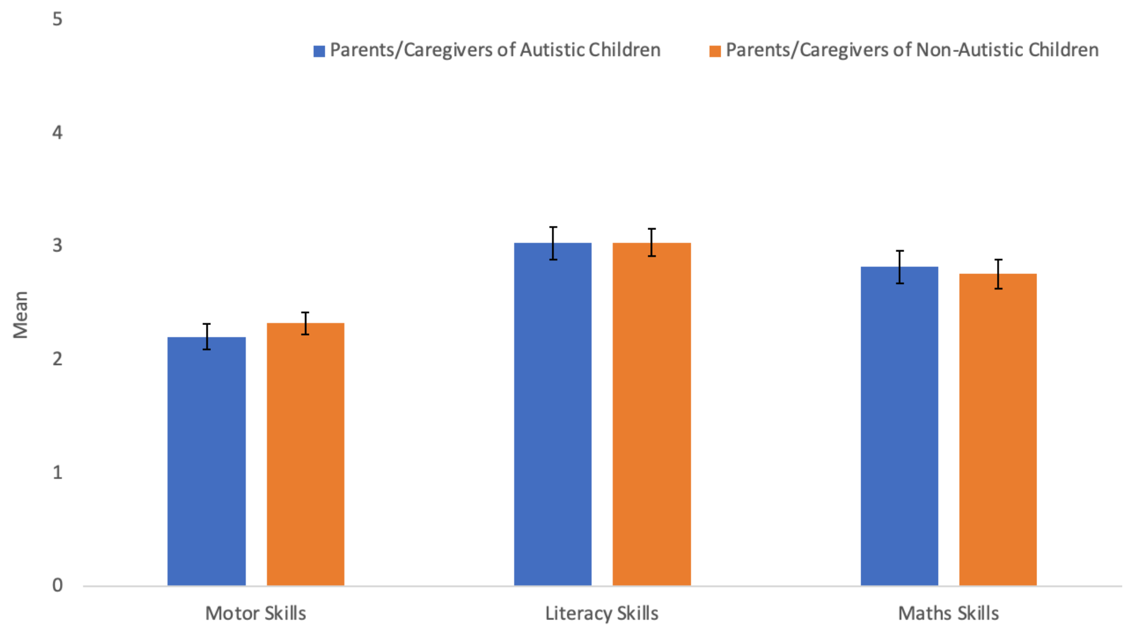


Figure 8: Mean (and standard error of the mean represented by error bars) scores of frequencies of motor, literacy, and maths skills activities that parents/caregivers facilitate to their children

In order to understand, parents/caregivers' priory for supporting motor skills, percentage score of parents/caregivers of autistic (*n* = 52), and non-autistic (*n* = 57) children's responses were calculated for both parent/caregiver group. Results indicated that, while 86.53% of parents/caregivers of autistic children wanted to support motor skills of their children to help their daily life skills (e.g., dressing, eating, or using the toilet), 13.46% of them wanted to support motor skills of their children to help their school related skills (e.g., maths, reading, or writing). In terms of non-autistic children's parents/caregivers, 84.21% of them wanted to support motor skills of their children to help their daily life skills (e.g., dressing, eating, or using the toilet), 15.78% of them wanted to support motor skills of their children to help their school related skills (e.g., maths, reading, or writing). After that, in order to understand whether any association between parent/caregiver group and their response to supporting motor skills, the chi-square test was conducted. Results revealed that there were no statistically significant association between parent/caregiver group and their response to supporting motor skills [($\chi^2(1) = 0.11$, $p = 0.73$].

Exploratory Analysis

The current survey data was collected from parents/caregivers of young children in the early years in the UK, which covers a period between 0 – 5 years. During these early years, children often attend nursery settings or stay at home between 0 - 3 years and attend reception class in school between 4 and 5 years. Given that parents/caregivers' perceptions may change across the development of their children, additional analyses were conducted to explore if there were significant differences between these two age ranges by adding age-group (i.e., 0 - 3; 4 - 5) as an additional *between-group factor* using a mixed-design ANOVAs with parents/caregivers -group and age (i.e., 0 - 3; 4 - 5) as between-group factors, and domain as the within-group repeated measures factor. Note, because the analyses were designed to examine the effect of age, only age-related statistical tests are reported below. Additionally, there was no information available regarding the number of children in a childcare setting versus those at home.

For beliefs, ANOVA revealed no significant effect for *age* $F(1, 110) = 2.00$, $p = 0.16$, $\eta^2 = 0.02$, *age x parent/caregiver-group*, $F\ (2, 220) = 0.55$, $p = 0.46$, $\eta^2 = 0.004$, *domain* x *age* interaction, $F\ (2, 210) = 0.16$, $p = 0.84$, $\eta_p^2 = 0.007$ or *domain* x *age x parent/caregiver-group* interaction, $F\ (2, 210) = 0.09$, $p = 0.91$, $\eta_p^2 = 0.007$.

For knowledge, ANOVA revealed no significant effects for *age*, $F(1, 110) = 2.37$, $p = 0.13$, $\eta_p^2 = 0.078$, *age x parent/caregiver-group*, $F\ (2, 220) = 0.96$, $p = 0.33$, $\eta^2 = 0.009$, *domain* x *age x parent/caregiver-group*, $F\ (2, 220) = 0.12$, $p = 0.88$, $\eta_p^2 = 0.001$, but the *domain* x *age group* was significant, $F\ (2, 220) = 4.406$, $p = 0.013$, $\eta_p^2 = 0.009$.

For activities, ANOVA revealed no significant effects for *age* $F(1, 110) = 0.53$, $p = 0.47$, $\eta^2 = 0.003$, *domain* x *age group*, $F\ (2, 220) = 0.214$, $p = 0.788$, $\eta^2 = 0.0001$, *age x parent/caregiver-group*, $F\ (2, 220) = 0.12$, $p = 0.74$, $\eta_p^2 = 0.0001$ and *domain* x *age x parent/caregiver-group,* $F\ (2, 193) = 3.13$, $p = 0.50$, $\eta_p^2 = 0.009$.

Discussion

This study obtained a detailed understanding of parents/caregivers' beliefs, knowledge and use of home-based activities regarding young autistic and non-autistic children's motor skills, literacy skills and maths skills. Gaining an understanding of these perceptions was important as they play an important role in why parents select certain early interventions (Mire et al., 2017) and therefore is pivotal for the development of early interventions targeting motor skills in young autistic children.

Section 1: Parents/Caregivers' Beliefs about Motor Skills of Young Children

The survey data indicated parents/caregivers believed that motor skills are important literacy skills and distractors. This finding was in contrast with our hypothesis and existing studies in older autistic children's populations, in that previous studies had shown that parents of autistic children (Pituch et al., 2010; Ghanadzadea et al., 2018) rated social skills and academic skills more important than physical skills and motor development. Although these studies worked with parents of autistic children aged between 2 – 21, they mainly worked with parents of older autistic children only included 13% (Pituch et al., 2010), and 22% (Ghanadzadea et al., 2018) young autistic children aged between 2 and 4. This inconsistency may stem from the emergence of motor milestones observed by families during early childhood. For example, children age between 0 and 5 can achieve important motor milestones such as sitting, walking, or eating with a spoon and fork, and these skills directly impact children's daily life skills. Studies results showed that young autistic children have difficulties in daily life skills, and the level of independence in daily life skills is one of the main concerns of parents (Jasmin et al., 2009). Consequently, it can be argued that parents/caregivers' perceive motor skills as important in the early years, given their significant impact on the children daily life skills. However, as children grow older and attain these motor milestones, other skills such as social interaction, communication, and literacy gain prominence, especially as they begin formal education.

In terms of non-autistic children’s parents/caregivers’, results were not consistent with existing study (Agard et al., 2021) that showed parents of non-autistic preschool children believed that physical activies are not important for their children. But important to note that, in contrary the current survey in the study Agard and colleagues, did not ask any specific question to parent about the importance of motor skills for children daily life skills or academic success. They just asked general questions to parents about physical activities (e.g., Why physical activities important for you?) (see example questions in Agard et al., 2021) . Using different items and questions about motor skills could be effect parents/caregivers’ responses. Moreover, the differences in parents' responses could be due to how the studies were advertised. The current study was promoted as a "young children development survey" rather than a "motor skills survey." However, it was unclear how the study (Agard et al., 2021) was advertised. Therefore, the impact of advertisement on the results between the studies could no compared.

Section 2: Parents/Caregivers' Knowledge about Motor Skills of Young Children

In examining the parents/caregivers’ knowledge about the development of motor, literacy, and mathematical skills results showed that, although there was a significant difference between their knowledge across three domains, there was no significant interaction between parent/caregiver groups and three domains. Parents/caregivers’ in both groups scored higher for motor skills knowledge compared to their knowledge about developmental milestones in literacy and maths, and their knowledge about developmental milestones for literacy was greater than their maths knowledge. These findings were consistent with our predictions and studies in the non-autistic children population, which showed that their parents have greater knowledge about literacy than mathematical development (e.g., Cannon & Ginsburg, 2008). In terms of parent's knowledge about motor skills compared to maths and literacy skills, as far as the authors known, there were no literature that compared the parents' knowledge about these three skills.

In terms of parents/caregivers' knowledge about motor skills compared to maths and literacy skills, as far as the authors known, there were no literature that compared the parents/caregivers' knowledge about these three skills. Based on the study (Agard et al., 2021) that showed non-autistic children's parents were not aware of the importance of motor skill, we hypothesised that, their knowledge about motor skills would be lower compared to literacy and maths. Since it was hypothesised that their believes affect their knowledge. But as mentioned before, this study mainly asked questions about physical activities. In the current study, one possible explanation for parents/caregivers having a higher level of knowledge about motor skills compared to literacy and math could be that motor skills (e.g., independent sitting) are perceived as less complex compared to literacy (combining and using two words) and math skills (e.g., showing finger numbers up to 5).

While parents/caregivers demonstrated greater knowledge about motor skill development compared to literacy and math development, the results revealed that 65.45% of parents/caregivers of autistic children and 50.91% of parents/caregivers of non-autistic children were unaware of when motor skill development begins. This high rate of incorrect answers regarding the onset of motor skills can be attributed to the fact that motor skill development begins before birth, and parents cannot observe these early stages. In terms of important motor skills, although limited number of responses were received for parent of autistic (n = 32) and non-autistic children (n = 33), results showed that parents/caregivers' thought that daily life activities that needs motor skills (e.g., eating, walking, handwriting, or dressing) were important for their young children. These results indicated that parents/caregivers' know motor skills that used in the daily life activities. Their knowledge of important motor skills may stem from their ability to observe their children's daily life activities.

Section 3: Activities that Parents/Caregivers Do with Their Young Children

In the examination of the frequency of activities that parents/caregivers do with their children across three domains (i.e., motor, literacy, and maths), the current study's findings showed that whilst there was a significant difference between the frequency of activities, there were no significant interactions between parent/caregiver groups and domains. In the line with our predictions, both groups of parents/caregivers did literacy skills activities the most with their children, followed by math activities, and focused the least on motor skills activities. We predicted that they do not believe that motor skills are important, that their knowledge of motor skills is lower than other skills and that their perceptions may affect the motor skills activities they facilitate to their children at home. But results showed that they believed motor skills are important and their knowledge about motor skills was higher than other skills. One possibility for focusing more on literacy and maths activities compared to motor activities is that parents/caregivers might think that motor activities are included in these activities and that children practice their motor skills automatically through play or that parents/caregivers are not aware of how they can support motor activities for preschoolers. Other explanations could be that, maybe parents/caregivers do not know how they can support their children motor skills, or motor skill activities are not suitable for home environment. Unfortunately, the findings from the current study do not provide insight into these possibilities. However, the current study does show that despite parents/caregivers rating motor skills to be important during the early years, they don't focus on motor activities with their child in the home.

The final question of the survey aimed to discern parents/caregivers' priorities in aiding the motor skills development of their young children. Findings revealed that 86.53% of parents/caregivers of autistic children and 84.21% of parents/caregivers of non-autistic children expressed a preference for supporting their children's motor skills to enhance their daily life abilities (e.g., dressing, eating, toileting) rather than focusing on school-related skills (e.g., math, reading, writing). This outcome suggests that, for parents/caregivers, prioritizing daily life skills over academic skills in the early years is more prevalent, regardless of their child's neurodevelopmental status.

Exploratory Analysis

In the current study, since the children's age group differences [(i.e., 0-3 (nursery aged), and 4-5 (reception aged)] may affect parents/caregivers' beliefs, knowledge, and the frequency of activities that they do with their children at the home, an exploratory analysis was conducted considering variations in children's age groups. The analysis revealed no statistically significant differences in nursery aged and reception aged children's parents/caregivers' beliefs, knowledge, and frequency of activities that parents do facilitate to their children across three domains (i.e., motor skills, literacy skills, maths skills). But it is essential to note that, the sample size of this study was small to do this kind of comparison, therefor it can be suggested that no differences between age groups might be because of small sample size.

Limitations

The current study has some limitations that should be considered when interpreting the results. Firstly, our sample size might be considered relatively small. However, in the current study, we targeted to collect data from parents/caregivers of young autistic and non-autistic children in a specific age group (i.e., 0 – 5) in the UK. When it is considered that, in the UK, children are generally diagnosed with autism, age of around 4.5, our target population was narrow for the autistic group compared to non-autistic population (Brett et al., 2016). Indeed, compared to sample size of existing studies (e.g., Ranzato et al., 2021) that worked with young children with special needs population (e.g., autism, down syndrome, or William syndrome) and focusing on parental perceptions or home-based activities, the current survey sample size might be regarded as relatively high. Secondly, in Section 3 "*Activities that Parents Do with Their Young Children*", although the results provided information about frequency of activities that parents/caregivers do with their children, it does not provide any information about the quality of activities. Also, the results did not clearly show why parents do fewer motor activities, although they think motor skills are important. However, our findings may guide future research, and future research specifically can investigate motor skill activities that parent do with their young children. Thirdly, due to the nature of online surveys, data could only be collected from parents with internet access, and our participants were mainly consisted of educated parents. Since parents/caregivers` education level might affect their perceptions and activities that they do with their children, this must be taken into consideration when interpreting findings. Finally, after the data collection, it was noticed that the response options were not presented in canonical order in the third section that is activities that parents do with their young children. That is, in the section, when families were asked how often they engaged in activities with their young children, the responses were listed as: (1) once a day, (2) several times a day, (3) once a week, (4) several times a week, (5) monthly or rarely, and (6) not at all. The presentation of response options in a non-canonical order can affect parents' responses in several ways. Parents/caregivers' may perceive the options differently depending on their order, or the first few options presented may seem more prominent or preferred. Moreover, parents may have mistakenly presumed that the options were presented in canonical order and therefore chosen a response option they did not intend to choose. To ensure that participants completed the question appropriately, previous literature attempted to compare the absolute frequencies within the groups for math and literacy items. However, as mentioned under the "Developing Survey Material" title, these studies were conducted exclusively with early years practitioners and parents of primary school children with William syndrome and Down syndrome. Therefore, a comparison of the absolute frequencies within the groups between current and previous studies for math and literacy items could not be conducted. Since a non-canonical order may affect parents/caregivers' responses, it was regarded the one of the most important limitations of the study.

Conclusions and Future Directions

The current study results indicated that both parents/caregivers' groups believed motor skills was important for their children's daily life skills, academic skills, and other skill development. Moreover, their knowledge about motor skill development was better compared to their knowledge about literacy and mathematical development. However, by examining the frequency of activities that parents/caregivers do with their children, the current findings demonstrate that parents/caregivers do less motor skill activities than literacy and maths skill activities. Overall, this evidence suggested that future research should focus on understanding parent considerations about motor skill activities and needs for doing motor skill activities at home to support their motor skill development. Based on their needs, new motor skill activities that are easy to implement and not time consuming, should be developed. This is also particularly vital for young autistic children when considering that they have motor skill difficulties and need to be supported in the early years. Therefore, the findings of the current survey could inform the development of parent led early interventions aimed at improving young autistic children motor skills.

Chapter 6: Practice specificity on motor learning: The feasibility of a home-based intervention for training handwriting in young autistic children

Introduction

As indicated in the literature review, autistic children show motor skills difficulties and or differences even in the early years of life, and it is suggested that motor skills should be supported with early interventions (Landa & Garrett-Mayer, 2006; Ozonoff et al., 2008; Biffi et al., 2018). In terms of the existing early interventions, the results of the systematic literature review showed that most of early intervention programmes designed to support young autistic children have limitations such as small sample sizes and/or lack of a control group. Moreover, many of these early interventions were specifically designed to support the core features of autism like social communication and language, rather than motor skills. Those that did target motor skills were focused on fundamental movement skills, and 90% were conducted in community settings (e.g., school) by professionals (e.g., teachers), which indicated a lack of early interventions that target fine motor skills in the home environment.

Given the lack of information regarding motor skills in early intervention studies, it is important outline (see introduction and literature review) the process of motor skill learning in order to develop the methodical ingredients. For example, motor skill learning is facilitated by providing learners with augmented information (i.e., knowledge of results) and practice (i.e., performing physical movements; or observing movements). In terms of practice, it is known that practice specificity (i.e., blocked-practice and/or random-practice) has differential effects on motor performance, motor learning and motor transfer (generality) (Battig, 1972; Shea &

Morgan, 1979; Magill & Hall, 1990; Raviv, et al., 2022). A blocked-practice trial-order is structured so that a **Task A** (i.e., place a pencil in a cup) is performed across a consecutive number of practice trials before performing a different **Task B** (i.e., pick up a counting block) and a different **Task C** – therefore, a blocked-practice trial-order is typically structured as follows: **AAA, BBB, CCC**. Whereas random-practice requires the same three tasks to be practised but in an unpredictable trial-order - therefore, a random-practice trial-order is typically structured as follows: **ACBBCACBA**. Results from a learning study (Shea & Morgan, 1979) indicated that blocked-practice underpinned more accurate motor performance during a practice phase of acquiring a new set of motor skills than random-practice. The data however revealed that random-practice led to better motor performance during periods of retention and transfer, which indicated benefits in the generality of motor learning. Based on these differential effects, efforts have been made to optimise the benefits of both blocked and random practice by creating mixed-practice design learning scenarios. For example, when combining these two practice structures, **blocked**-followed-by-**random** practice provided greater learning and transfer effects than **random**-followed-by-**blocked** practice (Lai et al., 2000) (see Introduction and Literature Review).

Based on the gap in the literature, the principal aim of this study is to examine the effects of practice type and structure on the acquisition and transfer of handwriting letters for young autistic children during a feasibility parent-led home-based motor intervention called “Autism Early Intervention for Motor Skills (AiMS)”. Due to the importance of handwriting in the early years (see in Literature Review), AiMS was designed to improve motor learning of handwriting letters in young autistic children via practice specificity that is related to a mixed-practice schedule: blocked-followed-by-random-practice.

Developing of AiMS Intervention

Observations, Pilot Studies and Meetings

The extensive groundwork laid through observations, pilot studies, and collaborative meetings played a pivotal role in shaping the development of the intervention, intervention tasks and materials for young autistic children. As a PhD student, I conducted 150 hours of observations in an autism reception class in London provided invaluable first-hand insight into the daily experiences, challenges, and interactions of autistic children within an educational setting (see Appendix 2). These observations not only informed the identification of specific areas requiring intervention but also facilitated a deeper understanding of the nuanced needs and preferences of the young autistic children population. Along with the observations, I also conducted pilot studies with young autistic children to test intervention tasks served as crucial testing grounds, allowing for the refinement and adaptation of intervention components (e.g., storybook, dosage, or motivators) based on direct feedback and observations of children's responses. This iterative process ensured that the intervention tasks were tailored to the unique learning styles, sensory sensitivities, and communication profiles of autistic children, thereby enhancing their accessibility and effectiveness. Furthermore, the development of the AiMS intervention was guided by principles of co-production with key stakeholders (Cullingham et al. 2023). I conducted collaborative meetings with a diverse group of stakeholders, including head teachers, reception class teachers, year 1 class teachers, teacher assistants, and parents. By engaging stakeholders in the decision-making process, the intervention was enriched with diverse perspectives and expertise, thereby increasing its relevance and effectiveness in educational settings. In the following section, details of developing the intervention materials and dosages were explained.

Developing of AiMS Materials: Storybook

An AiMS storybook was created to ensure that the key materials were suitable for children aged 4-6 years old and importantly for their parents/caregivers as they have a pivotal role in the implementation of home-based EI programmes (Gray & Wandersman, 1980; Vivanti & Stahmer, 2018). In terms of parents/caregivers, the final design of the intervention contents and instructions were deemed to be pitched at the right level, they were suitable for home environments, and the process was not too challenging and/or time-consuming (Gray & Wandersman, 1980) as this maximised the chances of a successful delivery of the AiMS intervention (Foster & Mash, 1999). In terms of the children, the storybook was designed to contain activities that were interesting to children such that the activities were enjoyable whilst participating the AiMS programme over the 6-week period of practice.

The work and information that underpinned the creation of the AiMS materials were based on the findings from Study 1 (i.e., the survey) and extensive pilot work in autism special schools. The survey results indicated that the most often used literacy activity of parents/caregivers was to co-participate (looking at or reading) with their young children in using picture books. Using this information as a foundation for developing the AiMS materials, 150 hours of observation was conducted in reception and Key Stage 1 classes in autism special schools. During this time, meetings and consultations were conducted with teaching staff (two autistic reception class teachers, one autistic Key Stage 1 class teacher, one teacher from a mainstream reception class, and one specialist experienced with young autistic children) and three parents of young children. Based on the survey results, observations, and discussions, the AiMS storybook was deemed to be the most appropriate and cost-effective method for delivering the tracing practice activities to children via their parents/caregivers.

After deciding on a storybook, further development centred on the concept of the story-line within the AiMS workbook. Through observations in preschool classrooms and consultations with teaching staff and parents, it was determined that transportation (e.g., cars, buses, bicycles) is an appropriate context specific theme. From discussions, it was apparent that most children are familiar with transportation vehicles in terms of observing and using them frequently both in and out of the school setting. Additionally, the presence of dashed lines on roads, which vehicles are guided by whist manoeuvring through traffic, provided the basis for the directional aspects of the tracing activities that constrained letter tracing that child carried out with a pen/pencil at home using the AiMS workbook. Therefore, the final novel AiMS storybook was developed as the letter-tracing intervention that required children to travel around the world to find different foods, flowers, or animals by tracing over the lines that described each letter.

Dosage of AiMS (Pilot Study)

For dosage, the number of trials used in AiMS was guided based on the work by Foster and colleagues (Foster et al., 2020a; Foster et al., 2020b) who examined motor control and learning adaptations in autistic adults following periods of blocked practice. The results from these studies are important as they specifically examined the principles of blocked practice and showed that participants made significant improvements in motor control and learning markers (reducing movement time; decreasing movement variability) following 30 practice trials. Therefore, and taking these learning effects into consideration, the total number of trials used for AiMS was related to the time children would be required to complete the tracing activities per day and the age of the children in terms of motor learning. As a main researcher, I conducted pilot tests to understand the time needed by the children to complete the Gokturk alphabet letters using the tracing technique. Four autistic children (who did not take part in the AiMS study) aged 4 and 5 years old participated in the pilot test. Each child demonstrated the motor and cognitive capability to perform the tracing activities. The pilot test involved the children working individually with a classroom teaching staff to trace fifteen Gokturk alphabet letters (5 trials for Gokturk letter 1, 5 trials for Gokturk letter 2, 5 trials for Gokturk letter 3) using a pencil and paper method. For each child, a total-time to comfortably complete the 15 tracing letters was recorded, which resulted a time range of 2 minutes to 6 minutes. Based on discussions with the teaching staff, it was decided that on average autistic children could complete 15 tracing activities within 5 to 10 minutes. Additionally, I conducted meetings with three parents/caregivers of young autistic children to discuss the task and potential daily time commitment and all agreed that dedicating 10 to 15 minutes a day for activities was feasible. Taken together, the final AiMS dosage was 5 trials for each (3) Gokturk letter (15 trials), which took approximately 10 to 15 minutes per day, 5 days a week, for 3 weeks for both blocked and random practice (75 trials per each symbol).

Methods

This study was preregistered on the Open Science Framework (https://osf.io/kg5uh).

Study type

This study was an experiment (intervention) study. Participants randomly assigned to groups.

Blinding

Blinding is typically referred to the concealment of group allocation involved in a research study. In AiMS programme the parents could infer the group their children are in based on the AiMS workbook, but even they know the group they randomly assigned, they did not know the blocked-followed-by-random-practice versus random-followed-by-blocked practice group's effect on children's letter writing performance.

Study design

As illustrated in Figure 9, the study was designed to be an AB/BA randomised crossover design based on practice specificity. Two groups [(i.e., Group 1 = **Blocked**-followed-by-**Random** (**BR**); Group 2 = **Random**-followed-by-**Blocked** (**RB**)] received the combined effects of blocked and random practice according to two different structures across Phase 1 and Phase 2.

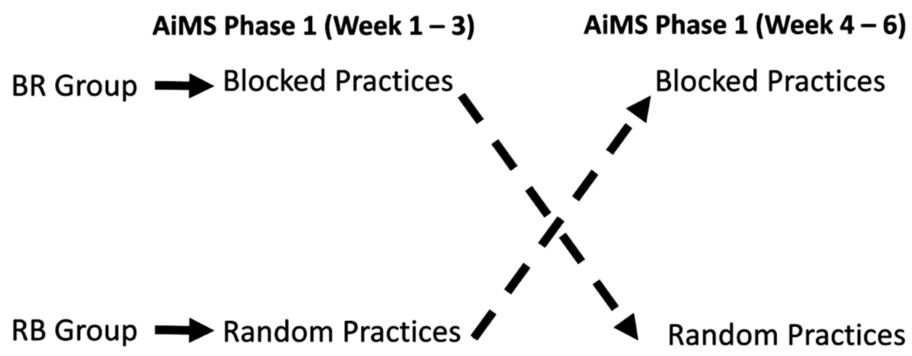


Figure 9: Illustrates the AB/BA crossover design practice structure.

Randomisation

Participants were randomly allocated to a group using a random number generator function of Excel.

Recruitment Process and Participants

Participants were recruited from 3 autism, 1 special needs, and 5 mainstream schools in London based on the following inclusion criteria: (1) children aged between 4 and 5 years old; (2) children have a formal diagnosis of autism spectrum disorder carried out by a clinician/specialist (e.g., a clinical psychologist, paediatrician, psychiatrist); (3) children can perform pen/paper/tablet tracing activities (i.e., tracing a straight line using a pen) independently. To recruit participants, the main researcher (TC) worked with teaching staff (e.g., head teachers, assistant headteachers, or SENCO) from special educational special needs schools, ASD schools, and mainstream schools in London via previously-established professional networks. The parents/caregivers of children who met the inclusion criteria were contacted by school staff. Additionally, social media platforms (i.e., X/Twitter; Facebook) were used to contact parents. Following contact, participant information in the form of an infographic was sent to the parents/caregivers to explain the goals of the AiMS intervention, the inclusion criteria, and information on how to volunteer.

Power analysis and Sample size

To determine a suggested minimum sample size for the study, we conducted a power analysis using G*Power. Our goal was to obtain .95 power to detect a large effect size of .80 at the standard .05 alpha error probability. The power analysis indicated a sample size of 16 was required to achieve power. End of the recruitment process, 18 young autistic children between aged 4 and 5 (*M* = 5.1, *SD* = 0.4), and their parents were recruited for the study. Participants randomly assigned to BR (*n* = 9), and RB (*n* = 9) groups.

In this study, both the intervention and control groups comprised young autistic children. This deliberate choice stemmed from the primary aim of the research, which focused specifically on understanding the impact of specificity of practices on young autistic children's motor learning and transfer skills (i.e., handwriting). Given the unique needs and characteristics of autistic children, particularly in the context of the intervention under investigation, it was deemed essential to maintain homogeneity within the participant groups. By exclusively including autistic children in both the intervention and control groups rather than non-autistic control group, the study aimed to isolate and assess the specific effects of specificity of practices within autistic population's motor skill learning and transfer skills. Moreover, including autistic children as the sole participants ensured a focused examination of how the intervention addressed the targeted challenges and goals pertinent to autistic development and well-being. Consequently, this approach facilitated a more nuanced understanding of the intervention's efficacy and its potential to meaningfully benefit young autistic children, without the confounding influence of differing neurodevelopmental profiles or needs present in non-autistic children.

AiMS Letters

According to the Early Years Foundation Stage (EYFS) statutory framework (https://www.gov.uk/government/publications/early-years-foundation-stage-framework--2) preschool children are required to learn how to write in uppercase and lowercase letters (DfE, 2023). It is suggested that uppercase letter writing is easier than lowercase letter writing and thus should be learnt first (e.g., Treiman & Kessler, 2004; Puranik et al., 2013). AiMS was therefore designed to support the acquisition of uppercase letter writing in young autistic children. Two types of alphabet letters were examined: novel alphabet letters (i.e., Gokturk Alphabet) and familiar alphabet letters (i.e., English Alphabet). Novel letters were used to investigate the effects of practice specificity on the acquisition of new motor skills and familiar letters were used to investigate how practice specificity influenced generality of learning by examining motor performance transfer effects from novel to familiar letters.

Novel Letters

During AiMS, children were instructed to practice and acquire 3 novel Gokturk alphabet uppercase letters. These 3 letters were selected by first mapping, for experimental control, the letter shape to familiar English letters in terms of number of strokes (e.g., 3) that make-up the letter and stroke amplitude. For note, uppercase letters in the English alphabet are formed in two ways: curved-lines and straight-lines. Specifically, the English alphabet consists of 15 uppercase horizontal and vertical straight-line letters (i.e., A, E, F, H, I, K, L, M, N, T, V, W, X, Y, Z) and 11 uppercase curved-line letters (i.e., B, C, D, G, J, O, P, Q, R, S, U). In this feasibility study, we focused on the acquisition of uppercase letters that have straight lines. A critical aspect of forming uppercase letters is the number of strokes that create a letter – there are 10 uppercase letters that are written with 1 stroke (i.e., I, L, J, O, C, V, W, U, S, Z), 12 uppercase letters that are written with 2 strokes (i.e., T, D, B, P, R, Q, G, N, M, X, Y, K), 3 uppercase letters that are written with 3 strokes (i.e., H, F, A), and 1 uppercase letter written with 4 strokes (i.e., E). Given the distribution of strokes in the English alphabet, the 3 novel Gokturk letters (see Table 6) had one stroke (i.e., Gokturk letter V), two strokes (i.e., Gokturk letter K), and three strokes (i.e., Gokturk letter A).

Familiar Letters

Three familiar English letters were used to examine how practice specificity influenced generality of learning by examining motor performance transfer effects from novel to familiar letters. The English letters are V (i.e., English letter V) , K (i.e., English letter K), and A (i.e., English letter A), which map to the 3 Gokturk letters in terms of stroke number and amplitude (see Table 7).

Table 6: Novel Gokturk letters (left to right; Gokturk Letter V; Gokturk Letter K; Gokturk Letter A)

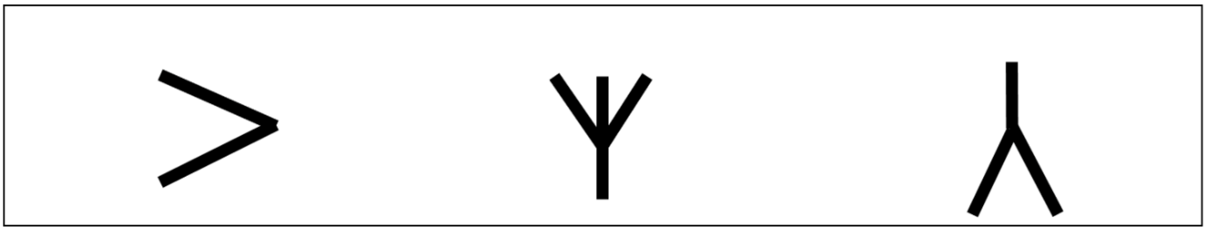
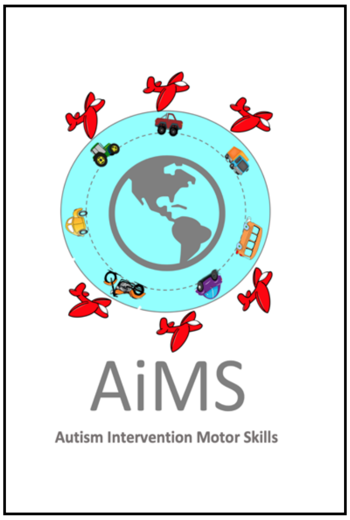


Table 7: Familiar English letters (left to right; English letter V; English letter K; English letter A)

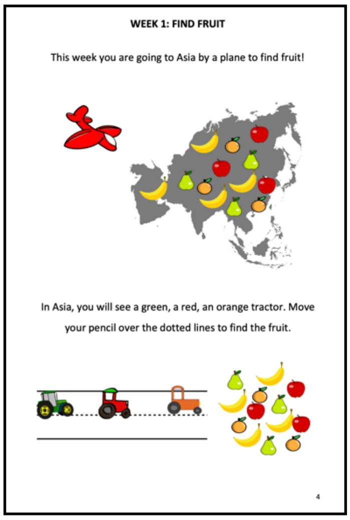
V	K	A

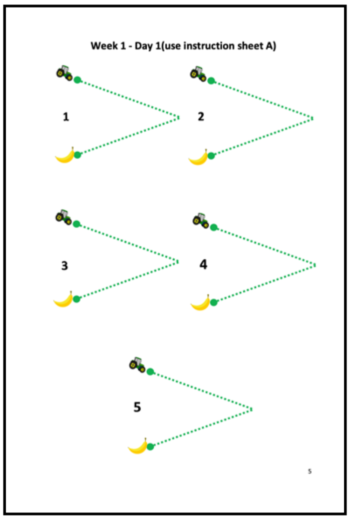
AiMS Workbook

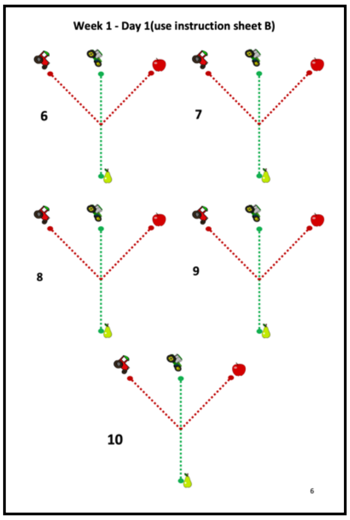
A workbook was used by a parent/caregiver to administer the daily AiMS letter-tracing practice activities. The final workbooks (BR and RB groups had specific workbooks) were edited by reception class teacher with 20 years teaching experience and included 90 pages with each page containing 5 tracing activities (see an example for the final version of AiMS workbook in Figure 10).

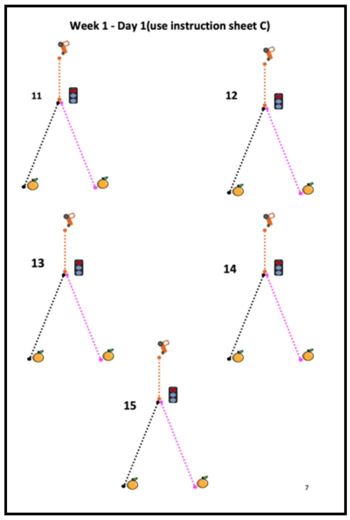

AiMS
Autism Intervention Motor Skills


Hello parents! You and your child going on an adventure around the world.
Across the next 6 weeks, you and your child will travel around the world doing different activities to win some stickers!
2


WEEK 1: FIND FRUIT
This week you are going to Asia by a plane to find fruit!
In Asia, you will see a green, a red, an orange tractor. Move your pencil over the dotted lines to find the fruit.
4


Week 1 - Day 1(use instruction sheet A)
1
2
3
4
5
5


Week 1 - Day 1(use instruction sheet B)
6
7
8
9
10
6


Week 1 - Day 1(use instruction sheet C)
11
12
13
14
15
7

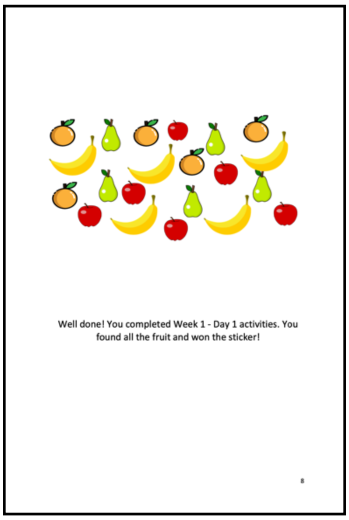

Well done! You completed Week 1 - Day 1 activities. You found all the fruit and won the sticker!
8

Figure 10: An example of final version of AiMS workbook.

AiMS Training

Videos and Instruction Sheets

The training videos (https://qualtrics.ucl.ac.uk/jfe/form/SV_8f5hjQwSwL1kZzU) designed to explain in detail the AiMS process in terms of how parents/caregivers should administer the activities to their child on each day. The first video explained "What is AiMS?", the second video explained "AiMS process, materials, and activities", and the third video explained, "How parents can conduct AiMS activities with their children." In the fourth video, "Top tips" was provided to parents in case if their children do not want to do activities. In the training videos, "How activities should be done" was shown through vitalizations, and a PhD student from UCL accompanied the main researcher by acting like a young child. The videos were uploaded to an online platform (i.e., Qualtrics) and sent to parents via links Moreover, the research team developed instruction sheets that explained how children should do tracing activities for each novel letter and were sent to parents (see Figure 11).

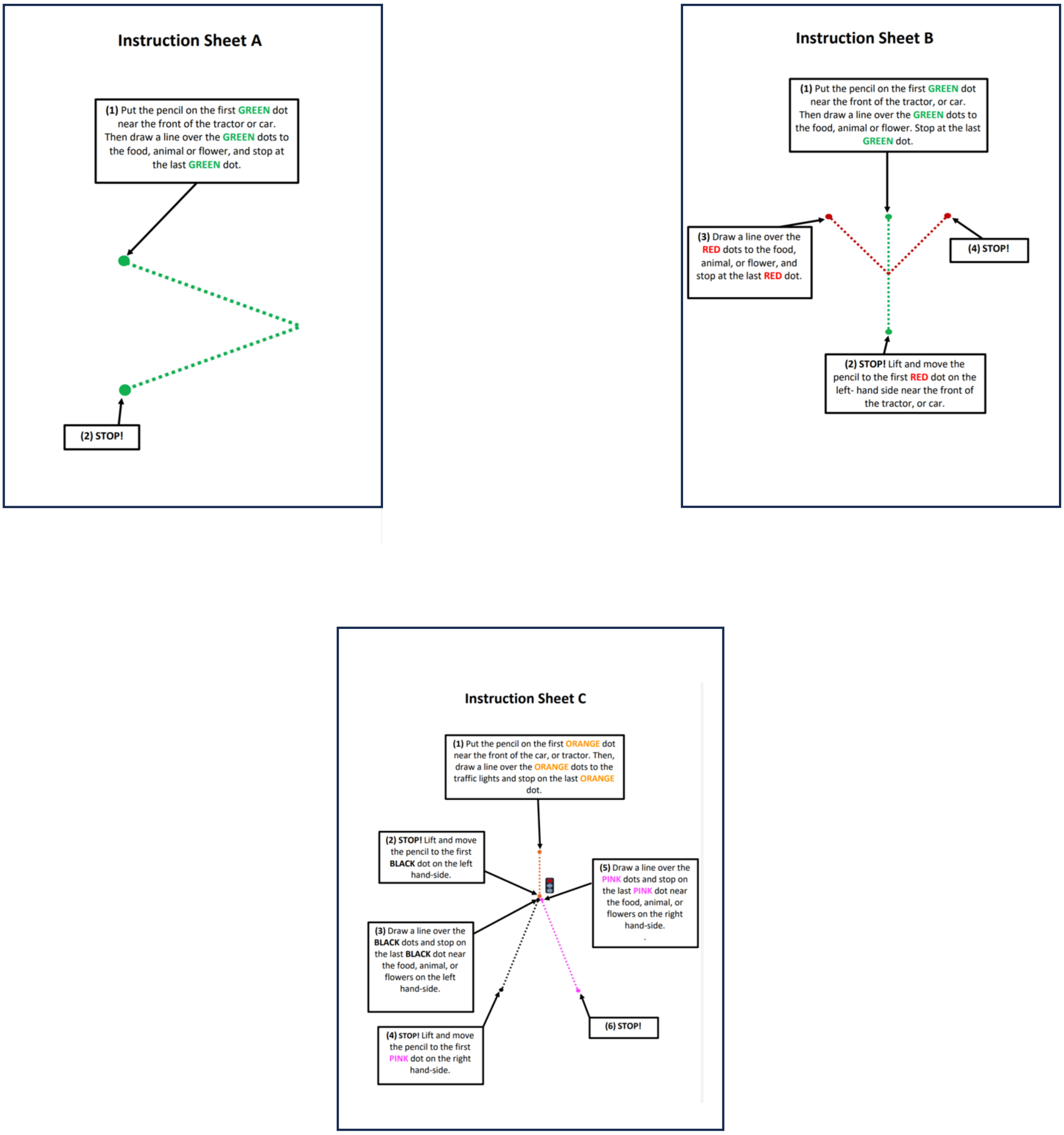


Figure 11: Instruction sheets that explained how children should do tracing activities for each novel letter

AiMS Dosage

AiMS was a 6-week intervention that was implemented at home by parents/caregivers 5 days week for 10 minutes per day. Each day, a child performed 5 tracing activities on each of the 3 novel letters (15 tracing activities in total The AiMS dosage was based our on previous work on motor learning in autism (e.g., Foster et al., 2020a; Foster et al., 2020b) and pilot work conducted with 4 young autistic children in reception classes and parent/caregiver meetings (see details in under the “Developing of AiMS Intervention” title).

AiMS Procedure

Following a pre-test, the AiMS instruction materials (i.e., workbook, pens, instruction sheets, motivators, link to training videos) were posted to parents/caregivers with an AiMS package (see Figure 12). During AiMS, children performed letter tracing activities on the 3 novel alphabet letters using the specified AiMS workbook. In Phase 1 (weeks 1 to 3), the **BR** group performed blocked-practice and the **RB** group performed random-practice. In Phase 2 (weeks 4 to 6), the **BR** group performed random-practice and the **RB** group performed blocked-practice activities.

Figure 12: AiMS package that sent to parents before following the pre-test.

Fidelity of AiMS

Intervention fidelity refers to the degree to which an intervention is implemented as intended and is an important process in establishing a functional relationship between intervention implementation and behavior change (Moncher & Prinz, 1991). Therefore, and based on the literature (e.g., Fallon et al., 2020), the following variables were recorded to provide an indication of fidelity of the AiMS programme:

1. ***How was the AiMS training provided to parents?***

As parents were the implementers of the intervention, it was important to ensure that parents understood and had the capacity to implement the intervention with their child. The results of Study 1 (the systematic review) indicated that the delivery of training in home-based EIs has changed from weekly face-to-face meetings with parents/caregivers (e.g., Ozonoff & Cathcart, 1998) to the utilisation of technology in the form of video recording, online meetings and applications to train and inform parents on implementation of the intervention (e.g., Cardon & Wilcox, 2011). Incorporating technology was therefore viewed as the most appropriate and time effective method to inform and train parents on the implementation of AiMS. The AiMS training used four in-house online videos that (1) explained "What is AiMS?"; (2) "AiMS process, materials, and activities"; (3) "How parents can conduct AiMS activities with their children"; (4) "Top tips" for a parent/caregiver to motivate their children to participate in the activities. In the training videos, the demonstration of "How activities should be done" was presented from the perspective of a home-setting with a PhD student from UCL portraying the role of a young autistic child and Tugce Cetiner acting as a parent/caregiver. The 4 videos were uploaded to an online platform (Qualtrics) and the online link were shared with parents/caregivers via email or WhatsApp.

After each training video, parents/caregivers were asked to answer task-related questions associated with the content of each video. After the video and question, the correct answers were provided to parents/caregivers. Following the completion of each set of questions and reviewing the answers, parents were able proceeded to the next video.

2. Was the AiMS protocol implemented?

In order to ensure the fidelity of the intervention it is not only important to train intervention implementers (i.e. the parents) appropriately but also to measure how and whether the intervention was actually implemented as intended. Various measures of implementation fidelity were taken:

1. Tugce Cetiner sent a reminder to the parents/caregivers via WhatsApp messaging or emails on each training day to prompt them to deliver the AiMS tracing activities.
2. Each day, following the completion of the AiMS activities, the parent/caregiver took a photo of the completed AiMS tracing page and sent it Tugce. This allowed careful tracking of the dosage of implementation for each child.

Measured variables

Control Measures

Autism Severity: Childhood Autism Rating Scale (CARS)

CARS questionnaire consists of 15 question items corresponding to autism symptoms. The parents/caregivers of participating children in the current study completed the questionnaire. CARS provided a ‘total’ score (range: minimum of 15 to a maximum of 60), which indicated autism severity. Scores below 30 indicated non-autism, scores between 30 and 36.5 indicated mild to moderate autism, and scores from 37 to 60 indicated severe autism.

Cognitive Abilities: British Ability Scale III (BAS III)

BAS **III** (early years) (ages 3.6 – 5.11 years) was administered to gain a measure of cognitive ability. The following 6 core skills were assessed: (1) verbal comprehension; (2) naming vocabulary; (3) picture similarities; (4) pattern construction; (5) matrices; and (6) copying. BAS III returns a total score for each skill and these scores will be presented in percentiles. From these measures, the verbal comprehension and naming vocabulary provided a “verbal ability score”; pattern construction and copying provided a “spatial ability score”; and the picture similarities and matrix provided a “non-verbal reasoning score”. Based on the scores, core skills are described as: 1st – 2nd (very low), 3rd – 8th (low), 9th – 24th (below average), 25th – 74th (average), 75th – 90th (above average) 91st – 97th (high) and 98th – 99th (very high). A “General Conceptual Ability (GCA)” score will be calculated using the three scores. If children are non-verbal, or they find the verbal tests very difficult to complete, a "Special Non-verbal Composite" score will be calculated using the "spatial and non-verbal reasoning" scores.

Motor Skill Performance: The Movement Assessment Battery for Children - Second Edition (MABC-2)

The MABC-2 measured children's fine and gross motor skill performance using the eight tasks across three categories: (1) manual dexterity (i.e., posting coins, threading beads, drawing trail), (2) ball skills (i.e., bouncing and catching a ball), (3) static and dynamic balance (i.e., one leg balance, walking heels raised, jumping on mats). Children's scores for the 3 categories will be converted into percentile scores, and these scores will be defined with a traffic light scoring system, including red (significant movement difficulty), amber (likelihood developing movement difficulty) and green zone (no movement difficulty).

Executive Function (EF): Behavior Rating Inventory of Executive Function - Preschool (BRIEF-P)

BRIEF-P is a questionnaire consisting of 63 items that measured different aspects of executive function skills: *inhibit, shift, emotional control, working memory and plan/organise*. The questionnaire was completed by all parents. The BRIEF-P scores will be converted to T scores. Based on the T scores, EF skill for each will be described as: higher than 70 (clinically elevated), 65 – 69 (potentially clinically elevated), 60 – 64 (mildly elevated) and less than 60 (normal range).

Post AiMS Questionnaire

After the completion of AiMS, all parents/caregivers completed an in-house designed questionnaire. The questionnaire was used to gather a general understanding of their opinions on the process of administering, and the impact, of the AiMS intervention - for example “Did you find the workbook easy to use?”, or “Do you think your child’s handwriting improved after completing AiMS?”.

Measurement of Children’s Letter Tracing Performance in Pre-Test, Post-Test-1, Post Test-2 and Retention-Test

Apparatus

A laptop (Dell Latitude 5420), graphics tablet (Wacom Intuos Pro XL), a hand-held stylus and acetate sheets illustrating the novel and familiar letters were used to control the experimental protocol (implemented by a MATLAB routine) and capture movement kinematics of the hand whilst tracing the letters.

Procedure

The motor behaviour tracing assessments were conducted in a room located at a school (supervised by a teacher or TA) or lab at UCL (supervised by a parent/caregiver). The laptop, graphics tablet and stylus were located on a table that was scaled to the height of a participant. First, and prior to the pre-test, the task and apparatus were verbally explained to participants, followed by a familiarisation period where participants practised tracing 3 different shapes using the stylus to trace shapes illustrated on acetates that were located on the tablet. Once participants indicated they understood the task, they performed the pre-test tracing activities on the graphics tablet – the pre-test was structured so that each participant performed two sets of tracing activities. In Set 1, participants performed a total of 9 trials where they traced each Gokturk letter (i.e., Gokturk Letter V, Gokturk Letter K, Gokturk Letter A) 3 times in a blocked-trial-order, with the letter presentation order randomised across participants. In Set 2, participants performed a total of 9 trials where they traced each English letter (i.e., English letter V, English letter K, English letter A) 3 times in a blocked-trial-order, with the letter presentation order randomised across participants. Before performing the tracing tasks, participants were instructed to “trace the letters fast and accurate”. The follow-up motor behaviour tracing assessments in Post-Test-1, Post Test-2 and Retention-Test were carried out using the same procedure as the pre-test. Pre-tests were conducted before the intervention began. Post-Test 1 was conducted after three weeks of the intervention, and Post-Test 2 was conducted after six weeks of the intervention. Finally, a Retention-Test was conducted four weeks after the intervention concluded.

Data Reduction

MATLAB Picking Routines

Routine 1 (LetterAnal.mat)

When working with MATLAB to analyse time-series data of letter movements, the routine named LetterAnal.mat was developed. This routine assisted researchers in selecting and verifying the start and end points of movements for letters and analysing the x and y position data dynamically.

Routine 2 (LetterAnalVel.mat)

The LetterAnalVel.mat routine was developed to analyse the velocity profiles of letter movements using the data obtained from the previous routine, LetterAnal.mat. The output was included comprehensive Excel file that encapsulates all the velocity data collected during the trials.

Dependent Variables, Research Questions, Hypotheses and Analysis Plan

Dependent Variables

Movement time (MT): Movement time represents the overall duration between the initiation (start) and completion (end) of each tracing movement performed for each letter. MT is a key indicator of improvement in motor learning performance because it reflects increased efficiency, reduced cognitive load, better coordination and timing, enhanced motor planning, effective feedback integration, and the development of muscle memory (Elliott et al., 2010; Magill & Anderson, 2010). Since all these factors contribute to quicker and more proficient execution of motor tasks, and demonstrating the progress in motor learning, MT was chosen as a dependent variable. MT was used as a variable to answer research question 1 and 2.

Letter Production Error (LPE): When motor skill learning improves, the error in performing the task decreases significantly. As individuals practice a motor skill, they develop better coordination and control over their movements, which leads to more accurate and precise execution (Magill & Anderson, 2010). To assess the changing error rate in young autistic children's letter writing performance, letter production error (LPE) was used as the independent variable. This measure provided a clear indicator of improvements in motor skill learning by quantifying the reduction in errors over time, thereby reflecting the child's progress in developing better writing skills. LPE represents the error in area of each individual letter. The first step of LPE calculation process was generating a bounding box around each letter using MATLAB functions. Subsequently, the standard letter area score was determined by multiplying the width and height of the bounding box for each standard letter. Following this, the letter area of children's produced letters was computed by multiplying the width and height of the corresponding bounding box. In the final step LPE was calculated by subtracting the children's produced letter's area from the standard letter area score. LPE was chosen as a dependent variable to understand motor learning improvement in children after AiMS. LPE was used as a variable to answer research question 1 and 2.

Peak Velocity (PV): Peak velocity represents the maximum speed achieved during tracing of letters' segments. Increasing PV reflects improvements in motor planning (Elliott et al., 2010). Motor planning involves the brain's ability to organize, sequence, and execute movements efficiently (Wong et al., 2015). As individuals practice and refine their motor skills, their brain becomes better at coordinating muscle activities and timing. This improved coordination allows for smoother and more efficient movements, which are often faster. Consequently, the highest speed reached during a movement which is PV, increases. PV was chosen as a dependent variable to understand motor planning improvement in children after AiMS. PV was used as a variable to answer research question 3 and 4.

Percentage Time to Peak Velocity (%TTPV): Time for peak velocity represents the specific time when the velocity reaches its highest point during tracing of letters' segments. A higher PTPV indicates that the peak velocity is achieved earlier in the movement, signifying a well-planned and executed action (Magill & Anderson, 2010). Therefore, a higher %PTPV is a strong indicator of improved motor planning, as it reflects the ability to initiate and control movements more effectively, minimizing unnecessary adjustments and delays (Elliott et al., 2010). %PTPV was chosen as a dependent variable to understand motor planning improvement in children after AiMS. TTPV was used as a variable to answer research question 3 and 4.

Research Questions, Hypotheses and Analysis Plan

RQ.1. Does the specific combined effects of blocked-followed-by-random-practice underpin significantly greater short term motor learning of performed novel letters, and generality of motor learning to the transfer of motor performance to unpractised familiar letters compared to random-followed-by-blocked practice?

HP.1. Based on the previous study (see in Lai et al., 2000), it was hypothesised that that that blocked-followed-by-random-practice will underpin more accurate and less variable motor learning of performed novel letters, and generality of motor learning to the transfer of motor performance to familiar but unpractised letters than random-followed-by-blocked-practice by reducing timing (shorter movement time), variability in timing, letter production error, and variability in letter production error during practice end of 6 weeks AiMS programme.

Analysis of Novel Letters: A mixed design repeated measures ANOVA was used to analyse novel letters: 2 Group (BR; RB) X 3 Phase (Pre-Test; Post-

Test1; Post-Test2) X 3 Novel Letters (Gokturk Letter V; Gokturk Letter K; Gokturk Letter A).

Analysis of Familiar Letters*:* A mixed design repeated measures ANOVA was used for analysing familiar letters: 2 Group (BR; RB) X 3 Phase (Pre-Test; Post-Test1; Post-Test2) X 3 Familiar Letters (English Letter V; English Letter K; English Letter A)

RQ.2. Does the specific combined effects of blocked-followed-by-random-practice underpin significantly greater long term motor learning of performed novel letters, and generality of motor learning to the transfer of motor performance to unpractised familiar letters compared to random- followed-by-blocked practice?

HP.2. Based on the previous study (see in Lai et al., 2000), it was hypothesised that that   that blocked-followed-by-random-practice will underpin more accurate and less variable motor learning of performed novel letters, and generality of motor learning to the transfer of motor performance to familiar but unpractised letters than random-followed-by-blocked-practice by reducing timing (shorter movement time), variability in timing, letter production error, and variability in letter production error during practice 4 weeks after AiMS programme.

Analysis of Novel Letters: A mixed design repeated measures ANOVA was used for analysing of novel letters: 2 Group (BR; RB) X 2 Phase (Post-Test2; Retention Test) X 3 Novel Letters (Gokturk Letter V; Gokturk Letter K; Gokturk Letter A)

Analysis of Familiar Letters: A mixed design repeated measures ANOVA was used for analysing of familiar letters: 2 Group (BR; RB) X 2 Phase (Post-Test2; Retention Test) X 3 Familiar Letters (English Letter V; English Letter K; English Letter A)

RQ.3. Does the specific combined effects of blocked-followed-by-random-practice underpin significantly different short-term motor control processes while performing novel and familiar letters compared to random-followed-by-blocked-practice?

HP.3. Based on the previous study (see in Lai et al., 2000), it was hypothesised that that blocked-followed-by-random-practice will underpin significantly motor planning processes of novel and novel and familiar but unpractised letters compared to random- followed-by-blocked practice by reducing variability in peak velocity and time for peak velocity end of 6 weeks AiMS programme.

Analysis of Novel Letters: A mixed design repeated measures ANOVA will be used for novel letters: 2 Group (BR; RB) X 3 Phase (Pre-Test; Post-Test1; Post-Test2) X 1 Novel Letter (Gokturk Letter K)

Analysis of Familiar Letters: A mixed design repeated measures ANOVA will be used for analysing of familiar letters: 2 Group (BR; RB) X 3 Phase (Pre-Test; Post-Test1; Post-Test2) X 1 Familiar Letter (English Letter K)

RQ4. Does the specific combined effects of blocked-followed-by-random-practice underpin significantly different long-term motor control processes while performing novel and unpractised familiar letters compared to random-followed-by-blocked-practice?

HP.4. Based on the previous study (see in Lai et al., 2000), it was hypothesised that blocked-followed-by-random-practice will underpin significantly motor planning processes of novel and novel and familiar but unpractised letters compared to random- followed-by-blocked practice by reducing variability in peak velocity, and time for peak velocity 4 weeks after AiMS programme.

Analysis of Novel Letters: **A mixed design repeated measures ANOVA** will be used for analysing of novel letters: 2 Group (BR; RB) X 2 Phase (Post-Test2; Retention Test) X 1 Novel Letter (Gokturk letter K)

Analysis of Familiar Letters: **A mixed design repeated measures ANOVA** will be used for analysing of familiar letters: 2 Group (BR; RB) X 2 Phase (Post-Test2; Retention Test) X 1 Familiar Letter (English letter K)

Results

Demographic Information and Characteristic of Participants

Each grouped was consistent of 9 participants. Children's demographic information and control measures scores [(i.e., BAS-3 General Cognitive Ability (GCA), BRIEF-P, MAB-C, CARS)] were presented in Table 8, and Table 9.

Table 8: Illustration of demographic information of children in BR and RB groups

Demographic Information	BR *(n)*	RB *(n)*
Gender		
Male	4	3
Female	5	6
School Type		
Special Needs School	8	6
Mainstream School	1	3
Class		
Reception	8	8
Year 1	1	1

Table 9: Illustration of descriptive statistics for the BR and RB groups: BAS-3 General Cognitive Ability (GCA), BRIEF-P, MAB-C, CARS scores

	BR Group M (SD)	RB Group M (SD)
BAS-3 / GCA	76.00 (12.48)	76.56 (15.02)
BRIEF-P	73.78 (14.43)	75.89 (17.47)
MAB-C	53.28 (8.85)	50.06 (10.22)
CARS	47 (9.97)	50 (9.20)

As indicated before, motor skills of young autistic children were measured with MAB-C. The results indicated that within the BR group, three children were classified in the amber zone and six in the red zone. Similarly, within the RB group, four children were in the amber zone and five in the red zone. According to the MAB-C classification, children in the amber zone are considered at likelihood developing motor skill difficulties, while those in the red zone are regarded as already having motor skill difficulties (Brown & Lalor 2009). Therefore, the results suggest that young autistic children who participated in the AiMS intervention have motor skill difficulties. These findings are consistent with existing literature, such as the study by Ketcheson et al. (2018), which showed that young autistic children exhibit motor skill difficulties compared to their neurotypical peers.

In order to understand baseline difference between groups' (i.e., BR and RB), pre-test results (i.e., BAS-3/GCA; BRIEF-P; MAB-C; CARS) were compared with t-tests. Before compare baseline differences between groups with t test, a normality test (i.e., Shapiro-Wilk test) was conducted. Results revealed that all but one variable was normally distributed ($p > 0.05$). Only BR group's BAS-3 / GCA' scores deviated from normality ($p < 0.05$) (see Table 10). It is important to note that the sample size was small ($n = 9$) for these responses, and thus, the non-normality was treated with some caution. This caution is due to the power of normality tests (e.g., Shapiro-Wilk, Kolmogorov-Smirnov, or Lilliefors) being low for small sample sizes (Razali & Wah, 2011). Therefore, baseline differences between the groups were evaluated using an independent t-test. The results revealed no-significant baseline differences between groups across all standardised assessments: BAS-3/GCS [($t(15) = -0.08$, $p = 0.935$), BRIEF-P [($t(16) = -0.27$, $p = 0.783$), MAB-C [($t(16) = 0.71$, $p = 0.485$), and CARS [($t(14) = -0.62$, $p = 0.542$). It was important to note that, to increase the reliability of the test results, the BAS-3/GCA scores of the children were evaluated with the Mann-Whitney U test as well. This non-parametric test is recommended for independent samples with non-normally distributed data (Wall Emerson, 2023). Consistent with the t-test results, the Mann-Whitney U test revealed no significant differences between the groups for BAS-3/GCA scores ($U = 40.50$, $p = 0.69$).

Table 10: Shapiro-wilk scores of BAS-3 General Cognitive Ability (GCA), BRIEF-P, MAB-C, CARS

	BR Group Shapiro-wilk scores	RB Group Shapiro-wilk scores
BAS-3 / GCA	0.035	0.749
BRIEF-P	0.198	0.761
MAB-C	0.410	0.512
CARS	0.082	0.530

Demographic Information of Parents

Although there were no significant differences between baseline skills of young autistic children in BR and RB groups, there were some differences in their parent's demographic information between groups. For example, while almost all parents in the RB group have university degree (*n* = 8), in BR group only 4 parents have this degree (see Table 11). Remaining parents in both groups have other qualifications (e.g., GCSE/O Level grade A*-C, vocational level 2 and equivalents

Table 11: Illustration of demographic information of parents in BR and RB groups

Demographic Information	BR *(n)*	RB *(n)*
Relationship with the child		
Mother	8	8
Father	1	1
Education level		
University degree	4	8
Other qualification	5	1
Ethnicity		
White	5	3
Black	2	3
Mixes or multiple ethnic groups	1	2
Other	1	1
Employment Status		
Employed or self employed	4	3
Unemployed	1	2
Student	1	1
Other	3	3
Parents' children number		
One child	1	1
More than 1 child	8	8

Motor Performance Phase Results

Movement Time (MT)

ANOVA revealed a significant main effect for *group* $F(1, 16) = 9.36$, $p < 0.001$, $\eta_p^2 = 0.37$, *phase* $F(2, 32) = 9.39$, $p < 0.001$, $\eta_p^2 = 0.37$ and *letter* $F(1.34, 21.36) = 8.93$, $p = 0.004$, $\eta_p^2 = 0.36$. As illustrated in Table 12, the BR group performed the letter writing task with a significantly shorter MT than the RB group (a difference of 961 ms). For *phase* (Figure 13, Table 12), there was no significant difference ($p > 0.05$) in letter writing MT between pre-test (*M* = 4076 ms; *SD* = 1023 ms) and post-test 1 (*M* = 4088 ms; *SD* = 1202 ms), but MT was significantly ($p < 0.05$) shorter in the post-test 2 (*M* = 3430 ms; *SD* = 887ms) than the pre-test (a difference of 646 ms). The *letter* effect (Table 12) indicated there were significant differences (*ps* < 0.05) in MT between letter *Ag* (*M* = 3703 ms; *SD* = 1359 ms) and *Kg* (*M*= 4543 ms; *SD* = 930 ms), and between *Kg* and *Vg* (*M* = 3347 ms; *SD* = 823 ms), but not between *Ag* and *Vg.* Finally, there were no significant interactions concerning *group* x *phase* $F(2, 32) = 1.72$, $p = 0.195$, $\eta_p^2 = 0.009$, *group* x *letter* $F(1.33, 21.36) = 2.37$, $p = 0.132$, $\eta_p^2 = 0.13$, *phase* x *letter* $F(4, 64) = 1.42$, $p = 0.24$, $\eta_p^2 = 0.008$, and *phase* x *letter* x *group* $F(4, 64) = 1.41$, $p = 0.24$, $\eta_p^2 = 0.008$.

Movement Time Variability (MTv)

ANOVA revealed a significant main effect for *group* $F(1, 16) = 9.39$, $p = 0.007$, $\eta_p^2 = 0.370$, *phase* $F(2, 32) = 3.81$, $p = 0.033$, $\eta_p^2 = 0.193$, and *letter* $F(2, 32) = 9.74$, $p < 0.001$, $\eta_p^2 = 0.379$. As illustrated in Table 12, MTv was significantly lower for the BR group than the RB group (a difference of 338 ms). For *phase*, there was no significant differences ($p > 0.05$) in MTv between pre-test (*M* = 905 ms; *SD* = 619 ms) and post-test 1 (*M* = 855 ms; *SD* = 396 ms), and post-test 1 and post-test 2 (*M* =

652; *SD* = 360), but variability was significantly (p < 0.05) lower in the post-test 2 than the pre-test (a difference of 253 ms). The *letter* effect indicated significant differences (*ps* < 0.05) in MTv between letter *Ag* (*M* = 657 ms; *SD* = 424 ms) and *Kg* (*M* = 1074 ms; *SD* = 568 ms), between *Kg* and *Vg* (*M* = 681 ms; *SD* = 382 ms), but not between *Ag* and *Vg.* The *group* x *letter* interaction was significant $F(2, 32) = 3.51$, $p = 0.042$, $\eta_p^2 = 0.180$ and indicated there were no significant differences (*ps* > 0.05) in MTv for the BR group when tracing the three letters. Whereas the RB group executed significantly greater MTv (*ps* < 0.05) when tracing *Kg* than *Ag* (a difference of 604 ms), and *Kg* than *Vg* (a difference of 666 ms). The interaction also showed there were no significant (*ps* > 0.05) differences between groups when tracing *Ag* and *Vg*, but the RB group had a significantly (p < 0.05) higher MTv than the BR group when tracing *Kg* (a difference of 645 ms). The *phase* x *letter* interaction $F(4, 64) = 4.52$, $p = 0.003$, $\eta_p^2 = 0.220$ indicated there were no significant (*ps* > 0.05) differences in MTv across the three letters (*Ag, Kg, Vg*) in the pre-test, and post-test2, but MTv was significantly greater in Post-Test 1 for letter Kg compared to *Ag* (a difference of 952 ms) and *Vg* (a difference of 732 ms).

Letter Production Error (LPE)

ANOVA revealed a significant main effect for *letter* $F(2, 32) = 9.21$, $p < 0.001$, $\eta_p^2 = 0.365$, but there were no significant effects for *phase* $F(1.37, 22.01) = 1.89$, $p = 0.182$, $\eta_p^2 = 0.106$, and *group* $F(1, 16) = 0.77$, $p = 0.391$, $\eta_p^2 = 0.046$. The *letter* effect indicated there were significant differences (*ps* < 0.05) in LPE between *Ag* (*M* = 1101 mm; *SD* = 927 mm) and *Kg* (*M* = 1590 mm; *SD* = 878 mm), and between *Kg* and *Vg* (*M* = 961 mm; *SD* = 736 mm), but not between *Ag* and *Vg* (see Table 12). Finally, there were no significant interactions concerning *group* x *phase* $F(1.37, 22.01) =$

1.96, $p = 0.173$, $\eta_p^2 = 0.109$, *group* x *letter* $F(2, 32) = 0.75$, $p = 0.483$, $\eta_p^2 = 0.044$, *phase* x *letter* $F(4, 64) = 0.20$, $p = 0.935$, $\eta_p^2 = 0.013$ and *phase* x *letter* x *group* $F(4, 64) = 1.80$, $p = 0.239$, $\eta_p^2 = 0.101$.

Letter Production Error Variability (LPEv)

ANOVA revealed a significant main effect for *group* $F(1, 16) = 5.53$, $p = 0.032$, $\eta_p^2 = 0.258$, but no significant effects for *phase* $F(2, 32) = 0.35$, $p = 0.703$, $\eta_p^2 = 0.022$, and *letter* $F(2, 32) = 2.29$, $p = 0.124$, $\eta_p^2 = 0.122$. As illustrated in Table 12, the BR group performed the letter writing task with a significantly lower LPEv than the RB group (a difference of 328 mm). There was also a *letter* x *phase* interaction $F(4, 64) = 4.66$, $p = 0.002$, $\eta_p^2 = 0.226$ that indicated there were no significant (*ps* > 0.05) differences in LPEv for Ag and Vg between pre-test, post-test 1, and post-test 2, but LPEv was significantly ($p < 0.05$) lower in post-test 2 compared to post-test 1 (the difference was 683 mm) for Kg. There were also no significant (*ps* > 0.05) differences in LPEv between Ag and Vg, and Ag and Kg in pre-test, post-test 1, and post-test 2, but in post-test-2 LPEv was significantly ($p < 0.05$) higher Kg compared to Vg (the difference was 823 mm). Finally, there were no significant interactions concerning *group* x *phase* $F(2, 32) = 0.06$, $p = 0.941$, $\eta_p^2 = 0.047$, *group* x *letter* $F(2, 32) = 0.79$, $p = 0.460$, $\eta_p^2 = 0.047$ and *phase* x *letter* x *group* $F(4, 64) = 1.13$, $p = 0.347$, $\eta_p^2 = 0.066$.

Peak Velocity (PV)

ANOVA revealed a significant main effect for *group* $F(1, 16) = 7.021$, $p = 0.017$, $\eta_p^2 = 0.200$, but not for *phase* $F(2, 32) = 3.12$, $p = 0.058$, $\eta_p^2 = 0.163$. As illustrated in Table14, the BR group performed the letter writing tasks with a significantly greater PV than the RB group (a difference of 38940 mm/ms). Finally, there was no significant interaction concerning *group* x *phase* $F(2, 32) = 1.14$, $p = 0.333$, $\eta_p^2 = 0.067$.

Peak Velocity Variability (PVv)

ANOVA revealed no significant effects for *group* $F(1, 16) = 0.14$, $p = 0.706$, $\eta_p^2 = 0.009$, *phase* $F(2, 32) = 0.71$, $p = 0.497$, $\eta_p^2 = 0.043$ and *group* x *phase* interaction $F(2, 32) = 0.032$, $p = 0.968$, $\eta_p^2 = 0.002$ (see Table 14).

Percentage Time to Peak Velocity (%TTPV)

ANOVA revealed no significant effects for *group* $F(1, 16) = 2.90$, $p = 0.107$, $\eta_p^2 = 0.154$, *phase* $F(2, 32) = 1.93$, $p = 0.162$, $\eta_p^2 = 0.108$ and *group* x *phase* interaction $F(2, 32) = 0.95$, $p = 0.395$, $\eta_p^2 = 0.056$ (see Table 14).

Percentage Time to Peak Velocity Variability (%TTPVv)

ANOVA revealed no significant effects for *group* $F(1, 16) = 0.24$, $p = 0.625$, $\eta_p^2 = 0.015$, *phase* $F(2, 32) = 1.001$, $p = 0.379$, $\eta_p^2 = 0.059$ and *group* x *phase* interaction $F(2, 32) = 0.16$, $p = 0.848$, $\eta_p^2 = 0.010$ (see Table 14).

<u>Motor Learning Phase</u>

Movement Time (MT)

ANOVA revealed significant effects for *group* $F(1, 16) = 9.51$, $p = 0.007$, $\eta_p^2 = 0.373$ and *letter* $F(2, 32) = 12.96$, $p < 0.001$, $\eta_p^2 = 0.448$. As illustrated in Figure 13 and Table 12, the BR group performed the letter writing tasks with a significantly shorter movement time than the RB group (a difference of 1282 ms). The *letter* effect (see Table 10) indicated there were significant differences (*ps* < 0.05) in movement time between *Ag* (*M* = 3357 ms) and *Kg* (*M* = 4238 ms), and between *Kg* and *Vg* (*M* = 3083 ms), but not between *Ag* and *Vg.* Finally, there was no significant main effect of *phase* $F(1, 16) = 0.82$, $p = 0.37$, $\eta_p^2 = 0.049$ and no significant interactions concerning *group* x *phase* $F(1, 16) = 0.16$, $p = 0.68$, $\eta_p^2 = 0.002$, *group* x *letter* $F(2, 32) = 2.95$, $p = 0.117$, $\eta_p^2 = 0.125$, *phase* x *letter* $F(1.47, 23.62) = 0.55$, $p = 0.53$, $\eta_p^2 = 0.033$ and *phase* x *letter* x *group* $F(1.47, 23.62) = 0.027$, $p = 0.941$, $\eta_p^2 = 0.002$.

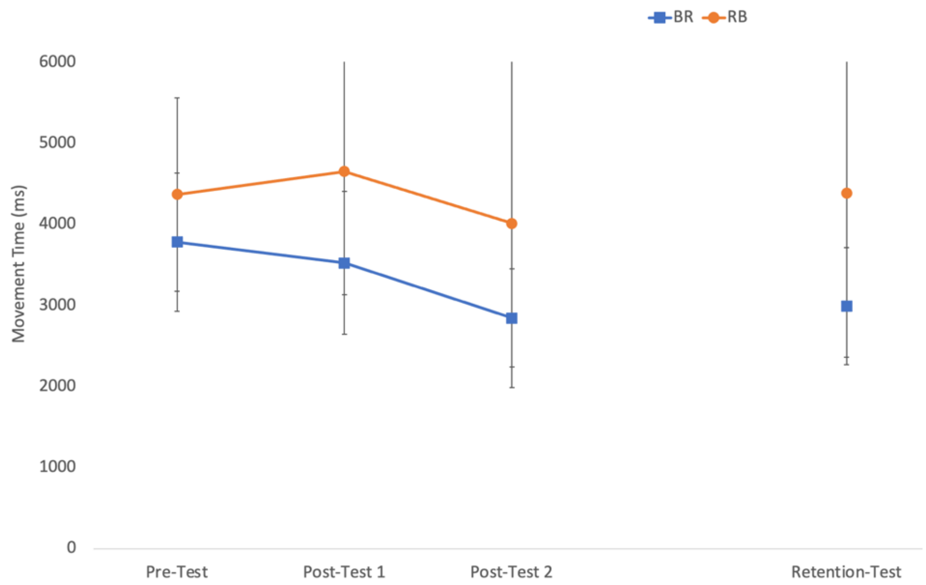


Figure 13: Mean (error bars represent standard deviation) movement time for tracing Gokturk letters presented as a function of group and phase.

Movement Time Variability (MTv)

ANOVA revealed a significant effect for *group* $F(1, 16) = 13.82$, $p = 0.002$, $\eta_p^2 = 0.463$, but not for *phase* $F(1, 16) = 1.00$, $p = 0.332$, $\eta_p^2 = 0.059$ or *letter* $F(2, 32) = 1.26$, $p = 0.295$, $\eta_p^2 = 0.073$. As illustrated in Table 12, MTv for the BR group was significantly lower than the RB group (a difference of 477 ms). There were no significant interactions concerning *group* x *phase* $F(1, 16) = 0.092$, $p = 0.766$, $\eta_p^2 = 0.059$, *group* x *letter* $F(2, 32) = 0.65$, $p = 0.528$, $\eta_p^2 = 0.039$, *phase* x *letter* $F(2, 32) =$

1.02, p = 0.372, η_p^2 = 0.060 and *phase* x *letter* x *group* $F(2, 32)$ = 0.21, p = 0.806, η_p^2 = 0.013.

Letter Production Error (LPE)

ANOVA revealed a significant effect for *letter* $F(2, 32)$ = 7.77, p = 0.002, η_p^2 = 0.327, but not for *phase* $F(1, 16)$ = 0.003, p = 0.954, η_p^2 = 0.0002, and *group* $F(1, 16)$ = 1.19, p = 0.291, η_p^2 = 0.069. The *letter* effect (see Table 12) indicated there were significant differences (ps < 0.05) in LPE between *Ag* (M = 1200 mm) and *Kg* (M = 1706 mm), and between *Kg* and *Vg* (M = 1173 mm), but not between *Ag* and *Vg.* A *group* x *letter* interaction $F(2, 32)$ = 4.09, p = 0.026, η_p^2 = 0.204 indicated that LPE for RB group when tracing *Kg* (M = 1163 mm) was significantly (p < 0.05) greater compared to *Ag* (M = 821 mm) and *Vg* (M = 579 mm), but not significantly (p > 0.05) different between *Ag*, and *Kg.* Whereas there were no significant differences (ps > 0.05) in LPE for the BR group across the three letters. Finally, there were no significant interactions concerning *group* x *phase* $F(1, 16)$ = 1.07, p = 0.315, η_p^2 = 0.063, *phase* x *letter* $F(2, 32)$ = 1.12, p = 0.338, η_p^2 = 0.066, and *phase* x *letter* x *group* $F(2, 32)$ = 2.38, p = 0.118, η_p^2 = 0.130.

Letter Production Error Variability (LPEv)

ANOVA revealed a significant effect for *letter* $F(2, 32)$ = 4.38, p = 0.021, η_p^2 = 0.215, but not *phase* $F(1, 16)$ = 0.026, p = 0.873, η_p^2 = 0.02 or *group* $F(1, 16)$ = 0.014, p = 0.740, η_p^2 = 0.001. The *letter* effect (Table 12) indicated there were significant differences (ps < 0.05) in LPEv between *Kg* (M = 1050 mm) and *Vg* (M = 634 mm), but not between *Ag (M* = 797 mm) and *Vg,* and between *Ag* and *Kg.* A *phase* x *letter* interaction $F(2, 32)$ = 3.59, p = 0.039, η_p^2 = 0.183 indicated there was no significant (*ps* > 0.05) differences in LPEv for letters *Ag* and *Vg* in the post-test 2 and retention test, but LPEv for letter *Kg* was significantly ($p < 0.05$) greater than *Vg* in post-test 2 (the difference was 823 mm). The *group* x *phase* interaction $F(1, 16) = 5.01$, $p < 0.05$ $\eta_p^2 = 0.239$. Finally, there we no significant interactions concerning *group* x *letter* $F(2, 32) = 0.72$, $p = 0.492$, $\eta_p^2 = 0.043$, and *phase* x *letter* x *group* $F(2, 32) = 2.38$, $p = 0.108$, $\eta_p^2 = 0.130$.

Peak Velocity (PV)

ANOVA revealed a significant effect for *group* $F(1, 16) = 12.14$, $p = 0.003$, $\eta_p^2 = 0.432$, but not for *phase* $F(1, 16) = 0.41$, $p = 0.530$, $\eta_p^2 = 0.025$. As illustrated in Table 14, the BR group performed the letter writing tasks with a significantly higher magnitude of peak velocity than the RB group (a difference of 58843 mm/ms). Finally, there was no significant interaction concerning *group* x *phase* $F(1, 16) = 0.72$, $p = 0.409$, $\eta_p^2 = 0.043$.

Peak Velocity Variability (PVv)

ANOVA revealed no significant effects for *group* $F(1, 16) = 2.70$, $p = 0.120$, $\eta_p^2 = 0.144$, *phase* $F(1, 16) = 0.38$, $p = 0.545$, $\eta_p^2 = 0023$ or a *group* x *phase* interaction $F(1, 16) = 1.76$, $p = 0.202$, $\eta_p^2 = 0.099$ (see Table 14).

Percentage Time to Peak Velocity (%TTPV)

ANOVA revealed no significant effects for *group* $F(1, 16) = 2.90$, $p = 0.107$, $\eta_p^2 = 0.154$, *phase* $F(2, 32) = 1.93$, $p = 0.162$, $\eta_p^2 = 0.108$, or a *group* x *phase* interaction $F(2, 32) = 0.95$, $p = 0.395$, $\eta_p^2 = 0.056$ (see Table 14).

Percentage Time to Peak Velocity Variability (%TTPVv)

ANOVA revealed no significant effects for *group* $F(1, 16) = 0.24$, $p = 0.625$, $\eta_p^2 = 0.015$, *phase* $F(2, 32) = 1.001$, $p = 0.379$, $\eta_p^2 = 0.059$, or a *group* x *phase* interaction $F(2, 32) = 0.16$, $p = 0.848$, $\eta_p^2 = 0.010$ (see Table 14).

Table 12: Illustrates handwriting dependent variables (DVs) as a function of Group (BR; RB), Phase, and Letter (Ag, Kg, Vg)

Group	*DVs*	*Pre-Test M (SD)*			*Post-Test 1 M (SD)*			*Post-Test 2 M (SD)*			*Retention-Test M (SD)*		
		Ag	**Kg**	**Vg**	**Ag**	**Kg**	**Vg**	**Ag**	**Kg**	**Vg**	**Ag**	**Kg**	**Vg**
BR	**MT (ms)**	3704(782)	4138(638)	3502(1137)	3048(764)	4075(911)	3448(971)	2661(504)	3178(721)	2700(596)	2662(757)	3571(753)	2737(659)
BR	**MTv (ms)**	860(560)	928(418)	751(879)	281(127)	856(254)	739(446)	422(266)	469(166)	405(117)	382(222)	575(274)	609(616)
BR	**LPE (mm)**	564(905)	1210(566)	622(705)	844(537)	1397(724)	966(692)	1513(1141)	1557(783)	1250(861)	1206(862)	1797(1086)	1908(1453)
BR	**LPEv (mm)**	687(323)	639(355)	433(287)	681(421)	459(351)	610(404)	882(617)	876(705)	300(187)	662(240)	998(481)	1083(1013)
RB	**MT (ms)**	4293(2114)	5116(864)	3700(600)	4627(2237)	5942(1532)	3391(797)	3886(1754)	4810(912)	3343(837)	4220(2138)	5393(2566)	3553(1381)
RB	**MTv (ms)**	859(699)	1087(812)	942(344)	646(390)	1975(944)	631(215)	871(502)	1126(813)	616(293)	901(807)	1148(1054)	1063(757)
RB	**LPE (mm)**	1313(1084)	1582(1155)	952(980)	1367(871)	1755(739)	1147(745)	1004(1027)	2036(1311)	831(435)	1076(765)	1432(906)	703(690)
RB	**LPEv (mm)**	817(705)	967(532)	909(657)	1124(738)	662(368)	1085(1083)	800(557)	1613(1323)	543(290)	842(506)	714(615)	609(375)

Ag: Gokturk Letter A; Kg: Gokturk Letter K; Vg: Gokturk Letter V; RB: Random followed by Blocked; MT: Movement Time; MTv: Movement Time Variability;

LPE: Letter Production Error; LPEv: Letter Production Error Variability; M: Mean; SD: Standard Deviation

Table 13: Illustrates handwriting dependent variables (DVs) as a function of Group (BR; RB), Phase, and Letter (Ae, Ke Ve)

Group	***DVs***	***Pre-Test M (SD)***			***Post-Test 1 M (SD)***			***Post-Test 2 M (SD)***			***Retention-Test M (SD)***		
		Ae	**Ke**	**Ve**	**Ae**	**Ke**	**Ve**	**Ae**	**Ke**	**Ve**	**Ae**	**Ke**	**Ve**
BR	**MT (ms)**	3935(806)	4243(569)	3250(685)	3554(920)	3773(1042)	3188(709)	2702(846)	3301(852)	2762(569)	2808(804)	3383(1020)	2756(705)
BR	**MTv (ms)**	559(261)	772(419)	648(430)	681(446)	712(494)	851(545)	496(403)	572(374)	572(238)	453(418)	446(193)	370(137)
BR	**LPE (mm)**	877(984)	606(510)	1096(1097)	432(456)	433(558)	655(687)	1102(952)	990(797)	1464(783)	681(522)	1005(840)	1131(534)
BR	**LPEv (mm)**	944(1476)	563(403)	1089(1626)	298(197)	602(673)	474(269)	460(283)	732(720)	730(583)	850(559)	727(472)	412(541)
RB	**MT (ms)**	3595(758)	4193(921)	3895(1585)	3334(610)	4206(976)	3481(546)	3554(949)	4391(1228)	3860(786)	3017(1431)	3386(1513)	3263(1409)
RB	**MTv (ms)**	841(418)	1117(388)	1270(1070)	830(355)	1243(700)	546(245)	716(431)	1071(562)	835(660)	650(386)	541(396)	678(491)
RB	**LPE (mm)**	501(689)	805(938)	581(693)	683(1169)	1042(1166)	597(431)	658(984)	852(891)	675(444)	772(1402)	755(1622)	807(696)
RB	**LPEv (mm)**	686(627)	925(746)	1006(653)	622(742)	1196(1627)	636(405)	568(352)	1099(822)	508(577)	413(412)	499(382)	753(771)

Ae: English Letter A; Ke: English Letter K; Ve: English Letter V; BR: Blocked followed by Random; RB: Random followed by Blocked; MT: Movement Time; MTv: Movement Time Variability; LPE: Letter Production Error; LPEv: Letter Production Error Variability; M: Mean; SD: Standard Deviation

Table 14: Illustrates handwriting dependent variables (DVs) as a function of Group (BR; RB), Phase, and Letter (Kg, Ke)

Group	***DVs***	***Pre-Test M (SD)***		***Post-Test 1 M (SD)***		***Post-Test 2 M (SD)***		***Retention-Test M (SD)***	
		Kg	**Ke**	**Kg**	**Ke**	**Kg**	**Ke**	**Kg**	**Ke**
BR	**PV (mm/ms)**	92210(36280)	87770(35580)	107370(54920)	113710(52230)	128470(49270)	115210(27250)	130830(55290)	131880(65060)
BR	**PVv (mm/ms)**	31980(22540)	25060(21280)	25030(18120)	40200(33120)	27190(18520)	24240(15980)	32400(18500)	26210(18660)
BR	**%TTPV**	51.66(17.68)	53.19(17.59)	59.04(67.13)	57.60(11.83)	66.05(10.14)	66.31(9.72)	61.70(10.32)	63.22(8.44)
BR	**%TTPVv**	17.75(8.77)	17.67(9.98)	14.65(8.84)	18.42(7.64)	12.22(10.69)	9.22(4.66)	14.60(8.10)	15.38(7.47)
RB	**PV (mm/ms)**	70220(28150)	89310(33900)	61710(31430)	94680(29290)	79290(22270)	108990(38880)	62320(35190)	87430(46490)
RB	**PVv (mm/ms)**	35840(2740)	30600(13000)	28010(26410)	35770(19620)	27770(15660)	51320(46720)	13520(24930)	20420(20630)
RB	**%TTPV**	67.19(17.45)	60.48(11.24)	67.03(13.42)	61.38(12.68)	69.72(14.71)	69.35(8.27)	53.58(24.48)	61.23(26.54)
RB	**%TTPVv**	17.30(10.36)	24.54(10.93)	16.92(5.83)	17.55(8.60)	14.75(10.65)	17.61(6.56)	20.94(13.29)	11.89(10.17)

Ke: English Letter K; Kg: Gokturk Letter K; BR: Blocked followed by Random; RB: Random followed by Blocked; PV: Peak Velocity; PVv: Peak Velocity Variability; &TTPV: Percentage Time for Peak Velocity; &TTPVv: Percentage Time for Peak Velocity Variability; M: Mean; SD: Standard Deviation; mm: millimetre; ms: millisecond

Transfer: Motor Performance Phase

Movement Time (MT)

ANOVA revealed significant effects for *phase* $F(2, 32) = 4.50$, $p = 0.019$, $\eta_p^2 = 0.22$, *letter* $F(2, 32) = 10.38$, $p < 0.001$, $\eta_p^2 = 0.39$, but not for *group* $F(1, 16) = 2.21$, $p = 0.156$, $\eta_p^2 = 0.122$. As illustrated in Table 13 and Figure 14, there was no significant difference ($p > 0.05$) in MT between pre-test ($M = 3852$ ms) and post-test 1 ($M = 3589$), but MT was significantly ($p < 0.05$) shorter in post-test 2 ($M = 3428$ ms) compared to pre-test (a difference of 423 ms).

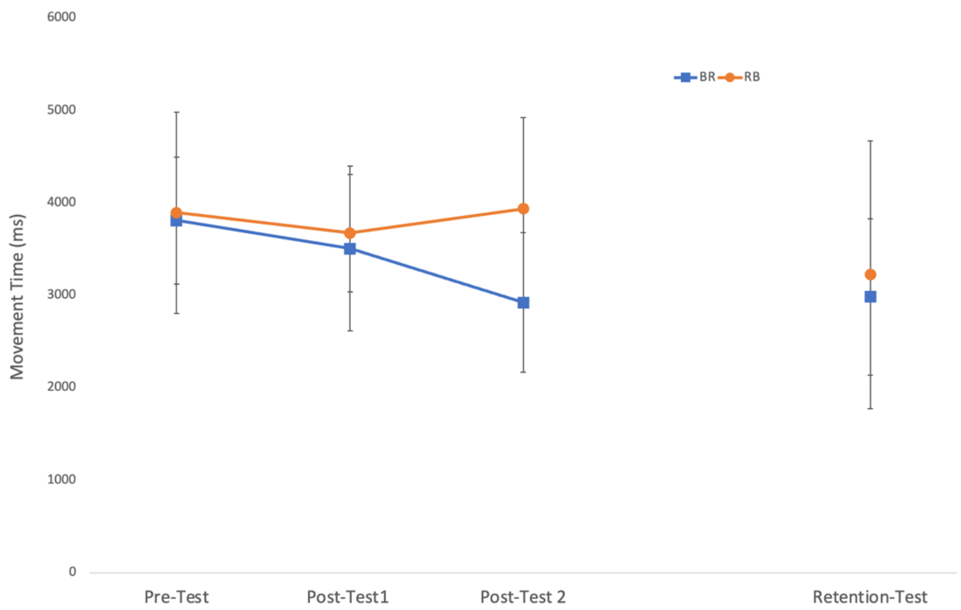


Figure 14: Mean (error bars represent standard deviation) movement time for tracing English letters presented as a function of group and phase.

For the *letter* effect (Table 13), there were significant differences (*ps* < 0.05) in MT between *Ae* (*M* = 3446) and *Ke* (*M* = 4018 ms), and between *Ke* and *Ve* (*M* = 3406), but not between *Ag* and *Vg.* The *group* x *phase* interaction was significant $F(2, 32) = 6.52$, $p = 0.004$, $\eta_p^2 = 0.29$ and indicated (see Figure 14) there was no significant (*ps* > 0.05) difference in MT for the BR group between pre-test and post-test 1, and between post-test 1 and post-test 2, but MT was significantly shorter in post-test 2 compared to pre-test (the difference was 887 ms). For the RB group, there were no significant differences (*ps* > 0.05) across the three phases. Importantly, the BR group had a significantly ($p = 0.047$) shorter movement time (*M* = 2922 ms) compared to the RB group at post-test 2 (*M* = 3935 ms). Finally, there were no significant interactions concerning *group* x *letter* $F(2, 32) = 1.95$, $p = 0.157$, $\eta_p^2 = 0.109$, *phase* x *letter* $F(4, 64) = 0.54$, $p = 0.65$, $\eta_p^2 = 0.033$ and *phase* x *letter* x *group* $F(4, 64) = 0.86$, $p = 0.48$, $\eta_p^2 = 0.051$.

Movement Time Variability (MTv)

ANOVA revealed a significant effect for *group* $F(1, 16) = 15.295$, $p = 0.001$, $\eta_p^2 = 0.489$, but not for *phase* $F(2, 32) = 1.52$, $p = 0.233$, $\eta_p^2 = 0.087$ and *letter* $F(2, 32) = 1.84$, $p = 0.175$, $\eta_p^2 = 0.103$. As illustrated in Table 13, the BR group performed the letter writing tasks with a significantly ($p < 0.05$) lower MTv than the RB group (a difference of 290 ms). Finally, there were no significant interactions concerning *group* x *phase* $F(2, 32) = 1.33$, $p = 0.279$, $\eta_p^2 = 0.077$, *group* x *letter* $F(2, 32) = 0.76$, $p = 0.473$, $\eta_p^2 = 0.046$, *phase* x *letter* $F(4, 64) = 0.63$, $p = 0.627$, $\eta_p^2 = 0.039$, and *phase* x *letter* x *group* $F(4, 64) = 1.71$, $p = 0.157$, $\eta_p^2 = 0.097$.

Letter Production Error (LPE)

ANOVA revealed no significant effect for *group* $F(1, 16) = 0.41$, $p = 0.528$, $\eta_p^2 = 0.025$, *phase* $F(2, 32) = 3.10$, $p = 0.059$, $\eta_p^2 = 0.163$, and *letter* $F(2, 32) = 0.33$, $p = 0.711$, $\eta_p^2 = 0.021$, but the *group* x *phase* interaction was significant $F(2, 32) = 4.08$, $p = 0.026$, $\eta_p^2 = 0.203$. As illustrated in Table 13, there were no significant (*ps* > 0.05) differences in LPE for the BR group between pre-test and post-test 1, but LPE was significantly ($p < 0.05$) lower in post-test 2 compared to post-test 1 (the difference was 678 mm). For the RB group, there were no significant differences (*ps* > 0.05) across the three phases. Finally, there were no significant interactions concerning *group* x *letter* $F(2, 32) = 2.10$, $p = 0.138$, $\eta_p^2 = 0.116$, *phase* x *letter* $F(4, 64) = 0.21$, $p = 0.929$, $\eta_p^2 = 0.013$, and *phase* x *letter* x *group* $F(4, 64) = 0.05$, $p = 0.994$, $\eta_p^2 = 0.003$.

Letter Production Error Variability (LPEv)

ANOVA revealed no significant effect for *group* $F(1, 16) = 0.87$, $p = 0.365$, $\eta_p^2 = 0.052$, *phase* $F(2, 32) = 1.59$, $p = 0.219$, $\eta_p^2 = 0.091$, and *letter* $F(2, 32) = 1.39$, $p = 0.263$, $\eta_p^2 = 0.080$. There were also no significant interactions concerning *group* x *phase* $F(2, 32) = 0.91$, $p = 0.410$, $\eta_p^2 = 0.054$, *group* x *letter* $F(2, 32) = 1.39$, $p = 0.264$, $\eta_p^2 = 0.080$, *letter* x *phase* $F(4, 64) = 0.92$, $p = 0.457$, $\eta_p^2 = 0.055$, and *phase* x *letter* x *group* $F(4, 64) = 0.12$, $p = 0.973$, $\eta_p^2 = 0.008$ (see Table 13).

Peak Velocity (PV)

ANOVA revealed no significant effect for *group* $F(1, 16) = 0.35$, $p = 0.560$, $\eta_p^2 = 0.022$, *phase* $F(2, 32) = 2.95$, $p = 0.06$, $\eta_p^2 = 0.156$ or an interaction concerning *group* x *phase* $F(2, 32) = 0.55$, $p = 0.570$, $\eta_p^2 = 0.034$ (see Table 14).

Peak Velocity Variability (PVv)

ANOVA revealed no significant main effect for *group* $F(1, 16) = 1.12$, $p = 0.304$, $\eta_p^2 = 0.066$, *phase* $F(2, 32) = 0.93$, $p = 0.402$, $\eta_p^2 = 0.055$ or an interaction concerning *group* x *phase* $F(2, 32) = 1.88$, $p = 0.168$, $\eta_p^2 = 0.106$ (see Table 14).

Percentage Time to Peak Velocity (%TTPV)

ANOVA revealed a significant effect for *phase* $F(2, 32) = 5.78$, $p = 0.007$, $\eta_p^2 = 0.136$, but not for *group* $F(1, 16) = 1.21$, $p = 0.286$, $\eta_p^2 = 0.071$. There was no significant difference ($p > 0.05$) in %TTPV between pre-test (M = 57%) and post-test 1 (M = 59%), but %TTPV occurred significantly ($p = 0.008$) later in the movement in post-test 2 (M = 68%) compared to pre-test. Finally, there was no significant interaction concerning *group* x *phase* $F(2, 32) = 0.22$, $p = 0.799$, $\eta_p^2 = 0.014$ (see Table 14).

Percentage Time to Peak Velocity Variability (%TTPVv)

ANOVA revealed a significant effect for *phase* $F(2, 32) = 5.15$, $p = 0.012$, $\eta_p^2 = 0.244$, but not for *group* $F(1, 16) = 2.99$, $p = 0.103$, $\eta_p^2 = 0.158$. There was no significant difference ($p > 0.05$) in %TTPVv between pre-test (M = 21%) and post-test 1 (M = 18%), but %TTPVv was significantly ($p = 0.010$) lower in the post-test 2 (M = 13%) compared to pre-test. Finally, there was no significant interaction concerning *group* x *phase* $F(2, 32) = 2.12$, $p = 0.136$, $\eta_p^2 = 0.117$ (see Table 14).

Transfer: Motor Learning Phase

Movement Time (MT)

ANOVA revealed significant effects for *letter* $F(1.14, 1.17) = 7.05$, $p = 0.013$, $\eta_p^2 = 0.306$, but not for *phase* $F(1, 16) = 1.40$, $p = 0.253$, $\eta_p^2 = 0.081$ and *group* $F(1, 16) = 3.267$, $p = 0.090$, $\eta_p^2 = 0.170$. The *letter* effect (Table 13, and Figure 14) indicated there were significant differences (*ps* < 0.05) in MT between *Ae* (*M* = 3021 ms) and *Ke* (*M* = 3616 ms), and between *Ke* and *Ve* (*M* = 3160 ms), but not between *Ae* and *Ve.* Finally, there were no significant interactions concerning *group* x *phase* $F(1, 16) = 1.40$, $p = 0.253$, $\eta_p^2 = 0.081$, *group* x *letter* $F(1.14, 18.36) = 0.42$, $p = 0.551$, $\eta_p^2 = 0.026$, *phase* x *letter* $F(2, 32) = 0.72$, $p = 0.493$, $\eta_p^2 = 0.043$ and *phase* x *letter* x *group* $F(2, 32) = 0.86$, $p = 0.432$, $\eta_p^2 = 0.051$.

Movement Time Variability (MTv)

ANOVA revealed significant effects for *group* $F(1, 16) = 10.34$, $p = 0.005$, $\eta_p^2 = 0.393$ and *phase* $F(1, 16) = 6.05$, $p = 0.026$, $\eta_p^2 = 0.275$, but not for *letter* $F(2, 32) = 0.30$, $p = 0.743$, $\eta_p^2 = 0.018$. As illustrated in Table 13, the BR group performed the letter writing tasks with a significantly lower MTv than the RB group (a difference of 264 ms). For *phase*, MTv was significantly ($p < 0.05$) lower in the retention-test (*M* = 523) than post-test 2 (*M* = 710) (a difference of 187 ms). Finally, there were no significant interactions concerning *group* x *phase* $F(1, 16) = 1.71$, $p = 0.410$, $\eta_p^2 = 0.0431$, *group* x *letter* $F(2, 32) = 0.10$, $p = 0.899$, $\eta_p^2 = 0.007$, *phase* x *letter* $F(2, 32) = 1.04$, $p = 0.363$, $\eta_p^2 = 0.061$ and *phase* x *letter* x *group* $F(2, 32) = 0.84$, $p = 0.440$, $\eta_p^2 = 0.050$.

Letter Production Error (LPE)

ANOVA revealed no significant effect of LPE for *group* $F(1, 16) = 1.31$, $p = 0.269$, $\eta_p^2 = 0.076$, *phase* $F(1, 16) = 0.22$, $p = 0.642$, $\eta_p^2 = 0.014$, and *letter* $F(2, 32) = 0.78$, $p = 0.465$, $\eta_p^2 = 0.047$. There were also no significant interactions concerning *group* x *phase* $F(1, 16) = 0.50$, $p = 0.486$, $\eta_p^2 = 0.007$, *group* x *letter* $F(2, 32) = 0.77$, $p = 0.470$, $\eta_p^2 = 0.046$, *letter* x *phase* $F(2, 32) = 0.05$, $p = 0.947$, $\eta_p^2 = 0.003$ and *phase* x *letter* x *group* $F(2, 32) = 0.54$, $p = 0.585$, $\eta_p^2 = 0.033$ (see Table 13).

Letter Production Error Variability (LPEv)

ANOVA revealed no significant effects of LPEv for *group* $F(1, 16) = 0.007$, $p = 0.937$, $\eta_p^2 = 0.0004$, *phase* $F(1, 16) = 0.27$, $p = 0.606$, $\eta_p^2 = 0.017$ and *letter* $F(1.43, 22.87) = 1.82$, $p = 0.190$, $\eta_p^2 = 0.102$. The *phase* x *letter* x *group* was significant $F(1.33, 21.33) = 4.92$, $p < 0.05$, $\eta_p^2 = 0.235$. Finally, there were no significant interactions concerning *group* x *phase* $F(1, 16) = 0.46$, $p = 0.504$, $\eta_p^2 = 0.028$, *group* x *letter* $F(1.43, 22.87) = 0.74$, $p = 0.444$, $\eta_p^2 = 0.044$ and *phase* x *letter* $F(1.33, 21.33) = 2.08$, $p = 0.160$, $\eta_p^2 = 0.115$ (see Table 13).

Peak Velocity (PV)

ANOVA revealed no significant effects of PV for *group* $F(1, 16) = 1.82$, $p = 0.196$, $\eta_p^2 = 0.102$, *phase* $F(1, 16) = 0.04$, $p = 0.831$, $\eta_p^2 = 0.003$ or *group* x *phase* interaction $F(1, 16) = 2.86$, $p = 0.110$, $\eta_p^2 = 0.152$ (see Table 14).

Peak Velocity Variability (PVv)

ANOVA revealed no significant effects of PVv for *group* $F(1, 16) = 1.002$, $p = 0.332$, $\eta_p^2 = 0.059$, *phase* $F(1, 16) = 3.20$, $p = 0.092$, $\eta_p^2 = 0.167$ or *group* x *phase* interaction $F(1, 16) = 4.13$, $p = 0.059$, $\eta_p^2 = 0.205$ (see Table 14).

Percentage Time to Peak Velocity (%TTPV)

ANOVA revealed no significant effects of %TTPV for *group* $F(1, 16) = 0.008$, $p = 0.929$, $\eta_p^2 = 0.0005$, *phase* $F(1, 16) = 1.72$, $p = 0.208$, $\eta_p^2 = 097$ or *group* x *phase* interaction $F(1, 16) = 0.34$, $p = 0.564$, $\eta_p^2 = 0.021$ (see Table 14).

Percentage Time to Peak Velocity Variability (%TTPVv)

ANOVA revealed no significant effects of %TTPVv for *group* $F(1, 16) = 0.88$, $p = 0.361$, $\eta_p^2 = 0.052$ and *phase* $F(1, 16) = 0.009$, $p = 0.928$, $\eta_p^2 = 0.0002$. The significant interaction concerning *group* x *phase* was significant $F(1, 16) = 6.25$, $p < 0.05$, $\eta_p^2 = 0.281$ (see Table 14).

Post AiMS Questionnaire

The findings from the questionnaire revealed that all parents ($n = 18$) confirmed the AiMS materials (i.e., workbook, instruction sheets, and training videos) were user-friendly, appropriate, and easy to use for their children. All 18 parents reported that their children enjoyed with doing AiMS activities. Additionally, all parents reported that their children enjoyed engaging in AiMS activities. One parent, the mother of P4 from the BR group, stated, "*My son loved doing activities, after AiMS, still he is asking for doing activities."* Regarding the dosage of activities, 95%

of parents indicated that their children did not encounter difficulties in completing 15 daily tracing activities over 6 weeks. For instance, the mother of P8 from the RB group expressed, *"At the beginning I thought it will be too much for my son, but after starting the programme, I saw that he could do daily activities easily!"* In terms of the effects of AiMS on children's handwriting and related skills, 89% of parents observed improvements in their children's handwriting skills, as well as other skills such as pen holding, drawing, colouring, and number writing. For example, the mother of P3 from the BR group shared, *"In general, my daughter didn't like doing pen and paper activities like handwriting, colouring, or drawing. But in the last week of the programme, she said she wanted to draw. She drew 3 trees, coloured them, and wrote numbers for each. This suddenly happened like magic!"* Furthermore, all parents noted that their children exhibited increased confidence in handwriting following the AiMS programme. The mother of P8 from the RB group mentioned, "*After the programme, I can clearly see my son is more confident when he writes something!".*

Exploratory Analysis

During the AiMS programme, children were required to engage in activities for 5 days a week over a span of 6 weeks. Upon completion of the AiMS programme, it was noted that certain children did not complete full of 15 days' worth of activities. For instance, a participant identified as P3 in the RB group did activities 12 days instead of the expected 15 days. Since these differences in dosage may affect results, to investigate potential discrepancies between groups regarding the number of days of activities completed by children, an exploratory analysis was carried out using an *independent t-test.* The results of an *independent samples t-test* revealed no significant difference [$t(34) = -0.31$, $p > 0.05$] between the BR ($M = 13.17$, $SD = 2.82$) and RB ($M = 13.44$, $SD = 2.55$) groups in the average total number of days carried out by the parents/caregivers and children.

Discussion

A feasibility randomised cross-over design study was conducted in the present chapter to examine the viability of a new parent-led home-based early intervention programme that trained young autistic children to learn to write novel letters during a hand-writing activity – the programme is called AiMS. Running a feasibility study was important because it tested the viability of the key ingredients (i.e., dosage; attrition; training materials; measurements techniques; is performance captured via the selected dependent variables) embedded within the intervention before it can be scaled to a mechanistic study, efficacy study and effectiveness study (Green et al., 2019). The motor skills aspect of AiMS was designed and developed based on the principles of motor learning theory and specificity of practice to facilitate motor control and generality of learning (i.e., retention and transfer) in young autistic children (see Shea & Morgan, 1979; Proteau, et al., 1992; Lee et al., 1994; Brady, 1998; Lai et al., 2000; Wolpert et al., 2011). To maximise motor learning, the six weeks AiMS intervention required children to practice letter writing in a workbook in a *blocked-followed-by-random-practice* (BR) structure compared to a control condition that required children to learn in a *random-followed-by-blocked-practice* order (RB). The specific practice structure of BR was designed to capture the benefits of both blocked practice (Brady, 1998; Lai & Shea, 1998)) and random practice (Shea & Morgan, 1979; Pollock & Lee, 1997; Ste-Marie et al., 2004) to facilitate the generality of motor learning (see Lai et al., 2000; Graser et al., 2019).

In terms of feasibility, the MT results from the motor performance phase indicated that all autistic children were significantly faster (i.e., a shorter movement time) at tracing the novel Gokturk letters after the 6-weeks AiMS programme. The faster movements indicated that children followed the task instructions to trace the letters "fast and accurate" in the pre-test, post-test1, post-test2 and retention phases. From a verbal instruction and developmental perspective, following the task instructions was an important finding given the autistic children were 4-5 years old and the fact that verbal task instructions can negatively influence motor learning outcomes if working memory is modulated (Chiviacowsky et al., 2013; Buszard et al., 2017; Van der Veer et al., 2022). The learning effect also indicated that children improved motor performance after practising the tracing activities in the workbook at home with their parent/caregiver and that the dependent variables (e.g., MT; MTv; LPE) were sensitive to capturing the changes in motor performance (see Green et al., 2019; Tickle-Degnen, 2013). Furthermore, the questionnaire data indicated the AiMS programme was suitable for implementation at home with all 18 parents/caregivers reporting the AiMS workbook was user-friendly, easy to use, their children enjoyed the activities, and 95% of parents/caregivers reported that did not encounter difficulties with the dosage as their children completed the 15 daily tracing activities across the 6 weeks of the programme. These findings are important for this feasibility study because follow-up interventions can be affected if the prescribed activities are too challenging, and too time-consuming, as parents/caregivers can feel inadequate or passive, which leads to a decreased likelihood of sustaining the implementation of an early intervention at home (Gray & Wandersman, 1980; Foster & Mash, 1999). Finally, and although not quantified using motor measurement tools, the parents/caregivers self-reported that they observed improvements in their children's handwriting, pen-holding skills, and increased interest in other pen and paper activities (drawing, colouring) after completing the AiMS programme.

As stated, all children significantly improved motor learning across (from pre-test to post-test2) the six weeks AiMS programme by executing faster (decreasing MT) and more consistent (decreasing variability) tracing movements. The data also indicated that letter Kg was most the challenging given that it was executed with the slowest MT, with more variability, and with greater letter production error. In terms of the learning effect, whilst this indicated that all children improved motor execution via two different practice structures, the group main effects indicated the BR group was significantly faster (by 961 ms), more consistent (by 338 ms), demonstrated greater consistency in letter production error accuracy, and generated a greater magnitude of peak velocity.

These results are the first evidence showing practice-order effects on the specificity of motor learning in young autistic children within a randomised cross-over design. The cross-over design was selected as it allowed the controlled investigation of motor learning within the autistic population, rather than comparing learning to a non-autistic group. The Gokturk learning effects indicated that young autistic children acquired sensorimotor processes that controlled the execution of faster tracing movements in post-test2. When learning to trace at home, children would have moved a pencil/pen along the letter segments, which required them to learn to apply the appropriate forces at the correct time (Culmer et al., 2009) and to integrate these motor signals to the visual input of the spatial properties of the observed letter (Elliott et al., 2010). Even without knowledge of results feedback, which is a key independent variable for motor learning (Salmoni et al., 1984), the children would have learned by engaging feedforward and feedback processes (Davidson &

Wolpert, 2005; Elliott et al., 2010) that generated internal action models that underpin motor control and learning (Gidley Larson et al., 2008; Gidley Larson & Mostofsky, 2008; Izawa et al., 2012; Marko et al., 2015).

In terms of motor control, and compared to the RB group, the greater magnitude of PV demonstrated by the BR group indicated that across trial-to-trial practice (Elliott et al., 2004) the children learned to become more effective at planning and specifying the parameters associated with increasing the magnitude and timing of muscular forces. This PV effect for the BR group was independent of the timing (%TTPV) and variability (%TTPVv) of peak velocity that was not significantly different between groups and occurred on average at 60% (BR) and 64% (RB) of the velocity profile, which is consistent with bell-shaped upper-limb aiming movements (Elliott et al., 2001). This greater magnitude of PV effect is important because although it is known that compared to non-autistic controls, autistic children demonstrate multiple differences in motor planning (DeMyer et al., 1972; Vernazza-Martin et al., 2005; Rinehart et al., 2006; Fabri-Destro et al., 2009; Fournier et al., 2010; Forti et al., 2011; Bäckström et al., 2021; Cavallo et al., 2021), under these specific BR practice conditions the lower-level motor planning processes (see van Swieten et al., 2010) can be modulated to successfully attain the task goals.

Whilst this indicated specificity of learning via *blocked-followed-by-random-practice* structure, the effects were based on post-tests that occurred after each phase. A strength of the current study was the use of a 4-week delayed retention period that was implemented to examine the long-term motor learning effects after the transient performance effects of practice had dissipated over a no-practice period (Magill & Anderson, 2014; Schmidt et al., 2018). Even after 4-weeks of not practising the Gokturk letters (note, parents/caregivers were asked not to practice with their children after post-test2), the MT, MTv and PV findings showed no significant decrements in motor control and learning in the retention test, and importantly the BR group remained significantly faster and more consistent at tracing the letters than the RB group. This effect confirmed the prediction that learning would be facilitated by performing *blocked-followed-by-random-practice* as this structure captures the combined benefits of both practice types. Therefore, completing blocked-practice first likely facilitated the initial development of sensorimotor representations (Foster et al., 2020) that could then be further generalised by engaging in random practice, which created contextual interference in motor and cognitive processes that facilitated retention and generality of learning (Lai et al., 2000).

The contextual interference experienced during random practice was related to the BR children tracing the 3 Gokturk letters for 15 trials per day across the three-week period, which resulted in 225 trials that were practiced in a fully randomised trial order. Therefore, after tracing a letter on trial *n* (e.g., Kg) the follow-up letter on trial *n+1* (Vg) would have been different in terms of the spatial characteristics and thus the children would have been required to generate a different action-plan to control the execution of tracing the next letter. Over practice, the trial-to-trial regulation of different actions plans related to the expected efferent and afferent sensorimotor consequences (Davidson & Wolpert, 2005; Elliott et al., 2010), which control motor execution and support the integration of the perceived motor signals to the visual input of the spatial properties of the observed letter, would have engaged a higher degree of multiple and variable cognitive processes that underpinned learning (Shea & Morgan, 1979; Lee, 1988; Magill & Hall, 1990).

The theoretical accounts that explain the contextual interference effect are the 'elaboration hypothesis' (Shea & Zimny, 1983) and the 'action-plan reconstruction hypothesis' (Lee & Magill, 1983; Lee & Magill, 1985). Whilst there is no definitive account for these effects (see Magill & Hall, 1990; Brady, 1998; Merbah & Meulemans, 2011), and these were not examined in the current chapter, both suggest that random practice engages greater effortful cognitive processing (Li & Wright, 2000; Immink & Wright, 2001. For example, cognitive effort is increased when learners engage in elaborative and distinctive processing to evaluate and compare different action-plans (within-skill and between-skill characteristics and relationships) residing together in working memory during practice. The processing activity results in an action representation for each of the practiced skills that is qualitatively more distinct and quantitatively more elaborate ('elaboration hypothesis'; see Wright et al., 1992). Whereas increased cognitive effort is associated with the requirement to up-regulate (i.e., reconstruct) and down-regulate (i.e., forget) different action-plans across random practice. This processing activity is suggested to support retention and transfer because of the similar processing demands between contexts ('action-plan reconstruction hypothesis'; see Cross, Schmitt, & Grafton, 2007). Of particular importance was the fact that the higher degree of multiple and variable cognitive effortful processes in the BR group not only supported long term motor learning, but also the transfer of the acquired processes to the execution of familiar, but unpractised, English letters in the transfer conditions (Lee, 1988).

Although practice specificity and contextual interference do not always support both retention and transfer (see Magill & Hall, 1990), the effects from tracing the unpractised English letters demonstrated that compared to the RB group, the BR group demonstrated significantly faster, less variable, and more accurate tracing movements from pre-test to post-test2. The important aspect of this finding is that both the BR and RB group had performed the same number of practice trials by the post-test2 period, but they were presented in different practice-orders. Therefore, the significant benefits in motor learning specifically occurred from receiving blocked-followed-by-random practice whereby the children must have benefitted from developing action-representations of the three Gokturk letters during blocked practice, which were then more effectively processed and evaluated during random practice, leading to significant contextual interference effects. This finding is consistent with Lai and colleagues (Lai et al., 2000) who demonstrated similar practice-order effects with adults learning a timing task. An interpretation for the practice order effects is that blocked-practice in the early acquisition trials reduced attentional load allowing children the capacity to acquire the spatial characteristics of the individual letters as they were not required to constantly change the movement parameters to trace different letters. Then, across the later acquisition trials when letter tracing was consistent the introduction of the random-practice structure allowed the children to concentrate on developing elaborative processes related to specifying the correct forces needed for executing the different letter configurations (Lai et al., 2000). Taken together, the combined practice order effects for the BR group are suggested to have underpinned the development of ‘transfer-appropriate processes’ (Lee, 1988; Franks et al., 2000) that the children in the BR group mapped to trace the unpractised English letters in transfer.

Limitations and Future Directions

In terms of limitations, whilst the AiMS workbook had several benefits (i.e., low-cost; easy to use) it did not offer an opportunity to examine changes in motor performance across the trial-to-trial practice days. This movement information would have enabled a more detailed understanding of the learning effects and as such one way to address this issue is to convert the workbooks into a digital format where the kinematics can be recorded via a smart tablet (see Lu et al., 2022; Chua et al., 2022). Second, although sample-size number was quantified using G power, and a crossover designed was used to add within a between group power, the sample per group was relatively small and as such a replication study with a larger sample size would enable the findings an insight into the generalisability liability of the learning effects. Third, a limitation of the current analysis, which was preregistered on OSF, was that the original data analyses plan did not contain apriori analysis to examine whether associations between motor skill learning outcomes and motor competency (i.e., MABC-2) and working memory (BRIEF-P data).

Fourth, parents' educational level was different between groups. While almost all parents in the RB group have a university degree (*n* = 8), only 4 parents in the BR group possess this qualification.). Parents' education level one of the most significant indicators of their socio-economic status (Ingels et al., 2005). Parents with higher education in general have high socio-economic status, and studies results showed that, parents with high socio-economic status this directly impact parents' participation to home-based intervention (Li et al., 2020). Furthermore, variation in educational background influence their ability to understand and implement the intervention strategies effectively, and parents with high educational level show higher performance in educating their children (Li et al., 2020). Furthermore, parents with higher education levels might have better access to resources, more familiarity with educational or therapeutic concepts, and potentially greater confidence in applying the intervention techniques. These parents may feel more confident in their ability to support their child's development, which can positively impact their engagement with the intervention. In the AiMS intervention, despite parents in the RB group having a higher educational level than those in the BR group, after the intervention, the children in the BR group showed better performance. Therefore, it can be suggested that having a higher educational level did not provide an advantage for parents in implementing the AiMS intervention. This also indicates that differences in educational levels did not influence the outcomes of AiMS. This might be attributed to the simplicity of AiMS activities, which did not demand complex skills from the parents. Although differences in educational backgrounds did not seem to affect AiMS results, future studies should be conducted with parents who have the same educational background to eliminate potential effects of these differences. As a final future direction, the findings from this successful feasibility study offer the opportunity to develop a larger efficacy-based study to measure the real-world impact of AiMS.

Conclusion

The effects of practice-specificity on motor control and learning was examined during a feasibility parent-led home-based early intervention program called AiMS. The findings indicated the AiMS training processes (workbook; videos; instructions) used by parents/caregivers were feasible and underpinned the delivery of AiMS. The fact that specificity of practice underpinned significant motor learning benefits in young autistic children provided the first evidence to show that practice-order enhanced cognitive-motor processing that underpinned the motor skill development that facilitated generality of motor learning in young autistic children.

Chapter 7: Discussion

The goal of the PhD programme of work was to develop a novel parent-mediated home-based motor intervention to train handwriting in young autistic children – the intervention was called “Autism Early Intervention for Motor Skills (AiMS)”. To achieve this goal, 3 studies were designed to develop the critical ingredients to examine the feasibility of the AiMS intervention. As illustrated in Table 15, the first study was a systematic review that investigated the critical ingredients of existing early intervention programmes that included motor skill outcomes. In study 2, a survey was designed to understand the beliefs, knowledge, and use of activities regarding motor skills for parents/caregivers of young autistic children in order to understand the implementation of any new intervention. The key findings from the systematic review and survey were appraised and synthesised to form part of the AiMS development – the literature was used to form the mechanics of the feasibility component to AiMS and was the theoretical basis underpinning motor learning in terms of practice specificity and trial order that formed the AB/BA randomised crossover experimental design.

Table 15: Summarises the purpose and key findings of each study in the PhD programme of work.

Study 1: Systematic Review	Study 2: Survey	Study 3: AiMS
Purpose	**Purpose**	**Purpose**
To examine the critical ingredients of existing early interventions that included motor skills outcomes for young autistic children.	To understand the beliefs, knowledge, and use of activities regarding motor skills for parents/caregivers of young autistic children.	To conduct a feasibility study for AiMS that examined the impact of specificity of practice trial order on motor control and learning in young autistic children.
Key Findings	**Key Findings**	**Key Findings**
N=10 EIs focused on motor skills; N=55 non-motor skill EIs focused on improving other skills (e.g., social; communication). Motor skills EIs mostly conducted at school by professionals (*n* = 9). All motor skills EIs used standardised measurement tools to assess motor skills. None examines changes in underlying motor control mechanisms. Small sample sizes, lack of control groups, and insufficient information on methodological ingredients (i.e., dosage; instructions) in motor skill EIs.	Parents believed motor skills are as important as literacy skills. . Parents had a greater knowledge of motor skills than literacy and maths skills. Parents perform fewer motor skills activities at home with their young children compared to literacy and maths activities.	In terms of dosage, materials, instructions, fidelity, and effectiveness AiMS was feasible to conduct at home by parents to support young autistic children's motor skills All children improved motor skill learning after performing the AiMS programme. All children retained motor skill learning after a 4-week long-term retention period. Blocked-practice-followed-by-random-practice underpinned greater motor control, learning & transfer. Practice specificity of trial order underpinned generality of motor learning.
[SR findings informed Survey and AiMS]	**[Survey findings informed AiMS]**	**[AiMS was successful]**

As the first study of this PhD programmes of work, the systematic literature review presented a narrative synthesis, and effect size calculations that quantified the meaningfulness of some early intervention effects, that provided information for understanding the critical ingredients of existing early interventions that supported motor skills outcomes in young autistic children. The systematic review was used to highlight current gaps in the literature (Craig et al., 2008; Denyer & Tranfield, 2009). The outcomes of the systematic review identified critical ingredients related to effective strategies, methodologies, and approaches used in previous interventions. A suggested by Munn et al. (2018), understanding these strengths and weaknesses helped to inform the development of the AiMS programme that was designed specifically for facilitating motor skill acquisition in young autistic children.

One of the main conclusions of the systematic review was that while most of the early interventions primarily focused on supporting language, social skills, or academic skills (i.e., non-motor skill early interventions), a small number (n=10) were designed to support motor skill outcomes. The limited number of motor skill interventions might be related to the fact that motor behaviour is not one of the diagnostic criteria for autism spectrum disorders (Zampella et al., 2021) and thus the majority of the well-known early intervention programmes (e.g., Early Start Denver Model, ESDM; Structured Teaching, TEACCH) specifically target the core dimensions of autism (social-emotional, communication, and adaptive skills). Whilst this outcome makes sense from a historical perspective, up to 87% of the autistic population demonstrate differences with some sensorimotor processing and importantly only a small percentage receive motor-focused support (Zampella et al., 2021). Therefore, and across development, these motor differences are often associated with some autism symptoms (i.e., imitation) and broader functioning, so the targeted development of AiMS is timely and consistent with how the field of autism is developing (Lord et al., 2014; Colombo-Dougovito & Block, 2019; Zampella et al., 2021).

In terms of setting and instructors, and consistent with French and Kennedy (2018) who reported lack of clarity on the active ingredients, the current systematic review data revealed heterogeneity in setting (i.e., schools, community centres, homes, nurseries) and instructors (i.e., teachers, speech and language therapists, researchers, clinicians) across most of the non-motor skill early interventions. Whereas the findings for the sampled motor skill early interventions indicted that 90% were conducted in community settings (e.g., schools) by professionals, most likely because the motor interventions were targeting fundamental motor skills that are part of most physical development curriculums in schools. Therefore, and given that most of the fundamental motor skills interventions require equipment and space, the gap from the systematic review highlighted the opportunity to develop a low resource parent- mediated home-based early intervention that targeted a specific fine motor skills activity, handwriting (see also Colombo-Dougovito & Block, 2019). Moreover, while professional mediated, community-based early interventions have many advantages such as utilising structured environments with accessible materials and requiring less time or trainers, the opportunity to develop the low resource AiMS intervention has been from an inclusion perspective because not all children can access certain community settings or professionals (Leaf et al., 2018). For example, it has been reported (see Lee & Meadan, 2021) that around the globe autistic children from low socioeconomic backgrounds face significant barriers in accessing educational settings and professionals.

Therefore, to fill a notable gap in the literature relating to a lack of parent-mediated, home-based motor skill interventions, AiMS was designed as a parent-mediated, home-based intervention to support motor skills of young autistic children. The parent-mediated, home-based early intervention AiMS programme is also important as it links to the framework outlined in the Ecological Systems Theory (Bioecological Model by Bronfenbrenner, 1979). Here, the AiMS programme, although not measured in the present study, may also support other psychological processes as child development is influenced by their environment and relational systems, which are organised into four levels: microsystem, mesosystem, exosystem, and macrosystem. Specifically, AiMS was delivered by parents/caregivers and therefore aligns with the microsystem that refers to the immediate environment closest to the child and which exerts a significant influence on children development. Therefore, and in addition to training the handwriting skills in the young autistic children, it is possible that the AiMS programme had a double-effect and supported improvements in children and family relationships (Juneja et al., 2012; Rojas-Torres et al., 2020), which is important given that parents/caregivers of autistic children are disproportionally affected by issues relating to mental wellbeing and family cohesiveness (Goldberg et al., 1997).

In AiMS intervention since the parents were main stakeholders, the survey was conducted to understand their beliefs and knowledge about motor skills, and motor skill activities that they facilitate to their children. The survey data was gathered from parents/caregivers of autistic and non-autistic children to get an understanding of the perceptions about motor skills by asking them about their beliefs, knowledge and the activities they did with their young child at home. This data from these categories would then inform the development of tailored teaching methods within the AiMS programme and facilitated the engagement and effective support for parents/caregivers to implement AiMS in their homes.

The data obtained from the believing and knowing section, played a crucial role in shaping the parent/caregiver training aspects of AiMS programme. Since the results revealed parents/caregivers already believed in the importance of motor skills, and they had knowledge of motor skill development, the AiMS programme did not need extensive training on the importance of this developmental area. Instead, the training videos training more focussed specifically on the practical instructional methods. The data obtained from the "knowing" section shaped the materials and activities of AiMS. The results revealed that the frequency of literacy activities was significantly higher compared to motor skills and maths skills activities among parents/caregivers. Given this finding, AiMS was designed to incorporate a motor skill that was related to a literacy-based activity as parents/caregivers are used to engaging with literacy activities at home and there it was seen to be convenient. This decision was important as it most like underpinned the feasibility outcome of AiMS (McConnell et al. (2015).

Using insights from survey results (and observations, and pilot studies see in Chapter 6), AiMS components (e.g., types of motor skill activities, parent training, and training videos) were developed and tailored. Following this, an important methodological aspect of AiMS intervention which is assessment method were selected based on the systematic review and relevant motor learning literature. Notably, consistent with other reviews (Colombo-Dougovito & Block, 2019; Ruggeri et al., 2020), the first study of this PhD (i.e., systematic review) was found that most existing early intervention programs utilize standardized measurement tools (e.g., MABC-2, TGMD, VABS) to assess motor skills development in children before and after an intervention. Whilst these standardised measurement tools are very important because they have been validated, offer normalised data to the population, are easy to implement, and are cost and time efficient (Downs & Strand, 2006), they can lack sensitivity in terms of assessing motor systems level changes that might be underpinning the progress made by children (Bacon et al., 2014). Therefore, other complementary measurement methods (e.g., kinematic analysis) are suggested to be used to provide information on how the underlying motor control and learning processes operate after engaging in a motor skills intervention (Gowen and Hamilton, 2014).

Based on the gap in the literature, kinematic analyses method was used in AiMS intervention. Assessing motor systems by using kinematic analysis method was important for the AiMS program because many autistic children demonstrate differences and/or difficulties in the underlying sensorimotor control and learning processes, with particular differences in motor planning (DeMyer et al., 1972; Vernazza-Martin et al., 2005; Rinehart et al., 2006; Fabri-Destro et al., 2009; Fournier et al., 2010; Forti et al., 2011; Bäckström et al., 2021; Cavallo et al., 2021). Motor planning was an important consideration when developing the AiMS measurement system because the acquisition of a handwriting motor skill involved the requirement of children to engage motor control processes to learn who to manipulate the object (pencil/pen) multiple times whilst tracing multiple letters. Therefore, and in addition to measuring motor performance using movement time variables, evaluating changes in kinematic markers associated with peak velocity and percentage time to peak velocity were added to quantify improvements in motor planning during motor execution (see Elliott et al., 2010).

Based on systematic review, survey, observations, pilot tests, and meetings, AiMS programme was designed to be a home-based, parent-mediated early intervention to support handwriting skills in young autistic children based on practice specificity. Given that AiMS was novel, it was important to establish whether the programme was feasible to implemented at home by parents. Conducting a feasibility study with a novel intervention provided an opportunity to address potential issues and uncertainties before having an opportunity to developing mechanistic, efficacy, and effectiveness studies with larger samples (Tickle-Degnen, 2013; Green et al., 2019; Pfledderer et al., 2023). The AiMS programme was evaluated using criteria outlined in feasibility guidelines (e.g., Bowen et al., 2014; Eldridge et al., 2016). Based on a recent review (Pfledderer et al., 2023) on feasibly indicators for behavioral interventions, feasibility was assessed using both quantitative (e.g., motor learning data from pre-test, post-test 1, post-test 2 and retention-test) and qualitative (e.g., parent questionnaire) data.

In this study, the primary aspects of the AiMS feasibility included assessing the appropriateness of the activities (e.g., tracing), materials (e.g., storybook), and dosage (e.g., 15 daily tracing activities) for young autistic children and their parents. During AiMS, engagement in the activities was recorded each training day by the parent/caregiver returning photos of the completed tracing tasks via WhatsApp. To be in line with GDPR requirements for processing personal data [i.e., Data Protection Act 2018 (DPA) and the General Data Protection Regulation (GDPR)], no photographic data was sent via photo of the child. The descriptive data indicated that most parents/caregivers and children completed the required 15 trials of tracing practice each day. The fact the AiMS engagement data was positive suggested that the practical aspects of completing the tracing tasks in the workbook was feasible.

This indicated that the developed materials were suitable for the age of autistic children and the dosage was set at a level that allowed children and parents/caregivers to integrate the task into their daily routine. This result was confirmed by qualitative data from the AiMS questionnaire, completed by parents after the intervention. All 18 parents/caregivers reported that the workbook was user-friendly and easy to use, their children enjoyed the activities, and 95% of parents/caregivers did not encounter difficulties with the dosage.

These results suggested the collaborative co-production process of designing of AiMS materials and dosages was successful. The co-production process was chosen because it involved collaboration with key stakeholders of the target population of parents/caregivers (Cullingham et al., 2023). Using this approach, the AiMS materials were developed and designed by capturing knowledge, and professional and lived experience from parents/caregivers and teachers (Kensing & Blomberg, 1998). As detailed in Chapter 6, as well as survey, the development of AiMS materials was tailored to 4-5-year autistic children by conducting observations of classroom settings and having consultations with teaching staff and parents/caregivers. Based on multiple sources of feedback, the materials were devised and refined and piloted with young autistic children and parents/caregivers. Further adjustments were made based on additional feedback, which led to the finalisation of the materials. The co-production process was an integral component of the feasibility process as it provided information for follow-up intervention development in this target population.

Another crucial finding of the AiMS feasibility was that the parents/caregivers and children adhered to the recommended programme guidelines and activities as this established a functional relationship between intervention implementation and the changes in motor learning outcomes. (Moncher & Prinz, 1991). During the AiMS, rather than opting for the traditional techniques for explaining activities with early intervention programmes like home visiting (e.g., Ozonoff & Cathcart, 1998) or the distribution of a written manual (e.g., Odom et al., 2010), which are time consuming and costly (Wainer et al., 2015), the AiMS programme and activities was explained by low-cost online training videos (e.g., Lee et al., 2008; Hall & Bierman, 2015). Furthermore, over the six weeks AiMS programme parents/caregivers agreed to be sent prompts to engage in activities. This was important as it provided the opportunity to monitor engagement and to offer an opportunity remind the parents/caregivers of the instructions to deliver AiMS (e.g., "Please do not forget, your child needs to complete 15 tracing activities daily independently"). This process was time effective and low cost, helped to guide the implementation of AiMS the indicating that technology such as video recording, online meetings, and applications is an effective approach for parent/caregiver training and fidelity assessment in early interventions (see Lee et al., 2008; Hall & Bierman, 2015).

After it was established that the AiMS intervention (including dosage, materials, and activities) was feasible for supporting young autistic children's motor skills at home through their parents, another important aspect of the feasibility study was investigated: the effect of the AiMS intervention on the children's motor learning and transfer skills. This aspect of feasibility was assessed using quantitative data (e.g., motor learning data from pre-test, post-test 1, post-test 2 and retention-test).

As showed in Chapter 6, after the AiMS programme, all children demonstrated significant improvements over practice in terms of motor learning with the movement time findings showing decreases in MT and variability MTv. The significant changes in accuracy and consistency, which were retained over a 4-week delayed retention period, were related to the children learning to trace at home by moving a pencil/pen along the letter segments, which required them to learn to apply the appropriate forces at the correct time (Culmer et al., 2009) and to integrate these motor signals to the visual input of the spatial properties of the observed letter (Elliott et al., 2010). These results provided evidence that the children learned to represent (as action models; see Wolpert et al., 2001; Elliott et al., 2010) and integrate sensorimotor associations between efferent (i.e., expected outcomes) and afferent (i.e., actual outcomes) as action-models. The development of action models as a function of practice is consistent with the suggestion (see Gidley Larson et al., 2008) that the underlying sensorimotor mechanisms operate to support the acquisition of new skills in autism. The AiMS learning effects support other motor learning studies that demonstrated improvements in autistic children and adults after practice (Gidley Larson et al., 2008; Gidley & Mostofsky, 2008; Zamani et al., 2014; Hayes et al., 2018; Taheri- Torbati & Sotoodeh, 2019; Foster et al., 2020a; Foster et al., 2020b), but importantly the findings offered an insight into how the sensorimotor mechanisms operate in young autistic children aged between 4-5 years old.

It was important to note that a distinctive aspect of the AiMS programme was that the autistic children did not receive knowledge of results feedback from their parents during each daily practice period. Knowledge of results is regarded as one of the key learning variables underpinning motor learning (see Salmoni et al., 1984) and is typically presented as quantitative information at the end a practice trial and reflects motor performance relative to a task goal (Trowbridge & Cason,1932; Bilodeau, 1966; Adams, 1987; Salmoni et al., 1984; Schmidt & Lee, 1999). In many autism studies, knowledge of results has been shown to be processed when learning timing tasks, force production tasks, and visuo-motor integration tasks (Zamani et al., 2014; Marko et al., 2015; Hayes et al., 2018; Foster et al., 2020a). For example, autistic participants learning to perform a sequence movement were provided with terminal knowledge of results presented on the monitor as "Too Fast" or "Too Slow" by a specific duration (e.g., 350 ms; Foster et al. 2020a). This quantitative information explicitly guides participants how to make a movement correction on the next trial (Trowbridge & Cason,1932) by providing a learner with the informational means to evaluate hypotheses regarding the accuracy of their own response against the task goal (Schmidt, 1975). Whilst this is a powerful augmented informational source that significantly helps to guide motor performance, the presentation on every trial down-regulates intrinsic learning mechanisms within a participant leading to detriments in long-term motor learning (see Wulf & Shea, 2007). The fact that all children that engaged in the AiMS programme made significant improvements in motor control, performance, and consistency without the availability of knowledge of results suggested that motor learning was operationalised via a contribution of self-determined intrinsic processes (Salmoni et al., 1984).

It is noteworthy that knowledge of results feedback was not directly examined in AiMS, but rather was not provided because the AiMS programme was designed to be implemented by parents/caregivers at home and thus needed to be feasible for implementation without additional instrumentation. Whilst it is likely that the motor control and learning effects for the novel tracing task were underpinned by intrinsic motor processes in the autistic children, the AiMS instructions did request that parents/caregivers encouraged their children during practice with positive reinforcement and motivational feedback statements (e.g., "well done" or "amazing job"). Although these are not as powerful and directive as knowledge of results, these rewarding statements have been shown to enhance future performance success can learning (Lewthwaite & Wulf, 2017) based on engaging cognitive, attentional, and neuromodulatory (dopaminergic) processes that underpin changes in performance as well as learning and memory (Wise, 2004; Gruber et al., 2016).

When engaging in motor learning, and as outlined in the introduction/theoretical framework chapter, one important indicator of improvements in motor skills is a change in the underlying motor control mechanisms (Gowen & Hamilton, 2014). As indicated in the systematic review chapter, none of the existing early intervention programmes (e.g., Vivanti et al., 2013; Libertus & Landa, 2014; Whitehouse et al., 2019; Felzer-Kim, 2020; Ketcheson et al., 2021) that supported motor skills in young autistic children examined changes in underlying mechanisms before and after an intervention. To address this gap, the analysis of specific kinematic markers relating to the magnitude and timing of peak velocity PV and PVv showed the BR group demonstrated a greater magnitude of PV across the AiMS programme. Whilst autistic children often demonstrate multiple differences in motor planning (DeMyer et al., 1972; Vernazza-Martin et al., 2005; Rinehart et al., 2006; Fabri-Destro et al., 2009; Fournier et al., 2010; Forti et al., 2011; Bäckström et al., 2021; Cavallo et al., 2021), the present findings indicated that under the specific BR condition the lower-level motor planning processes (see van Swieten et al., 2010) were modulated across trial-to-trial practice (Elliott et al., 2004) and indicated the children learned to become more effective at planning and specifying the parameters associated with increasing the magnitude and timing of muscular forces.

A major strength of the AiMS programme was the use of a 4-week delayed retention period that was implemented to examine the long-term motor learning effects. This addition was important as the findings from a scoping review (Holloway et al., 2023), which investigated the strategies that supported learning of motor tasks in autism, showed that most of the research attention was focused on skill acquisition, with fewer investigations focusing on retention, transfer, and generalisability of motor skills. Most of the retention tests implemented in motor learning studies were conducted immediately after the acquisition phase (e.g., Foster et al., 2020), after a 15-minute delay (e.g., Hayes et al., 2018), a 24-hour delay (e.g., Zamani et al., 2014; Navaee et al., 2018; Andy & Masters, 2019) and after one-week (e.g., Taheri-Torbati & Sotoodeh, 2019). Whilst these are common time delays in the motor learning studies, the 4-week delayed retention period allowed a novel investigation into long-term motor learning effects in young autistic children after the transient performance effects of practice had dissipated over a no-practice period (Magill & Anderson, 2014; Schmidt et al., 2018). The fact that the young children retained motor performance after this extended retention-test period is important because it indicated that even at the ages of 4 to 5 years old the learning mechanisms in autism underpinned significant learning benefits that were harnessed by training under specific practice conditions. The only other study that has examined practice specificity via contextual interference in autism was conducted with 12 autistic males ages 11-15 (Weber & Thorpe, 1992) who learned to perform gross motor movements (i.e., overhand throw, kick, and vertical jump) for 6-weeks and the post-test was conducted immediately after practice. As per the effects for the BR group from AiMS, children who trained the skills in a ‘tasks-interspersed group’ (i.e., contextual interference) showed significantly greater learning effects that children who learned in a ‘constant task’ group. Apart from linking the motor learning benefits to processes associated with ‘reinforcement learning’ via motivation (Dunlap, 1984), there was no suggestion as the motor-cognitive learning mechanisms that underpinned this practice specificity effect.

Although a motivational contribution possibly underpinned some performance effects at home in the AiMS study, the motor learning effects (Gokturk letter effects in post2 and retention) and transfer effects (English letter effects in post-test2) are suggested to be underpinned by the cognitive-motor processes engaged across the 225 trials of practice leading to contextual interference. At the trial level, intra-task processing and interference occurs after tracing a letter on trial n (e.g., Kg) and processing the follow-up letter on trial n+1 (Vg). Processing the different spatial characteristics would have required children to generate different action-plans to control the execution of tracing the next letter. The trial-to-trial regulation of different expected efferent and afferent sensorimotor consequences (Davidson & Wolpert, 2005; Elliott et al., 2010), which control motor execution and support the integration of the perceived motor signals to the visual input of the spatial properties of the observed letter, would have engaged a higher degree of multiple and variable cognitive processes that underpinned learning (Shea & Morgan, 1979; Magill & Hall, 1990).

These multiple and variable cognitive processing activities (elaborative processing; forgetting) that occurred during and between trials are therefore suggested to underpin the long-term retention effects (Young et al., 1993), but also to support the transfer effects. The transfer effects were indicative of the BR group being significantly more effective than the RB group in planning and executing the unpractised English letters across the transfer phases. In terms of processing, it is likely that the children in the BR group developed better ‘transfer-appropriate processing’ (Lee, 1988; Franks et al., 2000) that was developed by assessing the relations between the processing engaged during trial n (e.g., Kg) and trial n+1 (Vg). In the current context, these ‘transfer-appropriate processes’ seem to be domain-general as these processes were mapped to unpractised letters that had different spatial characteristics (transfer effects) and they supported long-term learning (retention phase).

From a theoretical perspective, it is likely that the practice-order effects were underpinned by the ‘elaboration hypothesis’ (Shea & Zimny, 1983) and the ‘action-plan reconstruction hypothesis’ (Lee & Magill, 1983; Lee & Magill, 1985). As stated, there is no definitive account for these effects (see Magill & Hall, 1990; Brady, 1998; Merbah & Meulemans, 2011), but both suggest that random practice engages greater effortful cognitive processing (Li & Wright, 2000; Immink & Wright, 2001). Cognitive effort would have been increased when the children engaged elaborative and distinctive processing to evaluate and compare the different action-plans during practice (‘elaboration hypothesis’; see Wright et al., 1992). Whereas increased cognitive effort would have been associated with the requirement to up-regulate (i.e., reconstruct) and down-regulate (i.e., forget) different action-plans across random practice trials (‘action-plan reconstruction hypothesis’; see Cross, Schmitt, & Grafton, 2007). Taken together, these effortful activities are suggested to have developed ‘transfer-appropriate processing’ leading to a higher degree of multiple and variable processes that supported long-term, and generality of, motor learning in young autistic children.

Impact on Theory and Practice

Young autistic children show motor skill difficulties and/or differences, and their motor skills should be supported in the early years (Lord et al., 2014). In the EYFS, motor skills are regarded as one of the seven primary areas (e.g., literacy, or maths) that need to be developed during the early years (DfE, 2023). Motor skill development is critical in the early years as these skills help young children to actively explore the environment, and with this active exploration, young children develop their knowledge of the world (Piaget & Cook, 1952). In the early years, young children's development is affected by their nearest environment, and this environment consists of their parents (Bronfenbrenner, 1979). One of the main theoretical implications from this PhD programme of the work is that parent-mediated motor skill early interventions are required to support young autistic children's motor skills.

Parents' perceptions including their beliefs and knowledge are important because they can influence the intervention that choose for their autistic children (Mire et al., 2017). The current findings indicated as well as their perceptions, the activities that they used with their children may also be important for their intervention choice. For example, although motor skills might be deemed to be important, if the motor skill activities are time-consuming, unsuitable for the home environment, or difficult for parents to integrate into their daily routines, it can significantly impact their intervention choice. Previous research (Gmmash et al., 2022) conducted with young autistic children's parents showed that these components impacted their choice of interventions for the home environment. The current findings suggested the need for researchers to consider young autistic children’s parents' considerations and needs for motor skill activities within the home environment.

The current findings of this PhD programme of the work increased the theoretical understanding of how the contextual interference effect (Shea & Morgan, 1979), practice variation (e.g., Schema Theory, Schmidt,1975) and practice-order (Lai et al., 2000) influenced young autistic children’s motor learning and transfer. The positive impact that contextual interference has on motor skill learning and transfer has been confirmed with many studies, but it is suggested (see Magill & Hall, 1990) that the effects vary based on the age and special needs of targeted groups, potentially resulting in different retention and transfer effects. The current finding demonstrated for the first time that the contextual interference processes that underpin retention and transfer of motor skills was found to operate in young autistic children aged 4-5 years. Furthermore, the findings increased theoretical understanding of contextual interference as it supported the development of motor planning skills (see Multiple-Process Model of Limb Control, Elliott et al., et al., 2010) of young autistic children who are known to show these types of difficulties and/or differences.

In terms of practical implications from this PhD programme of the work, seeing the importance of young autistic children’s motor skills development in the early years, the results can be used to design early interventions to support young autistic children motor skills in educational and home settings. The AiMS programme can be a time-efficient and motivational way to support motor skills in young autistic children motor skills in the home environment.

Limitations and Future Directions

While the AiMS programme provided valuable insights into the development of a feasibility study that trained young autistic children to acquire new motor skills that promoted long-term, and generality of, motor learning, it is important to recognise some limitations. Although the sample size was small (*n*=18), it is important to note that the purpose of a feasibility study is to test the fidelity of various methods (i.e., dosage; DVs; instructions) and as such a smaller controlled study is advised before conducting larger sample size studies designed for a target population as per a RCT (Green et al., 2019). Whilst the sample size (note: G power analysis demonstrated this number is predicated to return meaningful results) was constrained to a feasibility study, the number of participants (n = 18) was greater than other early motor skill interventions (e.g., Bremer et al., 2015; Bremer & Lloyd, 2016; Felzer-Kim, 2020) that were designed for young autistic children. It is important to acknowledge that to increase the generalisability of the AiMS intervention a follow-up study with a larger sample sizes should be carried out (Kadam & Bhalerao, 2010).

Although AiMS was designed to focus specifically on an autism sample in a cross-over design AB/BA study, a second limitation is the decision to not have a targeted control group. Adding a non-autistic control group would allow for the comparison of motor learning and transfer skills between autistic and non-autistic children, providing valuable insights into potential differences or similarities in these abilities across neurodevelopmental profiles. This type of comparison can contribute to the broader understanding of the unique motor learning characteristics of autistic children and how they may differ from other children with different developmental conditions and trajectories. For example, working with other special needs groups, such as those with Down syndrome or Williams syndrome who also show motor skill difficulties and/or differences (Hocking et al., 2008; Malak et al., 2013) would a better understanding of the AiMS generalisability across various neurodevelopmental conditions and tailor interventions to meet the specific needs of different groups.

Given that the AiMS feasibility study was successful, the next step would be to design and evaluate the AiMS programme in terms of an efficacy, mechanistic, or effectiveness study (Green et al., 2019). This approach could target how and if developing moot skills have cascade effects on associated school attainment factors like spelling and reading comprehension. Additionally, while this study focused on supporting motor learning and transfer skills through handwriting activities, future studies may extend this approach to target other important skills such as maths and spatial reasoning. In the early years, number writing is considered a critical mathematical skill (Byrge et al., 2014), and the AiMS letter writing activities can be adapted into number writing activities to facilitate the development of mathematical skills in autistic children. Moreover, and as demonstrated in the systematic review, future studies could also integrate the AiMS programme into other non-motor early interventions that support varied activities.

Conclusion

The main purpose of this PhD was to examine the effects of practice specificity on motor learning and transfer skills through handwriting activities for young autistic children within the feasibility of a novel parent-led home-based motor intervention called "Autism Early Intervention for Motor Skills (AiMS)". This was the first study in the literature where the effect of practice specificity on motor learning and transfer skills in young autistic children has been demonstrated. Furthermore, due to the pivotal role of the natural environment in the developmental process of young children (Landa, 2018), this study was specifically designed as a parent-mediated and home-based intervention. By emphasising the involvement of parents and integrating intervention activities into the home environment, this approach addressed a significant gap in the field of motor skill interventions by developing a successful feasibility study called AiMS.

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Appendix

Appendix 1: Survey for parental perceptions about motor skills and motor skills activities in the home: autistic and non-autistic young children

Block 1

Welcome to the "Young Children's Developmental Survey" If you have more than 1 child up to, and including the age of 5, please complete 1 survey per child.

Block 2

Participant Information Sheet

Title of Study: Parents' Perceptions About Young Children's Development

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Department: Psychology and Human Development

Name and Contact Details of the Researcher(s):

Spencer Hayes:

Jo Van Herwegen:

Tugce Cetiner:

Name and Contact Details of the Principal Researcher:

Spencer Hayes:

Jo Van Herwegen:

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1. Invitation Paragraph

Hello! You are being invited to take part in a study conducted by Tugce Cetiner, Dr Jo Van Herwegen, and Dr Spencer Hayes who are researchers from the Institute of Education, University College London. We are working on a project looking to support parents/caregivers to help their young children's development in the home environment. This part of the project is a short questionnaire (about 15 mins to complete) looking at your understanding of young children's development. The questionnaire is online and can be completed on your phone, tablet or computer. Before you decide whether to complete the questionnaire, please take some time to read the following information carefully and feel free to discuss it with others if you wish. If you agree to take part in the study, your participation is completely voluntary, and you have the right to withdraw at any time without providing a reason. Thank you.

2. What is the project's purpose?

The current project aim is to explore parents' understanding about young children's development.

3. Why have I been chosen?

We are looking to work with parents/caregivers that are 18 and older and have young children up to, and including the age of 5, that live in the UK.

4. Do I have to take part?

It is up to you to whether you'd like to take part in the short study. If you do agree, your participation is voluntary, and you have the right to withdraw at any time without providing a reason. We will delete your results and personal information immediately.

5. What will happen to me if I take part?

After reading this information you will be asked whether you'd like to complete the questionnaire. To do this, you will be asked to sign a consent form, which records your decision to volunteer. You will then complete an online questionnaire lasting approximately 15 minutes. You can do this on your phone, tablet, or computer. The questionnaire will start by asking for some information about your age range, your educational level and relationship status. We will also ask some information about your child's gender, age, and special educational needs. After this, you will be asked number of questions about young children's development. All of yours answer will be pseudonymised, which means that your personal details (e.g., your name) are not saved in such a way that they can be linked to any of your answers (e.g., child's special educational needs). In addition, the data will be stored in an university facility that is password protected. Only the research team (Tugce Cetiner, Dr Jo Van Herwegen, and Dr Spencer Hayes) will be able to access the raw data. In accordance with Open Science, we would also like the pseudonymised research data and methods to be available to other scientists. This allows other researchers to use and analyse the dataset so that they can also advance our understanding of child development.

6. What are the possible disadvantages and risks of taking part?

We don't think that there are any obvious disadvantages to taking part in the study. The questionnaire is online so there are no obvious physical risks. The questionnaire only focuses on your knowledge about child development, and therefore we are not asking about sensitive topics like religion, nationality, or disease.

7. What are the possible benefits of taking part?

Whilst there are no immediate benefits for you completing the questionnaire. But, we expect that your answers will help us design activities that can be carried out in the home and school to support young children's development in the future.

8. What if something goes wrong?

During the process, if you have questions that you like us to answering please contact Dr Spencer Hayes: spencer.hayes@ucl.ac.uk. If you feel that you'd like more support, then please contact the ethics@ucl.ac.uk.

9. Will my taking part in this project be kept confidential?

Yes, the raw data will be pseudonymised and kept confidential by the research team. You will not be able to be identified in any follow-up reports or publications. Data will be stored for a minimum of 10 years in a deidentified electronic format.

10. Limits to confidentiality

Please note that assurances on confidentiality will be strictly adhered to unless evidence of wrongdoing or potential harm is uncovered. In such cases the University may be obliged to contact relevant statutory bodies/agencies. Please note that confidentiality will be maintained as far as it is possible, unless during our conversation I hear anything which makes me worried that someone might be in danger of harm, I might have to inform relevant agencies of this.

Please note that confidentiality may not be guaranteed, due to the limited size of the participant sample. Confidentiality will be respected subject to legal constraints and professional guidelines. Confidentiality will be respected unless there are compelling and legitimate reasons for this to be breached. If this was the case, we would inform you of any decisions that might limit your confidentiality.

Confidentiality may be limited and conditional and the researcher has a duty of care to report to the relevant authorities' possible harm/danger to the participant or others.

11. What will happen to the results of the research project?

The results will be known to the researchers and used in Tugce Cetiner's PhD research project. The results will also be disseminated via an infographic, newsletters, schools, and scientific publications.

12. Local Data Protection Privacy Notice:

The controller for this project will be University College London (UCL). The UCL Data Protection Officer provides oversight of UCL activities involving the processing of personal data, and can be contacted at data-protection@ucl.ac.uk

This ‘local’ privacy notice sets out the information that applies to this particular study. Further information on how UCL uses participant information can be found in our ‘general’ privacy notice: For participants in research studies, click https://www.ucl.ac.uk/legal-services/privacy/ucl-general-research-participant-privacy-notice

The information that is required to be provided to participants under data protection legislation (GDPR and DPA 2018) is provided across both the ‘local’ and ‘general’ privacy notices.

The categories of personal data used will be as follows:

- Your email address
- Your demographic information (e.g., age, gender, or education level) - Your child profile (e.g., gender, age, or special educational needs)

The lawful basis that would be used to process your personal data will be performance of a task in the public interest.

The lawful basis used to process special category personal data will be for scientific and historical research or statistical purposes.

Your personal data will be processed so long as it is required for the research project (Data will be stored for a minimum of 10 years in a deidentified electronic format). If you are concerned about how your personal data is being processed, or if you would like to contact us about your rights, please contact UCL in the first instance at data-protection@ucl.ac.uk.

13. Who is organising and funding the research?

University College London

14. Contact for further information

Please do not hesitate to contact us should you have any questions.

Spencer Hayes:

Jo Van Herwegen:

Tugce Cetiner:

Enclosed with this information sheet is a consent form should you wish to take part in the study. Before starting to the questionnaire, you need to sign the consent form. This consent form will show that you read the information sheet and agree to the research project procedure as formal. Thank you for reading this information sheet and for considering to take part in this research study.

Block 3

CONSENT FORM FOR PARTICIPANTS

Please complete this form after you have read the Information Sheet and/or listened to an explanation about the research.

Title of Study: Parents' Perceptions About Young Children’s Development

Department: Psychology and Human Development

Name and Contact Details of the Researcher(s):

Spencer Hayes:

Jo Van Herwegen:

Tugce Cetiner:

Name and Contact Details of the Principal Researcher:

Spencer Hayes:

Jo Van Herwegen:

Name and Contact Details of the UCL Data Protection Officer:

Alexandra Potts:

This study has been approved by the UCL Research Ethics Committee.

Thank you for considering taking part in this research. The person organising the research must explain the project to you before you agree to take part. If you have any questions arising from the Information Sheet or explanation already given to you, please ask the researcher before you decide whether to join in. You will be given a copy of this Consent Form to keep and refer to at any time.

Please read following items, and if you are agree to consent, please click the tick box for each item.

- I confirm that I have read and understood the Information Sheet for the above study. I have had an opportunity to consider the information and what will be expected of me. I have also had the opportunity to ask questions that have been answered to my satisfaction and would like to take part in the online survey.

- I understand that my participation is voluntary and I am free to withdraw without giving a reason. If I decide to withdraw, all my data will be deleted.
- I consent to the processing of my personal information (related to the 11 questions that will be asked in the Questionnaire) for the research purposes explained to me. I understand that such information will be handled in accordance with all applicable data protection legislation.
- I understand that all personal information will remain confidential, stored pseudonymously and securely and that all efforts will be made to ensure I cannot be identified. Further, I understand that it will not be possible to identify me in any publications.
- I understand the potential risks of participating and the support that will be available to me should I become distressed during the course of the research.
- I understand the direct/indirect benefits of participating.

- I understand that the data will not be made available to any commercial organisation.
- I agree that my pseudonymised research data may be used by others for future research (no one will be able to identify you when this data is shared).
- I would be happy for the data I provide to be archived at deidentified electronic format.
- I understand that the information I have submitted will be published as a report and I wish to receive a copy of it.

- I am aware of who I should contact if I wish to lodge a complaint. I voluntarily agree to take part in this study.
- I voluntarily agree to take part in this study.

Block 4

In the following section, we are going to ask 11 questions dealing with your general characteristics (e.g., age, relationship status, or education level). Please answer the following questions by clicking the option that best describes you. Your answers will be treated in the strictest confidence and will be used only for this research project.

1) What is your relationship to the child?

    - Father
    - Mother
    - Other (please specify)

2) What is your current gender identity?

    - Male
    - Female
    - Non-binary / third gender
    - Prefer not to say
    - Other (please specify)

3) Which of the following best describes your current relationship status?

    - Married
    - Widowed

- Divorced
- Separated
- Single
- In a domestic partnership or civil union
- Other (please specify)

4) Which age group are you in?

- 18 - 29
- 30 - 39
- 40 - 49
- 50 - 59
- >60

5) What is the highest degree or level of education you have completed? *If currently enrolled, highest degree received. *If your qualifications were gained outside the UK, select the closest UK equivalent (if known).

- Higher Education & professional/vocational equivalents (Bachelor or Master or post-graduate),level 6 or above
- Foundation degrees and higher education diplomas level 5
- Higher national certificates level 4
- A leves, vocational level 3 and equivalents
- GCSE/O Level grade A*-C, vocational level 2 and equivalents
- Qualifications at level 1 and below

- Other qualifications: level unknown (including foreign qualifications)
- No qualifications

6) How would you best describe your ethnicity?

- White (English, Welsh, Scottish, Northern Irish or British)
- Irish
- Gypsy or Irish Traveller
- Asian or Asian British (Indian, Pakistani, Bangladeshi, Chinese)
- Black, African, Caribbean, or Black British (African, Caribbean)
- Mixed or Multiple ethnic groups (White and Black Caribbean, White and Black African White and Asian)
- Other Mixed (please specify) Other (please specify)

7) How would you describe your current employment status?

- Employed full-time Employed part-time Freelance-Contractor Self-employed Unemployed
- Student Retired
- Other (please specify)

8) Which country do you live in currently?

- England
- Wales
- Scotland Northern Ireland
- Other (please specify)

9) Which of this best describes the general area where you live?

- Urban
- Suburban
- Rural

10) Do you have access to green space in your area (e.g., garden, park, or playground)?

- Yes (please specify)
- No

11) How many children do you have?

- 1
- 2
- 3
- 4
- >4

Block 5

In the following section, we are going to ask 3 general questions about your young child. Please answer the following 3 questions based on your young child's current situation. Your answers will be treated in the strictest confidence and will be used only for this research project.

1) What is your young child's age (please express in years and months, e.g., 3 years, 5 months)?

Year(s)

Month(s)

2) What is your young child's gender?

- Male
- Female
- Non-binary / third gender
- Prefer not to say
- Other (please specify)

3) Does your young child have any formal diagnosis of a developmental condition (e.g., ADHD, autism, autism spectrum, Down syndrome)?

    - Yes (please specify)
    - No

Block 6

Developmental skills such as reading, walking, and counting help young children in the home and school. Based on this, we would like to know your opinions on developmental skills in young children generally. In the following section, we are going to ask you number of questions. Your answers will be treated in confidence and will be used only for this research project.

* In this section, please answer the questions according to “young children in general", not "your own young child".

Below are some statements about young children's developmental skills. Please read the statements carefully and indicate the level to which you agree with each statement by clicking one option. Please do not skip any statements.

	Strongly disagree(1)	Disagree (2)	Undecided (3)	Agree (4)	Strongly Agree (5)
Motor skills in general are important for young children to be able to carry out their daily life routines independently (e.g., eating foods, wearing clothes, or using toilet).					
Improvements in literacy skill (e.g., reading, or writing) during the early years (birth to 5 years old) can contribute to young children's success in reading in primary school.					
Watching educational TV shows (e.g., CBeebies) in the early years (birth to 5 years old) supports young children's language development.					
Improvements in motor skills leads to improvements in other skills (e.g., communication and language).					
Literacy skills (e.g., reading, or writing) development is important for maintaining					

young children's health and wellness.					
Literacy skills (e.g., reading, or writing) are important for young children to be able to carry out their daily routines independently (e.g., eating foods, wearing clothes, or using toilet).					
In the early years (birth to 5 years old), "play" is very important for the healthy development of young children.					
Maths is a very important skill to develop in the early years (birth to 5 years old).					
Motor skill development is important for maintaining young children's health and wellness.					
Improvements in motor skills contribute to developing better friendships in young children's daily life.					
Improvements in literacy skills (e.g., reading, or writing) during the early years (birth to 5 years old) can contribute to young children's success in maths in primary school.					
Improvement in literacy skills (e.g., reading, or writing) development leads to improvement in other skills					

development (e.g., language, or social).					
In the early years (birth to 5 years old), a positive relationship between parents and children has as an important impact on young children's development					
Improvements in literacy skills (e.g., reading, or writing) contributes to developing better friendships in young children's daily life.					
Improvements in motor skills during the early years (birth to 5 years old) can contribute to young children's success in maths in primary school.					
Healthy diet can improve educational outcomes in young children.					
Improvements in motor skills during the early years (birth to 5 years old) can contribute to young children's success in writing in primary school.					
Playing non-educational (e.g., Minecraft) tablet games can improve educational outcomes.					

Block 7

Developmental skills such as reading, walking, and counting help young children in the home and school. Based on this, we would like to know your opinions on skill development in young children. In the following section, we are going to ask a number of questions. Your answers will be treated in confidence and will be used only for this research project.

* In this section, please answer the questions according to “young children in general", not "your own young child".

When do you think motor skill development starts in young children?

- Starts before birth
- Starts at birth
- Starts at 6 months
- Starts at 8 months
- Starts at 1 year
- Starts over 1 year
- I don’t know

Please state the motor skills you think are important for young children to have before going to primary school. To do this, click the appropriate option, and then type in the list of motor skills.

- List
- I don’t know

Below are some actions based on young children’s skills. What age do you think young children in general can typically perform these actions? Please carefully read the actions and click one age option that best represents your answer. Please do not skip any actions.

	Under 1 year	Under 2 years	Under 3 years	Under 4 years	Older than 4 years	I don't know
Children can sit without support						
Children can combine and use two words (e.g., more biscuits)						
Children can focus on large and bright pictures in books.						
Children can show 'finger numbers' up to 5.						
Children can use scissors.						
Children can match basic shapes (e.g., triangle to triangle, circle to circle).						
Children can write some or all of their name.						
Children can do up buttons.						
Children can hear the initial sound of words that have the same initial sound, (e.g., dog and doll).						
Children can name some number words of interest to them with no sequence.						
Children can walk without help.						
Children can say their first words with meaning (e.g., when the child says "Da - da", the child is calling for his/her dad)						
Children can understand when small collections are made up of the "same number" (e.g., 2 balloons and 2 dolls).						
Children can jump up and down on the floor.						

Children can point to and name familiar objects and characters in books.						
Children can correctly use number words in sequence (e.g., they can say “one, two, three’’ while pointing to objects).						
Children can put on their own shoes.						
Children can understand the ‘one more than/one less than’ relationship between consecutive numbers.						

Block 8

Activities (e.g., playing with Lego, watching CBBC, or playing in a park) support young children’s skill development. Based on this, we would like to know the activities you and your young child engage in together. In the following section, we are going to ask you a number of questions.

*In this section, please answer the questions according to “your own young child”, not “young children in general".

Below are some activities that young children and parents often do together. How often do you and your young child engage in these activities? Please read the activities carefully and click one option that best represents your answer. Please do not skip any activities.

	Once a day (1)	Several times a day (2)	Once a week (3)	Several times a week (4)	Monthly or rarely (5)	Not at all (6)	Not age appropriate (7)
Playing in a park (e.g., walking over wobbly bridge, climbing a frame, or sliding down slides)							
Counting during daily activities (e.g., counting the number of apples when cooking)							
Activities that name the alphabet letters with singing songs or rhymes (e.g., singing A, B, C, D alphabet song)							
Looking at or reading a picture book							
Baking, chopping vegetables, and cooking							
Using Duplo or Lego							
Activities that encourage counting with singing songs or rhymes (e.g., singing 5 little monkeys' song)							
Doing exercise inside (e.g., Joe Wickes/ Wii)							
Referring to letters or written words in the environment (e.g., identify letters on signs)							
Writing/typing exercise							
Playing with a ball outside							
Playing with number flashcards							
Playing games involving letters (e.g., lotto, boggle, scrabble)							
Table-top activities (e.g., fingerprints, cutting paper and using glue, beading, writing, or painting)							

Playing memory games Practising reading words Swimming Dancing to music							
Playing educational games that involve counting, adding, or subtracting (e.g., on the computer, iPad or on paper)							
Playing memory games Practising reading words Swimming Dancing to music							
Playing educational games that involve counting, adding, or subtracting (e.g., on the computer, iPad or on paper)							
Playing memory games Practising reading words Swimming Dancing to music							
Using educational software or apps, focused on letters and sounds							
Flying a kite Using number activity books							
Play literacy games that involve reading or recognising letters and sounds (e.g., on the computer, iPad, or on paper)							
Playing board games involving numbers (e.g. snakes and ladders)							
Using educational software or apps, focused on letters and sounds							

Motor skill activities like cutting paper shapes (like a square) and copying words (like a child's own name) can also help children perform other skills such as eating food and doing maths. From the below options which set of skills do you think is most important for helping your child move into primary school (year 1)?

- Daily life skills (e.g., dressing, eating, or using the toilet)
- School related skills (e.g., maths, reading, or writing)

Block 9

We thank you for your time spent taking this survey! If you would like your contact details to be kept on file so that you can be contacted by us in the future to invite you to participate in follow up studies to this project, or in future studies of a similar nature, please tick yes below and add your email address. Thanks.

- Yes
- No

If you want to receive a summary report about the study you have completed, please click the yes box below add your email address.

- Yes
- No

Appendix 2: Observation hours in autism pre-school classrooms

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Phoenix Primary & Secondary School & Outreach Service

"Making A Difference Where It Really Matters"

www.phoenix.towerhamlets.sch.uk

Executive Headteacher Veronica Armson

Our School Values

Community | Respect | Engagement | Aspiration | Trust | Equality

Phoenix School
49 Bow Road, Bow, London, E3 2AD
Telephone: 020 8980 4740 Fax: 020 8980 6342

Phoenix Upper School
Paton Close, Bow, London E3 2QD
Telephone: 020 8629 8700 Fax: 020 8980 0107

7th July 2022

Dear Sir or Madam,

My name is Catherine McNerney, and I am Deputy Head at Phoenix School. This letter is written to confirm that Tugce Cetiner did 150 hours observation in our pre-school classes between January 2022 and July 2022.

Yours faithfully,

[redacted]

Catherine McNerney
Deputy Headteacher

Head@phoenix.towerhamlets.sch.uk | Admin@phoenix.towerhamlets.sch.uk | Finance@phoenix.towerhamlets.sch.uk

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