Analysis of the sentiments of the participants in a clinical study to evaluate a balance rehabilitation intervention delivered by a Virtual Coach

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***Abstract*—Multiple studies for balance rehabilitation interventions have been accomplished aiming to demonstrate that sensory interventions and cognitive functionality are crucial for postural control and improvement of the quality of patient's daily life. However, none of the existing studies is filling the lack of expert physiotherapists availability. A pilot randomized study was conducted to assess the acceptability of the HOLOBalance telerehabilitation system. HOLOBalance is an interactive AR rehabilitation system which encompasses multi-sensory training program to enhance balance and cognitive coaching, for older adults at falls risk. In this work, we present a sentiment analysis of the patients participating in this study using the VADER methodology to evaluate and quantify their attitude towards the HOLOBalance system. Our results highlight the importance of findings positive polarity towards the AR interaction, which is based on the use of a holographic virtual physiotherapist. The compound score of 0.185 indicates the valuable positive feedback gained from the user experience.**

Keywords—telerehabilitation, balance training, cognitive training, sentiment analysis, hologram, augmented reality.

I. Introduction

Over 30% of older adults fall in an annual basis [1] due to multiple factors [2] which are associated with balance dysfunction and consequently with falls [3]. Balance maintenance relies on sensory interventions that use inputs from vestibular systems to deliver feedback about position and movement of the body, while the control of musculoskeletal and neural interactions can adjust posture to environmental and balance changes [4]. Recently, multiple studies have demonstrated that vestibular frailty appears frequently in elderly who fall, [5-8] whereas 80% of them are suffering from vestibular dysfunction. Multi-sensory inputs are very important for postural control, but also cognitive function is considered very crucial for a safe promenade in the community. Executive function deficit is a common medical condition in older people which is related to balance ability demands (especially for tasks happening simultaneously), postural dysfunction, decreased gait speed and increased risk for falls [9, 10]. Cognitive impairment can play a significant role as predictor of falls in the older people community with great impact in their quality of life [11]. As a consequence, due to their multifactorial nature, falls should be addressed with interventions that target the improvement of daily living and well-being.

The physical, psychological, psychosocial and health-related consequences of falls [12, 13] is a major concern for many public health bodies to deal with [14, 15], despite the lack of compliance and implementation that many healthcare systems are shown for balance rehabilitation [16]. Balance rehabilitation involves individualized sets of exercises,

This work has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No [769574].

determined by a healthcare expert, aiming to treat patients of all ages [17]. Despite the fact that exercises are easy to be performed, up to 50% of older adults lose their adherence in these programs due to non-supervision. In addition, even in many established prevention programs that provide exercises to elderly, the fall rates are decreased by 30%–40%, but they are restricted because they do not provide training to identify vestibular balance function [18]. Vestibular function-based rehabilitation programmes that have been evolved for older adults have exhibited additional decrease of falls risk comparing to established programmes. These programmes need interventions guided by healthcare professional for optimized treatment, however, there is a low expert availability to provide these personalized interventions.

The HOLOBalance telehealth system has been deployed to provide solutions to the above-mentioned issues. HOLOBalance is a balance rehabilitation system, which is relied on augmented reality (AR) and multisensory rehabilitation (MSR) protocols [19]. For MSR the older patients should perform exercises in a regular basis by triggering the balance system and optimize the vestibular function.

Currently, several studies have been published for Virtual Reality (VR), Augmented Reality (AR), gamification, and telerehabilitation in various medical fields. Caetano et. al. (2014) [20] demonstrated some preliminary investigation of some computational techniques suggesting that Augmented Reality techniques on telerehabilitation are promising in the field of human rehabilitation. Another study [21] describes a pilot study using a prototype telerehabilitation system (Ghostman), as a visual augmentation system designed to allow a therapist and patient to inhabit each other's viewpoint in an augmented real-world environment. In this pilot study, the efficacy of Ghostman was explored by using it to teach participants to use chopsticks. There were some initial promising results but only in healthy population, including only participants who were right-handed and excluding individuals with neurological disorders. Berton A. et al. (2018) [22] performed 24 studies including 2472 patients. Studies mainly concern telerehabilitation (56%), and to a smaller extent VR (28%), AR (28%), and gamification (16%). Remote virtual technologies were used following knee and hip arthroplasty. The results of the study demonstrated that the heterogeneity of included studies prevented a meta-analysis of their results. Age and social context influence adaptability to technology, and this can modify compliance to treatment and outcomes. A good relationship between patient and physiotherapist is essential for treatment compliance and new technologies are useful to maintain clinical interactions remotely, concluding that remote virtual technologies allow the delivery of high-quality care at reduced costs. Finally, Borresen et al (2019) [23] studied the usability of a novel Augmented Reality based Telerehabilitation System with Haptics (ARTESH), to physically examine patients with upper extremity complaints remotely. This was a qualitative study with only a small sample of participants and with exclusion criteria for adults with inability to participate in a physical examination of the upper limb, due to severe weakness or pain.

The aim of HOLOBalance is to provide home-based prescribed exercises and exergames for balance improvement by displaying head mounted augmented reality and record the interactions of individuals. HOLOBalance introduces a balance physiotherapist hologram to provide guidelines and present the set of exercises to the patients. Additionally, participants in the framework of a pilot randomized study, are able to follow supplementary cognitive and auditory exercises included in their personalized training sessions. The inclusion criteria are to be: 1) Over 65 years old, 2) able to walk 500 meters independently or with a stick and 3) without cognitive impairment.

This paper focuses on the sentiment analysis of the feedback received from the study participants to quantify their opinions and attitudes towards the AR interaction and the other system components.

II. MATERIALS AND METHODS

A. *Study protocol*

The study protocol that was followed includes a pilot randomized study targeting to identify the acceptability of a balance telerehabilitation system (HOLOBalance) for elderly at falls risk in their home environment. In the framework of the study, the acceptability of the HOLOBalance programme was compared to an existing home exercise programme (HEP) that is commonly used in rehabilitation community (OTAGO HEP23). The goal of the study was also to investigate the effectiveness of this system through validated outcomes derived from the two different balance rehabilitation programmes. All the participants received an exercise program that was prescribed from a physiotherapist and it was based on their feedback and exercises performance. The data of the study was collected at week 0 and at the end of week 9. [24].

In this paper we present the overall experience of participants with the HOLOBalance system, analyzing their feelings and gain feedback on the system components (games, hardware etc.). The two versions of the system that were used from the participants were Holobox and the Head Mounted Display (HMD) versions [25].

Participants

For the Holobox version of the HOLOBalance system that has been developed in different medical sites, 29 older adults participated in total. Specifically, 9 participants from Freiburg (Germany), 16 from Athens (Greece) and 4 participants from London (United Kingdom).

The HMD of the HOLOBalance system has been deployed to home environment of 38 participants, including 14 from Freiburg (Germany), 20 from Athens (Greece) and 4 from London (United Kingdom).

B. *HOLOBalance system*

HOLOBalance can be used as an interoperable platform [25], in which the older adults with balance disorders can remotely connect and implement cognitive and balance training exercises, instructed by a balance physiotherapist hologram. The system also, utilizes motion/activity capture sensors to monitor the implementation of the coaching sessions and provide evaluation to the users in actual time.

1) Virtual Physiotherapist

The Virtual Physiotherapist is a home-based hologram that utilizes the functionality of augmented reality. Its main functionality is to provide specific guidelines to the patients for executing the personalized training program, demonstrates the set of exercises and provokes the patient to execute the training program with high accuracy providing real-time feedback about their performance. There are two solutions of the virtual physiotherapist: The first utilizes a mobile phone which is placed on an HMD and the second comprises of a Holobox, a holographic projector which generates virtual images of man-sized objects (Fig. 1). The Holobox is another option for the patients who have difficulties to perform their exercise using the first solution. The exercises performed by the hologram were recorded using a commercial motion capture system[1].

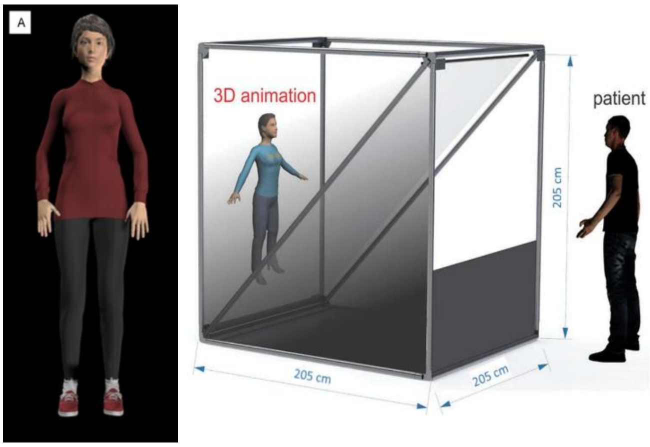

Figure 1. A schematic representation of a physiotherapist avatar (left side) and the Holobox that can project real human-sized 3D animations (right side) [24, 25].

2) Motion/Activity capture sensors

The Motion/Activity capture sensors solution (Fig. 2) is used to capture and assess the performance of training exercises of the Vestibular Rehabilitation therapy (VRT) plan. The Motion Capture and Wearable Sensors (MCWS) unit includes motion tracking of the patient and evaluation whether the prescribed exercises are performed as planned. For the patient movement capture a pair of pressure-based insoles, Inertial Measurement Units (IMUs) and a sensor camera are used. Also, a heart rate system utilizing the Polar H10 sensor is employed to monitor and quantify the stress levels before and throughout the rehabilitation exercises. The measurements from all sensors, except for the depth camera, are collected wirelessly to be used for real-time feedback.

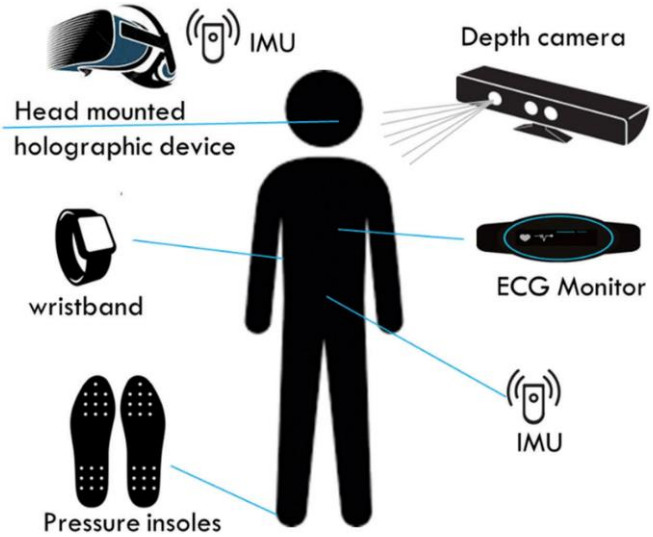

Figure 2. Set of sensors and devices used to monitor patients in HOLOBALANCE [25].

The HOLOBALANCE Dashboard provides and controls the two main graphical interfaces for the primary users of the system (patients and physiotherapists), using functionality that is provided by the user interface module from the cloud services. The two interfaces are presented in Fig. 3. The user interface for the patients is developed as a native mobile application, which allows them to monitor their activity and have an overview of their progress while using the HOLOBALANCE system.

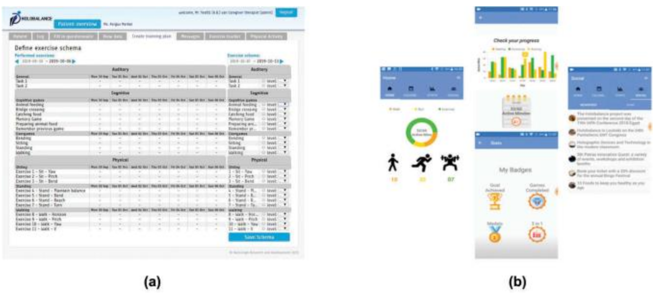

Figure 3. The main user interface of HOLOBALANCE for (a) physiotherapists and (b) patients.

C. Methodology

For the sentiment analysis, the VADER (Valence Aware Dictionary and sEntiment Reasoner) library was utilized. VADER is a rule-based lexicon tool for sentiment analysis, which is sensitive to polarity (positive/negative) and strength of sentiment [26]. VADER methodology is presented in the Fig.4.

[1] www.mocap.me

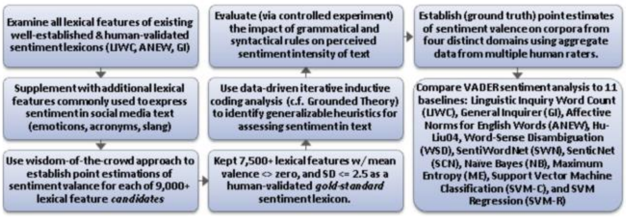

Fig. 4. *VADER analysis overview [27].*

For the scoring of the VADER method four scores are used as end points:

1. The estimation of the compound score is performed by adding the valence scores of each word and is normalized between -1 and +1 values. This metric is used for acquiring a single calculation of a sentence.

   Typical threshold values are:

TABLE 1. THRESHOLD VALUES FOR COMPOUND SCORE.

Sentiments	**Compound score**
Positive	≥ 0.05
Neutral	between -0.05 and 0.05
Negative	$\leq$ -0.05

2. The positive score is the ratio for portions of text which are included in the positive sentiment group.
3. The neutral score is the ratio for portions of text which are included in the neutral sentiment group.
4. The negative score is the ratio for portions of text which are included in the negative sentiment group.

III. RESULTS

The overall results from the study participants sentiments are summarized in Fig. 5 and 6, in which the compound scores for all the questions to the participants and the comparison of the compound scores for Holobox and the Head Mounted (indicated as Home-based) groups are illustrated, accordingly. In Fig.7, it is presented indicatively the analysis of the sentiments of the participants answering on a specific question. The questions target to analyze their spontaneous feedback for some aspects of the system, in addition to their overall experience with the system. Starting from the first question (Q1) that refers to the reasons why a patient enrolled to the program resulted to positive sentiment polarity. The second question (Q2) is directly connected to the user experience with the system (Fig.7). The compound score of about 0.185 shows the positive feedback from the users regarding the usability of the system, both for patients used the Holobox system and for those used the Home-based system. The subjective impression of improvement is expressed by Q3, where the positive compound score reveals that the users consider that the HOLOBalance system improves their condition. Q4, Q5 and Q6 express the opinions of users about the games and gamified exercises of the developed system while the answers of the study participants show that they haven't accepted them that well. Regarding the system from the hardware perspective (Q7) the sentiment feedback was positive while the answers from Q8 (about the least favorite parts of the system) and Q9 (about the frustrations or problems with the exercises or games) were negatively reported. Q10 and Q11 are referring to additions and possible modifications of the system respectively, where the positive compound score expresses the willingness of the users to participate in further improvements of the system. The positive polarity of about 0.4 of Q12 reveals that the end users would recommend the system to the other users. The possibility of considering HOLOBalance as a medical device for which the participants would pay for it, as it is stated in Q13, received positive polarity from the end users. It is important to mention that no significant differences have been documented between the participants in the Holobox system and the participants in the Home-based system (Fig. 6).

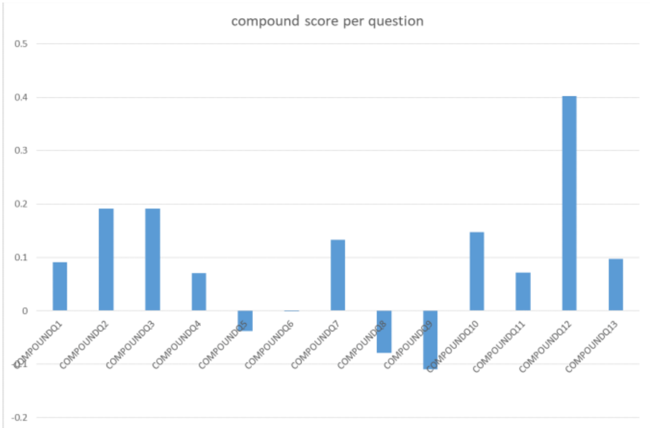

Fig. 5. *Compound score per question.*

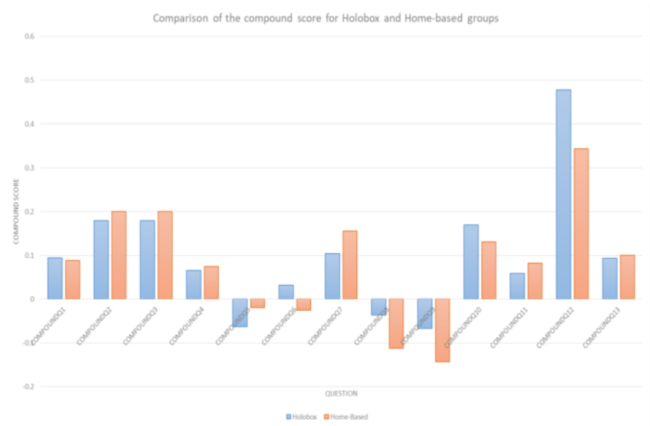

Fig. 6. *Comparison of the compound scores for HOLOBOX and the Home-based groups.*

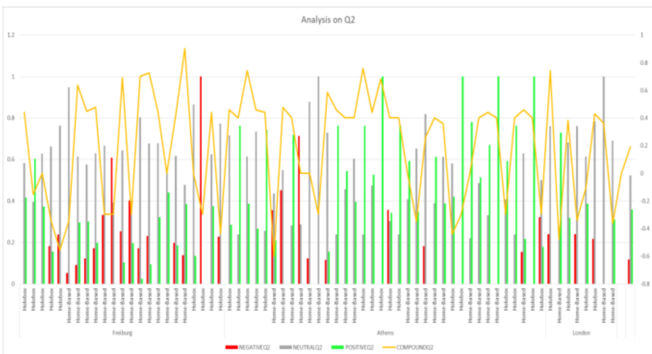

Fig. 7. *Participants' sentiments in the question "Can you describe your experience of using the Holobalance system?".*

IV. DISCUSSION AND CONCLUSION

The analysis of the participants emotions using the VADER methodology reveals the polarity (positive/negative) and the strength of the sentiments for the HOLOBalance system. In general, the received feedback from the users on their experience with the system was positive, pointing out the good usability of the system for both Holobox and Home-based versions and also the participants consideration about improvement of their condition. The results of the sentiment analysis about the least favorite parts of the system (Q8) and the frustrations or problems with the exercises/games (Q9) are in line with the wording of the questions and are not very useful for any conclusion about users' sentiments. Finally, the participants would strongly suggest the system to other end users, as well. Comparing to relevant studies from the literature, HOLOBalance is a completed telerehabilitation system based on augmented reality (AR), multisensory rehabilitation (MSR) protocols and gamification, with the two versions of the system (Holobox and Home-based) to be strongly accepted by the participants, showing their positive experience and feelings as an important indicator for the potential future exploitation of both versions depending on the clinical sites needs that will decide to adopt HOLOBalance.

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