Does the use of active videogame and computer-based technologies influence physiotherapy practice in mobility rehabilitation?

By

Heather Weber
BAppSc (Physio) Hons I

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ABBREVIATIONS

10mWT	Ten metre walk test
2MWT	Two minute walk test
6MWT	Six minute walk test
ACL	Anterior cruciate ligament
ADL	Activities of daily living
AOI	Area of interest
AVC	Active videogame and computer
BBS	Berg Balance Scale
BMI	Body mass index
CAVE	Computer assisted virtual environment
CB&M	Community Balance and Mobility Scale
COP	Centre of pressure
DGI	Dynamic Gait Index
DS	Down Syndrome
FRT	Functional Reach Test
GEM	Geriatric evaluation and management
HMD	Head mounted display
HR	Heart rate
IQR	Interquartile range
IRS	Intelligent Rehabilitation Solutions
KP	Knowledge of performance

KR	Knowledge of results
LOS	Length of stay
med	Median
MMAS	Modified Motor Assessment Scale
ms	Milliseconds
MS	Multiple sclerosis
PASS	Postural Assessment Scale for Stroke patients
PD	Parkinson’s Disease
RCT	Randomised controlled trial
SD	Standard deviation
SPSS	Statistical Package for the Social Sciences
TBI	Traumatic brain injury
TKR	Total knee replacement
TUG	Timed Up and Go
UBS	Unified Balance Scale
VOR	Vestibular-ocular reflex
VR	Virtual reality
WHODAS	World Health Organisation Disability Assessment Schedule

SUMMARY

Physiotherapy rehabilitation for mobility limitations has shown to be effective, particularly intensive programs based on motor learning principles. Virtual reality technologies, especially non-immersive active videogame and computer technologies are increasingly being studied and employed in mobility rehabilitation. The overall aim of this thesis was to explore if and how the use of active videogame and computer-based technologies influence the practice of physiotherapy in rehabilitation for mobility limitations.

Chapter 1 provided an introduction to the thesis and summarised the rationale that has led to the research objectives.

Chapter 2 reviewed key concepts in the existing literature pertaining to mobility limitations and physiotherapy rehabilitation, and provided context on the use of virtual reality for the rehabilitation of people with mobility limitations.

A systematic review presented in Chapter 3 investigated how virtual reality (VR) interventions are delivered in studies for mobility limitation rehabilitation, and specifically considered the described role of the therapist. This study identified that reporting of VR interventions in existing research studies generally lacks detail, and that the therapist role is poorly defined.

In Chapter 4, the validity of the Notch commercial sensor 3D motion capture system was studied by simultaneously recording gait with the Notch sensor and Vicon optical motion capture systems. This study demonstrated that the accuracy of the Notch sensor system is not sufficiently accurate to capture kinematic data for clinical or research use.

Chapter 5 provides the detailed protocol for the major study of this thesis, a large observational study in which patient and physiotherapist dyads undertook matched mobility rehabilitation exercises without and with active videogame and computer-based (AVC) technology. During these sessions physiotherapist focus of visual attention and provision of instruction and feedback were recorded and later analysed. This chapter included a detailed description of the different AVC technologies and the games used in this study.

Chapter 6 describes the examination and comparison of physiotherapists' focus of visual attention in mobility rehabilitation without and with AVC technologies. This study found that physiotherapists' primary focus of attention in rehabilitation without AVC technologies was the patient body, but that this shifted to the technology screen during rehabilitation with AVC technologies. While the reasons for this visual attention shift cannot be determined from this study, it is suggested that this may be unintentional, or therapists may be using the screen display to inform clinical practice.

In Chapter 7 the similarities and differences in physiotherapist instruction and feedback, in the same rehabilitation sessions without and with AVC technologies from Chapter 6, were investigated. The results of this study indicated that although AVC technologies provided continuous feedback and frequent instruction, overall amount of physiotherapist instruction and feedback during AVC rehabilitation with AVC technologies remained largely unchanged when compared to rehabilitation without AVC technologies. However, significant differences were observed in instruction and feedback types, with less frequent provision of performance instruction, knowledge of results (task or game) and internally focused statements within an AVC-based rehabilitation session.

Chapter 8 presents an overall discussion of the thesis, including the strengths and limitations of the thesis, and highlights future research plans in this field.

DECLARATION

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university; and that to the best of my knowledge and belief it does not contain any material previously published or written by another person except where due reference is made in the text.

Signed: Heather Weber

Date: 10/5/2021

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LIST OF PUBLICATIONS AND CONFERENCE ABSTRACTS ARISING DURING THIS RESEARCH

First author publications

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Publications

Gough, C., **Weber, H**., George, S., Maeder, A., & Lewis, L. (2021). Location monitoring of physical activity and participation in community dwelling older people: a scoping review. *Disability and Rehabilitation, 43*(2), 270-283. https://doi.org/10.1080/09638288.2019.1618928

Hassett, L., van den Berg, M., Lindley, R. I., Crotty, M., McCluskey, A., van der Ploeg, H. P., Smith, S. T., Schurr, K., Howard, K., Hackett, M. L., Killington, M., Bongers, B., Togher, L., Treacy, D., Dorsch, S., Wong, S., Scrivener, K., Chagpar, S., **Weber, H**., Pinheiro, M., Heritier, S., & Sherrington, C. (2020). Digitally enabled aged care and neurological rehabilitation to enhance outcomes with Activity and MObility UsiNg Technology (AMOUNT) in Australia: A randomised controlled trial. *PLoS Med, 17*(2), e1003029. https://doi.org/10.1371/journal.pmed.1003029

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Weber, H., Barr, C., & van den berg, M. (2021, October) *Physiotherapist-provided instruction and feedback during mobility rehabilitation with and without active videogame and computer-based (AVC) technologies.* Australian Physiotherapy Association Conference Thrive 2021, Brisbane Australia.

CHAPTER 1: INTRODUCTION

1.1 Introduction

1.1.1 Rehabilitation for mobility limitation

Mobility limitation, a restriction in an individual's capacity to independently move around their environment, can be caused by many different conditions such as stroke, brain injury, hip fracture and arthritis (AIHW, 2012), and is associated with loss of functional independence, poor quality of life, social isolation and increased mortality (Brown & Flood, 2013; Fried et al., 2000; James et al., 2011; Jorgensen et al., 2020). Physical rehabilitation programs are an effective intervention for mobility limitations, particularly programs that provide intensive task-specific exercises with appropriate feedback (Kwakkel et al., 2004; Sigrist et al., 2013; Veerbeek et al., 2014). Increased dose of such rehabilitation is associated with improved mobility outcomes in a wide range of diagnoses such as stroke (Pollock et al., 2014), brain injury (Cuthbert et al., 2014), hip fracture (Binder et al., 2004) and arthritis (Abbott et al., 2019). However, observational studies in inpatient rehabilitation wards have found patients can be inactive for much of the day, with little time spent in functional rehabilitation activities (West & Bernhardt, 2012). Opportunities to increase rehabilitation dose combined with the rise in demand on the services due to an ageing population (Webster & Celik, 2014) are driving the demand for innovative delivery models to meet this need.

1.1.2 Virtual reality and technology

Virtual reality (VR) based rehabilitation is reported as an affordable way to effectively increase activity and therapeutic dose and is being increasingly utilised for people in rehabilitation (Bonnechere et al., 2016; Hassett et al., 2019; Lange et al., 2009).

In rehabilitation, VR can be defined as "any computer hardware and software system that generates simulations of real or imagined environments with which participants interact using their own movements" (Levac, 2016) and can be used for physical, psychological and cognitive rehabilitation (Rizzo & Kim, 2005). Various VR systems have been used in mobility rehabilitation, from recreational 2D videogame technologies such as Nintendo Wii (Nintendo, Kyoto, USA) and Microsoft Xbox Kinect (Microsoft, Redmond, Washington, USA) to through to fully immersive, rehabilitation-specific, custom built programs such as computer assisted virtual environments (CAVE) or via a head mounted display (HMD) (Rose et al., 2018).

It has been advocated that VR technologies have the potential to provide many of the key principles of motor learning within rehabilitation. Firstly, VR-based rehabilitation may provide additional extrinsic visual, auditory, and haptic feedback to the patient (Baranowski et al., 2013; Darekar et al., 2015; Holden, 2005; Tieri et al., 2018). Secondly, VR systems may increase patient engagement and enjoyment of rehabilitation, also optimising learning and potentially increasing patient adherence and dose (Howard, 2017; Rose et al., 2018). Thirdly, VR technologies have the capacity to provide task-specific practice readily tailored to each individual (Brunner et al., 2016; Karamians et al., 2020).

Several efficacy studies have found VR-based rehabilitation to be safe and no less effective than usual care (Laver et al., 2017; Skjæret et al., 2016; Taut et al., 2017; van den Berg et al., 2016), but studies have varied considerably in intervention methodology, indicating optimal parameters for VR interventions are unknown (de Rooij et al., 2016; Zeng et al., 2017).

It has been suggested that the feedback, instruction and motivation provided by VR technology may reduce the need for therapist involvement in VR rehabilitation (Doyle et al., 2011). However other research has indicated that the therapist may remain an "active ingredient" in VR-based therapy (Brutsch et al., 2010; Levac, Rivard, et al., 2012; Levac & Galvin, 2013) and also therapists themselves report a need to be involved (Hamilton, Lovarini, et al., 2018). Levac and Galvin (2013) discuss VR as a 'tool' for use by therapists and not a therapy in itself, as it has not been proven that it can assume all the responsibilities of a therapist. The literature on the therapist role in the delivery of VR rehabilitation is sparse. Some VR software elicit increased feedback from therapists, to offset criticism given by certain programs (Levac & Miller, 2013) or to interpret technology feedback (Hamilton, McCluskey, et al., 2018). Some authors have advised therapists are needed to ensure maladaptive movement patterns are avoided (Lange et al., 2012), or to provide manual assistance (Bartscherer et al., 2005), while others have suggested therapists are needed for exercise prescription and progression (Laver et al., 2012; Levac et al., 2016a). Concerns have been raised that VR technologies may distract the therapist from the quality of the movement being performed (Tatla et al., 2015), or alienate the therapist from the therapy (Kramer et al., 2010). Resources for clinicians have focused on aspects such game selection (Levac et al., 2015) with little consideration of how the technology influences physiotherapy practice during therapy.

In usual rehabilitation without technologies attention and feedback may occur between the patient and therapist in a reciprocal manner. For example, physiotherapists may visually attend to the patient to assess movement and inform tailored feedback provided to the patient to promote motor learning. However, the introduction of VR technology in rehabilitation provides a third consideration. It is unknown how the addition of these engaging, feedback-based technologies affects the feedback and attention of the patient and therapist and in turn how this may affect the patient's movement performance. The complexity of this relationship is illustrated in Figure 1-1.

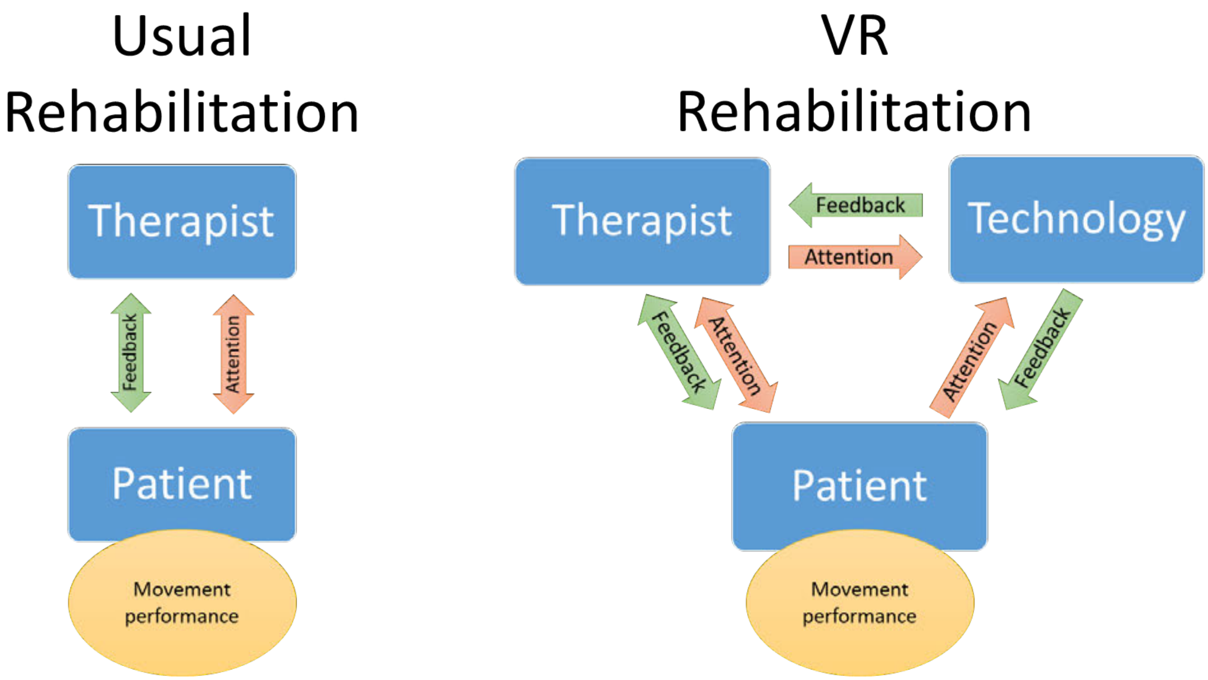

Figure 1-1 Relationship between patient, therapist and technology in usual and VR rehabilitation

Despite this rapidly expanding area of physical rehabilitation, little is known about the influence of VR technology on the practice of physiotherapy, including role of the therapist and the quality of patient movement.

1.2 Research aim and objectives

The aim of this research was to examine the influence of VR technologies on the practice of physiotherapy in mobility rehabilitation. Subsequently, a series of specific research objectives were developed and identified:

- To characterise the delivery of VR-based mobility rehabilitation in published literature, including the reported role of the therapist in this delivery
- To investigate the validity of a wearable sensor-based motion capture system to identify movement patterns in therapeutic rehabilitation settings
- To examine physiotherapists' focus of visual attention during usual mobility rehabilitation without AVC technologies and VR-based mobility rehabilitation, and identify similarities and differences in physiotherapist focus of visual attention between rehabilitation without and with VR technologies
- To analyse the provision of physiotherapist instruction and feedback during usual mobility rehabilitation without AVC technologies and VR-based mobility rehabilitation, and identify

similarities and differences in physiotherapist instruction and feedback between rehabilitation without and with VR technologies

The combined outcomes of these studies aimed to contribute to the knowledge base on the application of VR technologies in rehabilitation, and in particular provide insights into the influence of VR technologies on physiotherapist practice.

CHAPTER 2: LITERATURE REVIEW

2.1 Mobility Limitation

2.1.1 Mobility and mobility limitation

Physical mobility can be defined as the ability of humans to move independently within their environment (Bussmann & Stam, 1998). This includes being able to change and maintain body position, carrying, moving and handling objects, standing, walking and moving (World Health Organization, 2001). based on these definitions, in this thesis mobility limitation is defined as diminished capacity for independent mobility, regardless of its cause.

The incidence of mobility limitations begins to rise from about the age of 40 and increases through the lifespan (Ahacic et al., 2000). Several different health conditions can give rise to the bodily impairments that are linked to mobility limitations. Mobility limitations can be caused by health conditions such as stroke, brain injury, hip fracture and arthritis (AIHW, 2012), or result from age-related decline in the central nervous system (Sorond et al., 2015).

Mobility limitations are a primary cause of diminished ability to live independently (Fried et al., 2000) and are associated with functional disability in activities of daily living (ADLs), poor quality of life and depression (Brown & Flood, 2013; Brown et al., 2019; Heiland et al., 2016; Studenski et al., 2011; Weinberger et al., 2009). Restrictions in mobility are linked to diminished social activity and loneliness (Faria-Fortini et al., 2018; James et al., 2011), and increased health care costs (Hardy et al., 2011; Jørgensen et al., 2019). Several large longitudinal studies have also shown that higher levels of mobility limitations are associated with higher levels of mortality (e.g., (Hardy et al., 2011; Jorgensen et al., 2020)).

Limitations in mobility can range from very mild or preclinical, where limitation only exists in situations that are overtly difficult, through to severe limitation in people who are confined to bed (Brown & Flood, 2013). Preclinical mobility limitation can be the earliest evident sign of functional decline (Brown & Flood, 2013; Fried et al., 2000) and early intervention at this stage may be effective at delaying or preventing further downturns in capacity (Heiland et al., 2016).

The burden of mobility limitations on western health care systems is significant. European statistics reveal large variations between individual countries in the mobility of people over 65 years old, with on average 20% females and 16% males experiencing severe limitations in 2017 (Scherbov & Weber, 2017). Similar proportions of people with severe mobility limitations have also been reported in the United States (Musich et al., 2018; Vasquez et al., 2020), England (Gardener et al., 2006) and Australia (Bannerman et al., 2002). Whilst these proportions are not expected to increase, it is predicted that absolute number of people with mobility limitations will increase in proportion with the rising age of the population (Scherbov & Weber, 2017), causing concern for policymakers due to the potential escalations in health care costs.

Assessment of mobility

A range of clinical markers for mobility limitations have been identified in the literature, indicating the complexity of this impairment. Gait speed over a 4-metre distance is one commonly used assessment, with gait speed below 0.8m/s often used as a cut point for identifying mobility limitation in general population studies (Cawthon et al., 2020; Studenski et al., 2011). However, other cut points have been proposed from 0.3m/s-1.0m/s depending on the pre-existing health of the population (Miller et al., 2018) and dual task gait speed has also been suggested to assess mobility limitations (Rosso et al., 2019). Gait can be combined with other assessments of mobility, such as the Timed Up and Go test (Podsiadlo & Richardson, 1991). Other assessment methods include those focusing on balance (e.g. Berg Balance Test (Steffen et al., 2002)), or capacity to engage in community participation (e.g. Community Integration Questionnaire (Willer et al., 1994)). Assessment of mobility limitation can also be self-reported, such as within the World Health Organisation Disability Assessment Schedule 2.0 (WHODAS) (Üstün et al., 2010), the Lower Extremity Functional Scale (Binkley et al., 1999), or the Rivermead Mobility Index (Collen et al., 1991). These varied clinical markers are the key targets for improvement in mobility rehabilitation.

2.1.2 Movement quality

Movement quality, the specific characteristics of how a movement is performed in time and space, is a complex concept but integral to the practice of physiotherapy (Skjaerven et al., 2008) and improved movement quality has been linked to improved gait speed and reduced falls risk in conditions such as Parkinson's disease (Brodie et al., 2014) and stroke (Punt et al., 2017). Assessment and analysis of the kinematics of patient movement is inherent to understanding existing movement patterns and in turn, planning and evaluating interventions. Objective movement analysis can influence clinical decision making, such as objective gait analysis in people post-stroke, which has been found to significantly change treatment plans for surgery and botulinum toxin therapy (Ferrarin et al., 2015). Objective movement analysis can also assist in ascertaining if a patient uses compensatory movement strategies (Kwakkel et al., 2008).

Various methods to assess patient movement can be used, depending on the setting and accuracy required. This section considers different approaches to the measurement of human movement kinematics, ranging from simple visual observation through to 3D optical motion capture.

Visual observation

Physiotherapists commonly use visual observation to assess movements, such as gait, in clinical practice (Hayashi et al., 2020; Toro et al., 2003; Wilson et al., 2019). This requires no preparation and is relatively quick and inexpensive, requiring no additional equipment. Although visual observation may be used to guide rehabilitation practice, accuracy in determining joint kinematics is low and there remains considerable variations between clinicians (Williams et al., 2009). In addition, therapists may only view one body part, from one angle, at any given time, and therefore are likely to miss other movements of importance.

2D video analysis

Video analysis uses 2D video camera images to record movement for later observation and analysis. This analysis can range from clinician viewing and note taking through to the use of specialised software to measure on screen angles, such as Silicon Coach (www.siliconcoach.com). Video capture in 2D can be performed in situ and is inexpensive, portable, and requires minimal additional participant time prior to motion capture. However accurate data capture is limited to the video field of view and the movement plane perpendicular to the camera, and can be affected by parallax errors (Paul et al., 2016; Reinking et al., 2018; Schurr et al., 2017). In addition, manual data processing and analysis post-capture can be time and labour intensive.

Markerless 3D video systems

Markerless 3D video systems, such as the Microsoft Kinect camera, are another relatively low cost motion capture option, using an optical camera combined with infrared depth sensing technology, but when used for kinematic data capture with a single camera as designed they currently lack accuracy for assessment of research and clinical outcomes (Muller et al., 2017; Pfister et al., 2014). As with all camera systems, data capture is also limited to the field of view of the camera.

3D sensors

Recent advances in technology have seen the rise of inertial sensors. These are units containing accelerometer, magnetometer and gyroscope components to measure movement through space. The information is relayed via Bluetooth or USB connection to a computer, where the software reconstructs the information to generate kinematic data. Advantages of these sensors include portability and the potential for motion capture in a range of different contextual environments (O'Reilly et al., 2018), however, validity testing of several of these systems use custom processing scripts specifically written for research purposes, rather than commercial software provided with the sensors (Petraglia et al., 2019). Furthermore, validity of these systems has been shown to vary depending on the complexity and speed of the movement and plane in which studied (Poitras et al., 2019).

3D optical motion capture

The current “gold standard” of movement assessment is 3D optical motion analysis with a motion capture system in a laboratory setting. These systems, such as the Vicon Motion Capture System, employ multiple infrared cameras to track retroreflective markers worn on the body in a predetermined arrangement and are highly accurate (Dorociak & Cuddeford, 1995; Windolf et al., 2008). However such systems are predominately limited to a laboratory setting, which may influence the movement performance (Foucher et al., 2010), and the extended calibration and marker placement time makes this system less suitable for a patient population.

In current clinical practice visual observation is frequently used, with 2D video also used in some settings, however both methods lack accuracy. Optical motion capture systems are accurate, but only available in laboratory settings. In order to be a useful tool for the clinician, a system to assess movement needs to be straightforward to use, provide quick and reliable data that is easily interpreted, be affordable, and be able to be used in patient settings. New tools such as sensor systems are needed, however before use they must be validated for suitability to be used in a clinical setting.

2.2 Rehabilitation for mobility limitations

Physical rehabilitation has been established as an effective intervention for mobility limitations (Binder et al., 2004; Pollock et al., 2014; Whitlock Jr & Hamilton, 1995). Rehabilitation commonly involves different types of exercise to improve mobility, and task-specific exercises involving functional strength, balance and a variety of mobility tasks are most effective, particularly when prescribed with effective feedback to promote motor learning (Eng & Tang, 2007; Kwakkel et al., 2004; Sigrist et al., 2013; Veerbeek et al., 2014).

2.2.1 Motor learning

Movements involved in mobility such as gait are highly skilled and complex, and require sophisticated motor control (VanSwearingen & Studenski, 2014). The process of acquiring, reacquiring or enhancing such motor skills is specifically known as motor learning (Magill, 2017). Motor learning is distinct from motor skill performance; motor learning is a relatively permanent change in capacity to execute movement due to practice, whereas motor skill performance is a specific observed movement, and can be influenced by performance variables (Magill, 2017). The sequential stages involved in motor learning, as progress is made from initially learning a skill to refinement and mastery, were first described by Fitts and Posner (1967) as three stages, named the cognitive, associative and autonomous stages. The first cognitive stage involves the learner consciously thinking of how, when and what movements are required to result in the desired action (Schmidt, 2019). In the second associative stage, some parts of the movement may become automatic and the learner can focus on specific details within the action, while the third autonomous phase involves practice to refine and optimise the largely automatic action (Fitts & Posner, 1967).

Physiotherapists frequently apply a motor learning approach to rehabilitation, using active, repetitive, task-specific practice with appropriate feedback to promote attainment of motor skills (Carr & Shepherd, 1989; Kwakkel et al., 2004; Veerbeek et al., 2014). Rehabilitation programs based on motor learning principles promote cortical neuroplastic changes in people with both musculoskeletal (Boudreau et al., 2010; Gokeler et al., 2019) and neurological disorders (Cramer et al., 2011; Sampaio-Baptista et al., 2018) for retained improvements in performance. Traditional impairment-based programs focusing on commonly found deficits, such as diminished leg muscle strength and power (Bean et al., 2008; Ward et al., 2016), may have some benefit (Jacob et al., 2019). However, comparative studies have shown motor learning programs to be superior to impairment-based programs in improving several aspects of mobility including gait (Brach et al., 2016; VanSwearingen et al., 2011). Observational research indicates that in clinical practice motor learning-based rehabilitation is primarily delivered as individualised task-specific practice with clinician feedback (Kimberley et al., 2010; Tole et al., 2014; Tyson et al., 2018).

A number of key principles are used in motor learning programs, including extrinsic feedback and instruction, motivation, and practice, each of which will be discussed below.

2.2.2 Instruction and feedback in mobility limitation rehabilitation

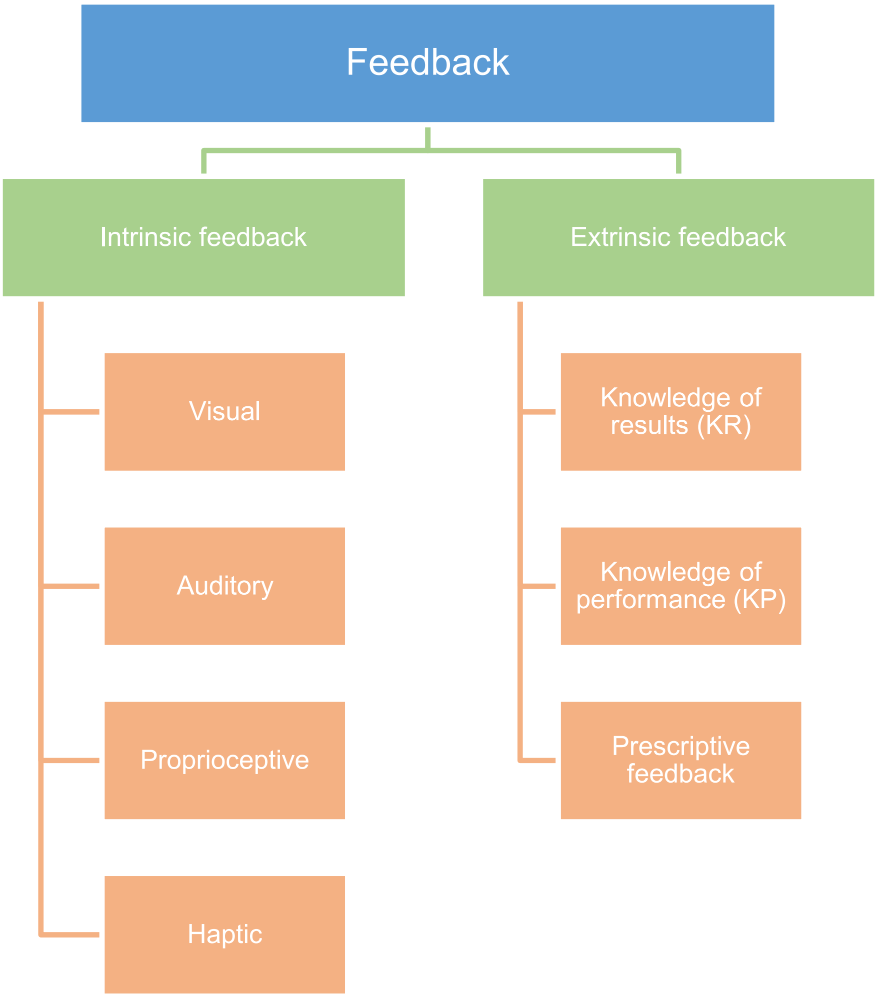

Figure 2-1 Feedback characteristics (adapted from Magill (2017))

Instruction provides information to direct the individual on what and how to perform the desired movement, while feedback provides information to the individual about the movement being practiced (Magill, 2017). Feedback is typically classified as intrinsic or extrinsic feedback (Magill, 2017; van Vliet & Wulf, 2006) (Figure 2-1). Intrinsic feedback is sensory feedback inherent to the task such as seeing one's own leg taking a step or feeling the floor underfoot. Extrinsic feedback, also known as augmented feedback, is feedback external to the patient, and is an important component of rehabilitation delivery as intrinsic patient mechanisms may be impaired (Carr et al., 2011). In rehabilitation extrinsic feedback is traditionally provided by the physiotherapist, who is able to tailor specific feedback to promote relearning of motor skills and optimise patient outcomes (van Vliet & Wulf, 2006).

Modality

Modality refers to the way in which instruction and feedback is provided. When performing motor tasks, intrinsic feedback is visual, auditory, proprioceptive or haptic in nature (Magill, 2017). Extrinsic instruction and feedback provided by physiotherapists to people undergoing rehabilitation is typically auditory, visual or haptic in nature (Talvitie, 2000).

Visual instruction and feedback can be provided in a variety of different ways (e.g., physiotherapist modelling the desired performance or demonstrating observed performance, use of a mirror, viewing a recorded video of the attempt). Auditory instruction and feedback is often provided in the form of spoken words from a therapist but can also be non-verbal (e.g., clapping to cue gait timing). Haptic, or touch feedback involves actions such as a physiotherapist using manual facilitation techniques to guide body position and encourage a different quality of movement. Each of these feedback modalities may be helpful when learning a motor task (Magill, 2017), but auditory feedback can be particularly helpful for people with stroke (Fleszar et al., 2019; Thielman, 2010), possibly due to altered processing mechanisms (Robertson et al., 2009) or to compensate for visual distraction (Secoli et al., 2011). A detailed observational study assessing modality and characteristics of feedback of five physiotherapists providing inpatient physiotherapy found that physiotherapists primarily provide auditory and haptic feedback during rehabilitation, and less visual feedback (Talvitie, 2000).

Content

Extrinsic feedback can be categorised into providing knowledge of performance (KP) or knowledge of results (KR) (Schmidt, 2019; van Vliet & Wulf, 2006). KR provides information about the outcome of a performance. Examples in rehabilitation include the physiotherapist informing the patient of the distance just walked, or the length of time spent standing on one leg. In contrast, KP provides information about the how the performance was carried out, for example a physiotherapist may report “you didn’t lift your left foot enough as your leg came through”, or “your hips came too far over to the left as you balanced”. KP can also involve prescriptive feedback, where instruction to improve the next attempt, based on the previous attempt, is provided, such as “take a longer step with your left leg”. KP is superior to KR for motor learning in healthy adults (Sharma et al., 2016) and in people following stroke (Cirstea & Levin, 2007; Levin & Demers, 2020; Soares et al., 2019) as it encourages the patient to actively problem solve movement components during practice and this can transfer to the real world task (Carr et al., 2011; Cirstea & Levin, 2007).

Schedule

The schedule of feedback relates to the timing and frequency of the feedback provision. The timing of feedback is relative to the performance, in that it can be provided concurrently or at the completion of an activity, and can be based on a summary of all efforts or provide feedback on each repetition (van Vliet & Wulf, 2006). In healthy learners, concurrent feedback can improve immediate performance, however, appears to be detrimental to true motor learning, as subsequent performances conducted after a delay and without concurrent feedback are inferior (Schmidt, 2019). Potentially this is due to concurrent feedback encouraging reduced reliance on intrinsic mechanisms, therefore the effect of concurrent feedback in people with altered intrinsic feedback mechanisms may be different, as concurrent extrinsic feedback may beneficially supplement flawed intrinsic feedback (Molier et al., 2010). Similarly, delayed feedback, where there is an opportunity to self-reflect on performance prior to feedback delivery, promotes motor learning in people without impairments, but this may not be true of motor learning in people with impairments (van Vliet & Wulf, 2006).

Several studies indicate that motor learning is facilitated by providing feedback infrequently, rather than after every attempt (Magill, 2017; Schmidt, 2019; Winstein, 1991), as the leaner does not become dependent to the information provided. Similarly, reducing feedback frequency as the motor skill develops, known as fading feedback, encourages reliance on intrinsic mechanisms, and is reflected in improved performance when the feedback is removed (Magill, 2017). Self-controlled timing schedules, where learners can choose when to receive feedback, appears to facilitate motor learning (Carter et al., 2016; Fairbrother et al., 2012), with the majority of people choosing to receive feedback after successful trials. Optimal feedback schedules for people in rehabilitation is still in debate, but likely to be specific to the learner, taking stage of learning and type and degree of impairment into consideration (Levin & Demers, 2020).

Focus of attention

Movement instruction and feedback provided to a patient can provide an internal focus, external focus or both. When concentrating on the effect of the movement on the surrounding environment, this is said to have an external focus, while attention towards the movement itself has an internal focus (Magill, 2017).

Motor learning research suggests an external focus is of greater benefit than internal focus for motor learning in people without impairments (Wulf & Prinz, 2001) as well as people with impairments such as Parkinson’s disease and following stroke (Wulf, 2013). A double-blind RCT with 62 people receiving inpatient stroke rehabilitation services demonstrated that overall instructions with an external focus do not result in superior task automaticity or clinical outcomes when compared to internally focused instructions (Kal et al., 2019). However, further analysis of these results indicated that patients with relatively high balance performance and sensory function, and low capacity for attentional focus improved more with externally focused than internally focused instructions. This suggests that the direction of attentional focus may need to be tailored to the individual.

Mirrors are commonly used in rehabilitation for patients to obtain visual knowledge of performance during movement. Viewing the body in a mirror can either invoke an internal or external focus of attention, depending on if the user directs their attention to their own body parts or to the environment. A study by Halperin et al. (2016) compared movement outcomes in two different tasks in healthy individuals who were provided with instructions that were internally focused, externally focused, neutral or to look in the mirror, and found performance with mirror feedback resulted in superior performance to internally focused instructions but inferior to externally focused instructions. This suggests that mirror feedback could be open to interpretation by the individual, depending on whether the focus in the mirror remains on individual body parts or the outcome of the movement as a whole.

Observation of eight physiotherapy sessions providing gait rehabilitation with patients following stroke found physiotherapist instruction and feedback statements were mainly internally focused (67%), with externally focused (22%) and mixed focus statements (11%) less frequently provided (Johnson et al., 2013). A larger observational study assessing physiotherapists' attentional focus in 20 gait rehabilitation sessions with patients following stroke found that therapist instruction was predominately externally focussed, while feedback was mainly internally focused (Kal et al., 2018). Focus of attention did vary with patient attentional preference and stage of rehabilitation, suggesting therapists adjust their provision of attentional focus to the individual patient.

Framing

Instruction and feedback can be further classified by whether it is positively or negatively framed; drawing attention to elements of movement success or error. In instruction, a positively framed instruction focuses on the action to be performed, not the action to be avoided. An example is "stand up tall" rather than "don't lean over". Research in sport tasks such as kicking a penalty goal suggest that focusing attention on the desired outcome ("aim for the open space") directs visual attention to the movement goal and results in a more successful outcome than when attention is focused on what not to do ("do not shoot within range of the goal keeper") (Binsch et al., 2010). Positively framed feedback similarly focuses on the successful elements, rather than identifying performance errors. For example, if a movement was accurate but poorly timed, the therapist could provide positive feedback on the accuracy or negative feedback on the timing. Studies have suggested positive feedback increases self-efficacy and motivation, both important factors in motor learning (Saemi et al., 2012; Wulf & Lewthwaite, 2016), while others argue that accurate knowledge of errors is required in order to improve performance (Magill, 2017).

2.2.3 Motivation

Over the past decade, the effect of motivation has been increasingly studied in the motor learning literature, and has shown that motivation and related psychological states such as self-confidence, autonomy, engagement and support encourage motor learning (Chiviacowsky, 2020). Motivation can inspire more effective motor learning via two distinct mechanisms 1) increased enjoyment encouraging increased practice dosage (Holden, 2005) and 2) reducing internal distractions to allow for increased focus on the task (Wulf & Lewthwaite, 2016).

Motivation can be provided by adjusting the content, timing, and control of feedback to provide the learner with a greater sense of self-confidence and autonomy and therefore improve motor learning. For example, Chiviacowsky and Harter (2015) manipulated learners' perception of success by providing feedback after every other trial but with different benchmarks of what was a successful performance. They found that when learners were provided with more occasions of feedback confirming that their performance was successful, they developed self-efficacy in the practised task, and demonstrated superior motor learning than those who were provided with fewer successful feedbacks or no specific feedback. Several studies have found that providing feedback after successful, rather than unsuccessful, movements can promote improved learning and motor skill performance as the person's sense of self efficacy and competence in the task is raised (Abbas & North, 2018; Saemi et al., 2012; Wulf et al., 2010). Finally, providing the individual with autonomy by giving control over various aspects of the practice conditions, such as choice of the frequency and amount of feedback, also contributes to more effective learning (Carter et al., 2014; Lewthwaite & Wulf, 2010; Wulf & Lewthwaite, 2016).

In addition to feedback as a source of motivation, therapists have also been observed to provide direct motivational statements to patients during rehabilitation (Carr et al., 2011; Talvitie, 2000). These statements lack specific movement information but provide general encouragement, such as "great work" and "good". These statements may provide validation of effort and encourage further attempts (Wulf et al., 2010), leading to improved affective state. Observational studies have found motivational statements to be a significant component of physiotherapist's treatment patterns, and are provided to patients more often than either KP or KR (Carr et al., 2011; Talvitie, 2000).

2.2.4 Practice

Rehabilitation is characterised by motor learning though practice. Practice characteristics that contribute to successful rehabilitation include practice content, distribution, and dose, each of which will be described below.

Practice content

Motor learning is optimised when practice is task-specific, functional, and provides a "just right" challenge (Veerbeek et al., 2014). Whilst some transfer of training does occur to other tasks (e.g. gait training can improve standing balance (Howe et al., 2011), training the specific task required to meet patients' functional goals is more effective (Hornby et al., 2016). Progression of task complexity by manipulating the difficulty level, according to the cognitive and motor skills of the learner, also enhances motor learning. Tasks should be challenging enough to keep the patient engaged and stimulated, but also achievable to maintain motivation (Guadagnoli & Lee, 2004).

Distribution of task practice

Practice tasks can be prescribed as blocked practice or varied practice. In blocked practice, tasks are practiced repetitively in a series of successive trials aimed at reducing performance error, while in variable practice the tasks are more diverse, and can be presented in random order with the aim of increasing trial and error learning (Magill, 2017). Practice variations can occur in characteristics that have a direct effect on the motor skill (e.g., walking on different surfaces) or an indirect effect on the skill (e.g. walking with and without overt observation). Varied practice has been shown to be superior to block practice in people with and without impairments (Magill, 2017; Mount et al., 2007).

Practice Dosage

In physical rehabilitation, higher repetitions of task-specific practice are associated with improved outcomes (French et al., 2016; Grimley et al., 2020; Hornby et al., 2016; Kwakkel, 2006; Lang et al., 2015; Lohse, Lang, et al., 2014; Pollock et al., 2014; Veerbeek et al., 2014). In the literature rehabilitation dosage is often reported as total scheduled therapy time, however this does not accurately indicate active time or number of repetitions (Hornby et al., 2016; Lohse, Lang, et al., 2014). It is important to note that it is the active repetitions that contribute to motor learning rather than total scheduled therapy time.

Despite this established dose-response relationship, observational studies have repeatedly found that people in both inpatient and outpatient rehabilitation receive less than the recommended dosage of task-specific therapy, as active therapy time within sessions is commonly low, and number of repetitions within active therapy time is often small (Elson et al., 2009; Kaur et al., 2012; Kimberley et al., 2010; Lang et al., 2007; Lang et al., 2009; Peiris et al., 2013; Tole et al., 2014; Tyson et al., 2018; West & Bernhardt, 2012).

2.3 Virtual reality

Virtual reality technologies have the potential to provide extrinsic feedback, motivation, and high repetitions of task-specific practice to promote motor learning and hence are being increasingly used clinically and researched in rehabilitation (Maier et al., 2019).

2.3.1 The use of virtual reality in clinical rehabilitation

Virtual reality (VR) is a term first used in 1989 and relates to the "creation of interactive, computer-based multimedia environments in which the user becomes a participant with the computer in a "virtually real" world” (Helsel & Roth, 1990). In physical rehabilitation this definition has been refined further, with Levac et al (2016) providing the caveat that movement is the interactive tool:

"any computer hardware and software system that generates simulations of real or imagined environments with which participants interact using their own movements” (Levac et al., 2016b, p. 2).

VR systems are increasingly being used in clinical rehabilitation, both in people with neurological (e.g. stroke (Laver et al., 2017), multiple sclerosis (Massetti et al., 2016), traumatic brain injury (TBI) (Rose et al., 2005), Parkinson’s Disease (Dockx et al., 2016)) and non-neurological (e.g. falls and ageing (Neri et al., 2017; Skjæret et al., 2016; Zheng et al., 2020)) conditions.

Multiple systematic reviews been conducted assessing the evidence for VR-based rehabilitation in people with mobility limitations. Systematic reviews in the post-stroke population have demonstrated that VR interventions are beneficial in improving mobility, both as an adjunct or as an alternative to conventional rehabilitation (Corbetta et al., 2015; de Rooij et al., 2016; Iruthayarajah et al., 2017; Lohse, Hilderman, et al., 2014; Luque-Moreno et al., 2015). For example, de Rooij et al. (2016), in a systematic review and meta-analysis of 21 high quality studies found that VR interventions resulted in significant improvements in gait speed, Timed Up and Go test (TUG) and Berg Balance Scale (BBS) test compared to usual care in people who were between 13 days and 11 years post-stroke.

Other reviews have also shown benefits of VR on mobility outcomes in older adults (Høeg et al., 2021; Neri et al., 2017; Skjæret et al., 2016; Zheng et al., 2020). Most recently Høeg et al. (2021) conducted a meta-analysis of 10 studies investigating the effect of VR-based rehabilitation on the motor function of older adults. Results indicated that, compared to conventional therapies, VR interventions significantly improved outcomes of balance and mobility. However, adverse events and participant dropout rates were higher in the intervention groups, although authors note this could be due to motion sickness from the immersive studies included.

Systematic reviews evaluating the use of VR in rehabilitation interventions have reported on the VR technology used, treatment approach, and dose characteristics (e.g., session frequency and duration). Several authors, on analysis of these intervention characteristics have noted the heterogeneity of these components (e.g. Alashram et al., 2020; de Rooij et al., 2016; Iruthayarajah et al., 2017; Lei et al., 2019; Lohse, Hilderman, et al., 2014; Neri et al., 2017; Zheng et al., 2020). In contrast, other aspects of intervention important for clinical implementation, such as intervention mode (e. individual or group), tailoring of exercises, and person delivering the intervention (Hoffmann et al., 2017), have been reported in only a few studies (e.g.Lohse, Hilderman, et al., 2014). Cano Porras et al. (2018), in a systematic review of 97 VR studies in the rehabilitation of balance and gait in neurological conditions, found that half of the included studies lacked therapeutic validity, particularly due to the omission of rationale relating to dose and customisation of therapy to individual needs, and argues that studies should develop more detailed VR intervention protocols.

2.3.2 Immersive and non-immersive systems

In rehabilitation a range of hardware options to capture patient movement have been utilised. These range from a standard computer mouse, through to forceplates, sensors and cameras (Weiss et al., 2009). Combined with a vast array of software systems this makes for a wide variety of rehabilitation VR technologies. This section will provide an overview of VR systems used in rehabilitation.

Immersion reflects the extent to which the technology supports the individual to perceive they are "in" the virtual environment. Factors that increase immersion include an enriched virtual environment that is both multisensory and multidirectional, the exclusion of "real world" external stimuli, and accurately matching the user's movement with the virtual environment (Slater et al., 1996). Immersion necessitates high levels of sensory fidelity, particularly visual and auditory fidelity, in the way the virtual environment is presented (Bowman & McMahan, 2007). As an example, for the technology to provide a thoroughly immersive auditory experience, it should provide auditory output that is in stereo, and reactive to the position of the individual, as this provides an auditory experience that is similar to the real world.

VR technologies that aim to provide a more immersive experience generally surround the individual with visual stimulus, either in a computer assisted virtual environment (CAVE) or via a head mounted display (HMD) (Rose et al., 2018). CAVE systems use several large screens to surround the individual, creating a room or cave, and glasses can be worn to assist in providing a 3D effect. HMD systems incorporate a headset which displays different images to each eye. The brain combines these into one image which is perceived as three-dimensional. As the headset moves through space, the images change to reflect the different parts of the environment that is being "viewed". Both CAVE and HMD systems can be combined with further components to increase sensory immersion, such as stereoscopic sound for auditory immersion, or omnidirectional treadmills to provide the perception of moving bodily through the physical environment. Further interaction with the environment and haptic feedback can also be incorporated with the use of additional hardware such as handheld controllers or gloves.

In contrast to immersive VR, a single 2D screen such as a television or computer monitor is typically considered non-immersive VR (Rose et al., 2018), and may be referred to as active videogame and computer-based (AVC) technologies. Patient movement to interact with the virtual environment may still be 3D in nature, however the resultant feedback will be limited to a 2D display such as with active video games like Nintendo Wii Fit (Nintendo, Kyoto, USA). Although less expensive than immersive systems, 2D systems provide less sense of presence which may limit the transfer of training to a real world context (Tieri et al., 2018).

2.3.3 Recreational versus rehabilitation-specific commercially available systems

Recreational VR systems are hardware and software systems originally designed for those pursuing movement-based VR for leisure purposes. The programs were developed with end-user entertainment in mind rather than as a therapy product, although some have advertised potential to be used for general fitness purposes. Recent research has identified that the Nintendo Wii and Microsoft Xbox Kinect recreational systems are the most commonly available VR systems for therapists in Canada, US and Scotland (Levac, Glegg, et al., 2019; Thomson et al., 2016).

The Nintendo Wii (Nintendo, Kyoto, USA) is a gaming console with a handheld sensor-based controller that provides interaction with software on the screen. In mobility rehabilitation, the Wii system has been frequently combined with the Wii Balance Board, a force platform for the user to stand on with four corner pressure sensors to detect changes in the user's centre of pressure. Several games exist, with the Wii Fit and Wii Sports discs reported to be most clinically used (Hassett et al., 2019) likely because these include games which involve movements practiced in rehabilitation, such as standing balance and co-ordination (Deutsch, Brettler, et al., 2011). The prevalence of Wii in clinical settings is probably due to its widespread promotion, relatively low cost, and longevity as one of the earliest movement-controlled gaming devices. However, as a recreational gaming console, the Wii is limited in its capacity to be customised for rehabilitation and may offer inappropriate feedback (Putnam et al., 2014). The primary movement input device, the Wii Fit board, requires movements in standing over a fixed base of support, or stepping on and off the board, limiting dynamic balance and gait training, In addition, the board does not tilt, limiting proprioceptive feedback (Tripette et al., 2017).

Microsoft Xbox (Microsoft, Redmond, Washington, USA) uses a gaming console linked to a Kinect camera, a motion sensor camera device with both traditional red-green-blue (RGB) and infrared input to detect whole body 3D movement. Over 100 Xbox Kinect games which encourage movement have been produced (Kamel Boulos, 2012), with Kinect Adventures and Kinect Sports commonly used clinically (Hassett et al., 2019). An analysis of these two programs for suitability in stroke rehabilitation conducted by Givon Schaham et al. (2018) found that both can be played by people with stroke who have capacity to stand and that these games promote whole body movements and physical activity. In particular, these games encouraged practice of dynamic balance activities, similar to dynamic balance practice in usual rehabilitation.

Recreational systems have advantages in that they are widely available and relatively inexpensive. Generally, they are easily portable and can be quickly set up without specialist installation or extensive calibration. However, while recreational systems can encourage movement, tailoring individual games to patients goals and capacity is a barrier to clinical use (Lange et al., 2009). Games may also not consider quality of movement and may not be able to be sufficiently slowed to patient needs (Pirovano et al., 2016). For these reasons it has been purported that they have a limited role in rehabilitation (Proffitt et al., 2019).

Rehabilitation-specific VR systems have been developed explicitly for a therapy market and include commercially available and prototype systems (Hassett et al., 2019). Commercially available, rehabilitation-specific systems are defined as being readily accessible to purchase by the general public or health professionals and do not require extensive customised installation or set up, while prototype technologies are bespoke systems not produced for sale. Many prototype systems are developed for proof of concept research studies. Both commercially available and prototype rehabilitation-specific systems often utilise one or more recreational hardware components, such as the Microsoft Kinect motion sensor camera or the Wii Fit Balance Board in combination with software written for rehabilitation purposes. Examples of rehabilitation-specific systems include Intelligent Rehabilitation Solutions (Doctor Kinetic, Eindhoven, The Netherlands; www.doctorkinetic.com), Jintronix (Jintronix, Seattle, WA, USA; www.jintronix.com), and GestureTek Health (GestureTek, Toronto, Canada; www.gesturetekhealth.com).

Advantages of rehabilitation-specific systems are inherent in their design which intends to provide activities that can be to be tailored to the requirements of a patient population. Exercises can be tailored by adjusting factors such as dose, speed of movement, type of feedback and range of movement (Hassett et al., 2019). The recent meta-analysis of Maier et al. (2019) compared the effect of rehabilitation-specific and recreational VR rehabilitation on motor function in people post-stroke, and found that rehabilitation-specific systems provided superior recovery and functional outcomes compared to recreational systems. The proposed principles available in rehabilitation-specific systems that the authors attribute to this finding include task-specific practice, varied practice schedule, well matched level of challenge and provision of explicit and implicit feedback.

2.3.4 Rationale for VR in mobility limitation rehabilitation

VR technologies have the potential to provide extrinsic feedback, motivation, and high repetitions of task-specific practice to promote motor learning and hence are being increasingly used in rehabilitation of mobility limitations. This section will consider the rationale for VR use in rehabilitation practice.

Feedback

VR systems can provide additional extrinsic KP and KR feedback to expedite motor learning and encourage neuroplasticity (Baranowski et al., 2013; Darekar et al., 2015; Holden, 2005; Tieri et al., 2018). This is especially important in conditions where a patient's own internal feedback mechanisms are impaired (van Vliet & Wulf, 2006). The attentional focus of VR feedback is predominately external as the individual's attention is focused on the effect of their movement in the virtual environment, a further advantage for motor learning (Baranowski et al., 2013). The mode of feedback provided by VR systems is primarily visual, with auditory and tactile modalities less frequently observed (Lee et al., 2017). Feedback provided by technologies typically includes both KP and KR (Hassett et al., 2019), however, KP feedback can lack accuracy (Deutsch, Guarrera-Bowlby, et al., 2011). This can lead to compensatory movement patterns when patients aim for high scores at the expense of the intended movement pattern (Lewis et al., 2011). Rehabilitation-specific gaming systems tend to present less extraneous information resulting in improved KP feedback (Yates et al., 2016). Patients have reported to particularly value positive and successful feedback, with high scores in VR games providing motivation to continue to play (Lewis & Rosie, 2012). Similarly, feedback that is sarcastic, negative or patronising has been perceived as irritating and annoying (Baranowski et al., 2013), and lower game scores as discouraging (Lewis et al., 2011). One flaw of VR-based rehabilitation identified in the literature is the fact that, unlike therapists, not all systems allow feedback to be adjusted and adapted to individual users (Parker et al., 2011). Therefore, when using VR systems, therapists may need to provide patients with additional feedback in order to ensure that patients produce the specific movements required (Deutsch, Guarrera-Bowlby, et al., 2011).

Motivation, engagement, immersion and presence

A second advantage of VR rehabilitation is the potential to increase patient motivation and engagement (Holden, 2005; Howard, 2017; Janssen et al., 2017; Lewis & Rosie, 2012; Rand et al., 2014; Rizzo & Kim, 2005; Rose et al., 2018). Several studies have found VR rehabilitation increases patient motivation and enjoyment compared to usual care (e.g. Cano Porras et al., 2018; Mirelman et al., 2009), although frequently these concepts are poorly reported (Rohrbach et al., 2019). Virtual environments that are highly immersive have been associated with high levels of presence, the subjective experience of being “in” the virtual environment (Rose et al., 2018). Presence contributes to engagement, the level of engrossment within an activity, and a combination of cognitive and affective states (Rohrbach et al., 2019). Many aspects of VR rehabilitation can contribute to patient motivation and engagement including novelty, type and amount of feedback, optimal challenge, available progressions, socialisation, goal orientated tasks and extrinsic rewards (Lewis & Rosie, 2012; Rohrbach et al., 2019).

Practice content, distribution, and dose

The use of VR in rehabilitation has the potential to provide high repetitions of task-specific practice matched to the individual’s needs for optimal motor learning (Levin et al., 2015; Weiss et al., 2009). Rehabilitation-specific systems are more readily tailored to patient’s ability and goals than recreational systems; recreational systems can be too fast or clinically inappropriate for some people undertaking rehabilitation (Hassett et al., 2019; Levin et al., 2015), and the emphasis can be on the movement end point rather than the quality of movement (Pirovano et al., 2016).

The additional motivation generated by the novel, gamified nature of VR rehabilitation may increase therapy dose by encouraging patients to perform more repetitions and to rest less within a therapy session (Holden, 2005; Janssen et al., 2017; Lewis & Rosie, 2012; Rand et al., 2014; Rizzo & Kim, 2005). Moreover, it has been suggested that VR rehabilitation practice can be more easily tailored within a single therapy session than usual care as the burden of setting each task up occurs virtually, resulting in less down time during therapy (Brunner et al., 2016; Karamians et al., 2020) and allowing for varied practice schedules. Unfortunately reviews have found dose is seldom meaningfully reported in VR interventional studies (Knols et al., 2016; Lohse, Hilderman, et al., 2014) and little research has been performed to determine if these theoretical concepts carry through in mobility rehabilitation practice. The few studies in this area have been conducted in people with stroke receiving upper limb therapy, and have reported that VR rehabilitation may result in up to five times more repetitions that usual care (Rand et al., 2014), and this increased activity may be greater in patients with more movement impairment (Brunner et al., 2016). Further research is required to establish the effect of VR on rehabilitation dosage in people with mobility impairments.

2.3.5 Safety of VR rehabilitation

Several reviews into the use of VR in rehabilitation have considered the safety of VR rehabilitation, particularly the reporting of adverse events. A large Cochrane review on VR rehabilitation in stroke found that studies which monitored for adverse events reported only a few minor adverse events (pain, headaches and dizziness), and no serious adverse events (Laver et al., 2017). Similar results have been reported in systematic reviews on VR use in other populations such as people with Parkinson’s Disease (Canning et al., 2020), and older adults (Zheng et al., 2020). However, a relatively low proportion of studies within these reviews have explicitly reported adverse events, as one example, only 23 of the 72 studies included in Laver et al. (2017) reported monitoring for adverse events at all. In addition, it has been noted that the intervention protocols of VR rehabilitation trials frequently employ additional safety measures such as walking aids and gait belts (Skjæret et al., 2016). Overall, the current literature on VR rehabilitation would indicate it is safe for use in clinical practice.

2.4 Therapist role in VR rehabilitation delivery

The literature on actual therapist involvement in the delivery of VR rehabilitation is sparse. As VR technology has the capacity to provide feedback and motivation, some research has suggested it may reduce the need for therapist involvement in VR rehabilitation (Doyle et al., 2011; Gonçalves et al., 2019; Levac & Galvin, 2013). However other research has indicated that the therapist can be an “active ingredient” in VR-based therapy (Brutsch et al., 2010; Levac, Rivard, et al., 2012; Levac & Galvin, 2013; Pimentel Piemonte et al., 2017). A qualitative systematic review of therapist experience in technology-based rehabilitation found therapists themselves report a need to be involved in order to facilitate ideal patient movement and optimise patient benefit (Hamilton, Lovarini, et al., 2018).

In a randomised controlled trial, Pimentel Piemonte et al. (2017) compared balance training in people with Parkinson’s disease with the Nintendo Wii to Wii training with additional therapist manual and verbal guidance. Patients who received Wii training with additional therapist guidance over the 14 session (7 week) trial demonstrated significantly greater improvements in gait and balance compared to the Wii only group. Although these results have only been reported in brief as a conference abstract, it suggests that the therapist plays a significant factor in VR rehabilitation outcomes.

In the clinical use of VR technologies, concerns have been raised that VR may distract the therapist from the patient movement (Tatla et al., 2015), while others suggest that the use of VR may free the therapist to concentrate more on patient movement (Laufer et al., 2011; Weiss et al., 2006). There is no known observational research to support or refute these suggestions.

Program prescription

In both usual care and VR-based rehabilitation, a key role of the therapist is to prescribe task-specific, contextual, goal orientated practice activities (Glegg et al., 2014). This prescription role includes initial selection of a suitable technology and also prescribing and progressing program games and activities tailored to individual needs and preferences (Hassett et al., 2019). Lack of knowledge about VR systems, and difficulty matching technologies with the patient have been previously identified as barriers to therapist use of VR (Levac et al., 2017; Levac, Glegg, et al., 2019; Thomson et al., 2016). Much of the existing literature to guide therapists on the implementation of VR in rehabilitation has been focused on VR exercise prescription with several resources written to aid therapists in identifying and matching appropriate VR games for use in therapy (Deutsch, Brettler, et al., 2011; Givon Schaham et al., 2018; Harvey & Ada, 2012; Levac et al., 2015; Levac, Pradhan, et al., 2018).

Instruction

Little has been explicitly written about therapist instruction during VR rehabilitation. Brutsch et al. (2010) assessed the active participation of children with neurological conditions during robotic assisted gait training with no instruction or feedback, only VR feedback or VR feedback plus therapist instruction. Results showed that patients were significantly more active when receiving therapist instruction in addition to VR, compared to only VR alone. Although the study was small (n=10 patients), with only 2 minutes of walking in each condition, this indicates that therapist instruction can contribute to improved patient performance.

Some VR intervention studies in people with stroke have suggested that therapist instruction may contribute to improved patient movement patterns (Fritz et al., 2013; Hung et al., 2014). Fritz et al. (2013) investigated the effect of an intervention using recreational technologies compared to a usual exercise group on outcomes of balance and mobility in people with stroke. They found no significant between-group differences, however remarked that “therapist assistance to participants about more optimum movement choices may be needed before significant improvements are seen” (Fritz et al., 2013, p. 224). This suggests that therapist instruction, in addition to the instruction provided by the technology during VR rehabilitation, was not a part of the intervention protocol, however could potentially be an influential factor in terms of patient outcomes. In another example, Hung et al. (2014) studied the effect of balance training with the Wii Fit on balance in people with stroke, compared to conventional exercise. Results at the end of the intervention period indicated that the intervention group performed significantly better in some balance tests than the usual care group. The authors argued that when using the Wii Fit / VR technologies "therapists needed to guide them (patients) to facilitate optimal movement" (Hung et al., 2014, p. 1636). Although neither of these papers specifically measured therapist instruction in VR interventions, both alluded to the importance of it, suggesting that therapist guidance during VR rehabilitation is a factor that requires investigation.

Feedback

The literature is conflicted with regards to the provision of therapist feedback delivery during VR rehabilitation. In qualitative studies therapists have reported that the use of VR technologies in rehabilitation influences the amount of feedback therapists provide. Some have reported to provide additional feedback to assist in the interpretation of the technology feedback (Hamilton, McCluskey, et al., 2018), or to counteract unhelpful feedback provided by the technology (Levac, Miller, et al., 2012; Levac & Miller, 2013). Other therapists report providing less feedback so as not to overwhelm the patient (Levac, Miller, et al., 2012), or due to the patient being engaged with the technology (Tatla et al., 2015).

2.5 Summary

VR interventions are being increasingly used in clinical practice as mobility limitations rise in prevalence with associated serious implications for individuals and the health care system. Rehabilitation for mobility limitations is effective, and involves repetitive, task-specific practice with appropriate feedback. VR technologies provide an opportunity for therapists working with people with mobility limitations to expand their rehabilitation service delivery, by using VR systems to deliver engaging, repetitive practice with extrinsic feedback. Current evidence suggests VR rehabilitation is safe, and can provide improved mobility outcomes compared to usual care, but how physiotherapy practice is conducted in the delivery of this VR interventions has been poorly characterised to date. Further studies are needed to determine how the introduction of VR technologies affects the practice of physiotherapy.

CHAPTER 3: HOW COMMERCIALLY AVAILABLE VIRTUAL REALITY INTERVENTIONS ARE DELIVERED AND REPORTED IN REHABILITATION FOR MOBILITY LIMITATIONS: A SYSTEMATIC REVIEW

Preface:

The literature review in Chapter 2 introduced the use of VR interventions to address mobility limitations in rehabilitation and addressed the rationale for this. It also highlighted little is known about the practice of physiotherapy during VR mobility rehabilitation. Chapter 3 aimed for an in-depth evaluation of how VR intervention programs are delivered and the role of the physiotherapist within this. In conducting this systematic review, this chapter met the initial research objective to characterise the delivery of VR-based mobility rehabilitation in published literature, including the reported role of the physiotherapist in this delivery, and informed subsequent studies completed within this thesis.

The protocol for this systematic review was prospectively registered with the International prospective register of systematic reviews (PROSPERO). The completed registration is available in Appendix A. This chapter, with several changes to the discussion, was published in *Physical Therapy*, and a copy of the publication is provided in Appendix B.

Publication:

Weber, H., Barr, C., Gough, C., & van den Berg, M. (2020). How Commercially Available Virtual Reality-based Interventions Are Delivered and Reported in Gait, Posture, and Balance Rehabilitation: A Systematic Review. *Physical Therapy*. https://doi.org/10.1093/ptj/pzaa123

3.1 Introduction

Mobility limitation can result from many conditions and is a primary cause of diminished ability to live independently (Fried et al., 2000). Physical rehabilitation is an effective intervention for mobility limitation, with higher intensity linked to greater recovery in a wide range of diagnoses such as stroke (Pollock et al., 2014), hip fracture (Binder et al., 2004) and dementia (Pitkala et al., 2013).

The use of virtual reality (VR) in rehabilitation is increasing in prevalence as it provides an opportunity for activity in an enriched environment, with resultant enhanced motivation and participation (Lewis & Rosie, 2012). VR technology in physical rehabilitation has been defined as "any computer hardware and software system that generates simulations of real or imagined environments with which participants interact using their own movements" (Levac et al., 2016b). The safe yet varied virtual environment can provide a stimulus for increased task repetition and dose intensity (Lewis & Rosie, 2012). A further advantage lies in the additional external feedback provided by the technology which may facilitate motor learning, especially in people with neurological conditions (Levac et al., 2016a).

Several hardware systems have been used in rehabilitation therapies, with devices including handheld controllers, balance boards and full body motion capture cameras commonly used to transfer patient movement into virtual environment interaction. Display options vary in immersive qualities from flat 2D screens to fully immersive head mounted displays and entire room displays (Holden, 2005). Software systems are also diverse and include casual recreational gaming systems designed for entertainment through to rehabilitation-specific programs designed for tailored task-specific practice.

Research into the benefits and efficacy of VR mobility rehabilitation has been conducted in several conditions, both neurological (e.g. stroke (Corbetta et al., 2015; Laver et al., 2017), cerebral palsy (Snider et al., 2010), multiple sclerosis (Massetti et al., 2016), TBI (Rose et al., 2005), Parkinson's Disease (Dockx et al., 2016)) and non-neurological (e.g. falls and ageing (Neri et al., 2017; Skjæret et al., 2016)). This growing body of evidence generally indicates that VR is safe and no less efficacious than usual care (Levac et al., 2017), with higher levels of patient motivation and adherence (Cano Porras et al., 2018).

Although systematic reviews have demonstrated that VR interventions are an acceptable alternative or addition to usual care, variation in intervention methodologies is considerable, preventing meaningful and detailed synthesis of results, and indicating the optimal interventional procedures are unknown (Corbetta et al., 2015; Tieri et al., 2018). While it has been argued that additional feedback and motivation provided by the technology may promote independence and reduce therapist involvement in technology assisted therapies (Doyle et al., 2011), other research has indicated that the therapist may remain an "active ingredient" (Brutsch et al., 2010; Levac, Rivard, et al., 2012; Levac & Galvin, 2013), and therapists themselves report a need to be involved (Hamilton, Lovarini, et al., 2018). Guidelines to inform the delivery of VR rehabilitation remain sparse, with resources for clinicians focusing on providing information on game selection (Levac et al., 2015) with little consideration of dose parameters, mode of delivery, or therapist involvement.

It remains unclear how therapists implement VR rehabilitation interventions and further exploration is required to gain a greater understanding of what is involved in VR rehabilitation, including the why, who, how, and how much of VR therapy, with particular attention to how therapists are involved in supervised VR rehabilitation. Therefore, this systematic review aimed to describe how commercially available VR technology is being used in clinical intervention studies addressing mobility limitations. The objectives were to assess (1) how the technology intervention is being reported and delivered, and (2) the therapist role in intervention design and delivery. Knowledge gained from this review will contribute to our understanding of how commercially available VR technologies are being used in clinical research and is the first step towards providing clinicians with further guidance for implementation.

3.2 Methodology

This systematic review protocol was registered with PROSPERO (registration number CRD42018105668) (Appendix A).

3.2.1 Data sources and searches

The systematic search was conducted on the following electronic bibliographic databases: MEDLINE (Ovid), CINAHL, Cochrane, SCOPUS and EMBASE. Non-English articles and articles published prior to 2007 were not included. We defined the advent of currently commercially available body movement-controlled technology as the Nintendo Wii, released at the end of 2006, therefore only papers published post this date were considered relevant.

Search terms covered the concepts of virtual reality (including VR, exergaming, serious gaming, computer environments), mobility impairments (including balance, gait, postural control) and interventional trials (RCT's, controlled trials, crossover studies). A full list of topic headings and keywords is in Table 3-1. Reference sections of relevant articles were also hand searched, to identify any further relevant studies.

Table 3-1 Search strategies.

Medline via Ovid (1946-present)
1. Virtual Reality/ or therapy, computer-assisted/ or computer-assisted instruction/ or Video Games/ or user-computer interface/ or computers/ or computer systems/ or software or computer graphics/ or microcomputers/ or computers, handheld/ or smartphone/ or minicomputers/
2. (virtual realit* or virtual-realit* or VR).tw,kf.
3. ((virtual or simulat*) adj3 (environment* or object* or world* or treatment* or system* or program* or rehabilitation* or therap*)).tw,kf
4. (computer* adj3 (graphic* or gam* or interact*)).tw,kf.
5. (computer adj1 assist* adj1 (therap* or treat*)).tw,kf.
6. (computer adj1 generat* adj1 (environment* or object* or world* or realit*)).tw,kf.
7. (video gam* or gaming console* or interactive gam* or Wii or gaming program* or serious gam* or playstation or xbox or x-box or kinect or gesturetek or ipad* or mobile device*).tw,kf.
8. exergam*.tw,kf.
9. (user adj1 computer adj1 interface).tw,kf.
10. Or/1-9
11. walking/ or gait/ or walking speed/ or postural balance/ or mobility limitation/
12. gait disorders, neurologic/ or gait apraxia/ or gait ataxia/
13. (gait or locomot* or ambulat* or walk* or mobility).tw,kf
14. (postur* adj1 (control or stability or instability)).tw,kf.
15. (balanc* adj3 (disorder* or stand* or dysfunction*)).tw,kf.
16. Or/11-15
17. treatment outcome/ or controlled clinical trial/ or clinical trial/ or control groups/ or double-blind method/ or single-blind method/ or cross-over studies/ or cohort studies/
18. Random Allocation/ or Clinical Trials as Topic/ or Randomized Controlled Trials as Topic/
19. (random* or RCT or RCTs).tw,kf.
20. (controlled adj5 (trial* or stud*)).tw,kf.
21. ((control or treatment or experiment* or intervention) adj5 (group* or subject* or patient*)).tw,kf.
22. (quasi-random* or quasi random* or pseudo-random* or pseudo random*).tw,kf.
23. ((control or experiment* or conservative) adj5 (treatment or therap* or procedure or manage*)).tw,kf.
24. Or/17-23
25. 10 and 16 and 24
This Medline search was adapted for searches of all other data bases (Medline, EMBASE, CINAHL, Scopus and Cochrane Library).

Inclusion criteria are listed in Figure 3-1. Commercially available technology was defined as being currently easily accessible to purchase by either the general public or qualified therapists. Both immersive and non-immersive technologies were included provided they were "plug and play" technologies. Studies were excluded if they utilised study designs other than interventional studies, or if interventions were exclusively for the upper limb. Novel and experimental technologies purposefully designed for specific research and not widely obtainable on the market were excluded. Similarly, specialist technologies requiring expert customised installation were also excluded.

Study design

- Interventional study design
- >10 participants in intervention arm

Population

- Any mobility limitation including restrictions in balance, ambulation and postural control
- > 18 years old
- Supervised inpatient or outpatient setting

Intervention

- Primary aim to achieve an improvement in an individual's functional mobility, reflected by a primary mobility outcome measure. By this standard, studies primarily aiming to examine change in cognitive or cardiovascular function were excluded.
- Intervention using a commercially available VR rehabilitation technology.

Outcome

- Reported intervention characteristics, including the role of the physiotherapist during the intervention

Figure 3-1 Inclusion criteria

3.2.2 Study selection process

Titles and abstracts were independently assessed by two reviewers against the inclusion and exclusion criteria. Subsequently, full texts were obtained for potentially eligible studies and were independently reviewed by the same two reviewers for eligibility. Any discrepancies were resolved by a third reviewer.

3.2.3 Data extraction

One reviewer extracted the data from each study, which was independently verified by a second reviewer and any discrepancies were resolved by a third reviewer. As the aim of this study was to assess reported information, study authors were not contacted for further information, but all published sources were used including appendices, online supplements, and separately published protocols.

Study characteristics were extracted including aim of study, study design, setting, sample size and participant demographics, intervention (and control) type and primary outcome measures. All information related to the intervention was extracted consistent with the Template for Intervention

Description and Replication (TIDieR) checklist and guide (Hoffmann et al., 2014; Hoffmann et al., 2017) including information on the justification, content, procedures and dosage of the intervention, and details of the therapist role. Where an element of dosage was not specifically stated but could be reasonably derived it was calculated. For example, if dosage was described with number of weeks and sessions per week, these figures were multiplied to obtain the total number of sessions. Where any quantitative descriptors were reported as a range the midpoint was used to calculate dose. If an item was not reported this was stated; if an item was mentioned but not explicit or clear this was also recorded.

Any mention or description of the role of the therapist, in the provision and supervision of the intervention, before, during or after an intervention session, was transcribed verbatim into an Excel spreadsheet. Key concepts related to therapist roles were grouped together and categorised to synthesise results into themes. Statements were not limited to a single category if more than one concept was present. As with study characteristics, the second reviewer verified data extraction and all authors agreed on the synthesis of results.

3.2.4 Data analysis and quality assessment

Methodological quality of the included studies was assessed based on a modified version of the CASP tool (Critical Appraisal Skills Programme, 2019) for RCT and cohort studies. Each of six assessment criterions was assessed as low, medium or high quality. Studies rated as high quality in five or six criteria were rated as high quality overall, studies which were rated as medium quality or higher in five or six criteria were rated as medium quality overall and all other studies were rated as low quality. These assessments were conducted by one reviewer and verified by a second reviewer.

3.3 Results

3.3.1 Search results

Initial database searching and hand screening identified 7601 studies. After duplicates were removed, 4897 titles and abstracts were independently screened for inclusion and 284 articles were retrieved and assessed in full text. Twenty-nine articles met the inclusion criteria and were included in the review. The Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) (Tricco et al., 2018) flow diagram is presented in Figure 3-2.

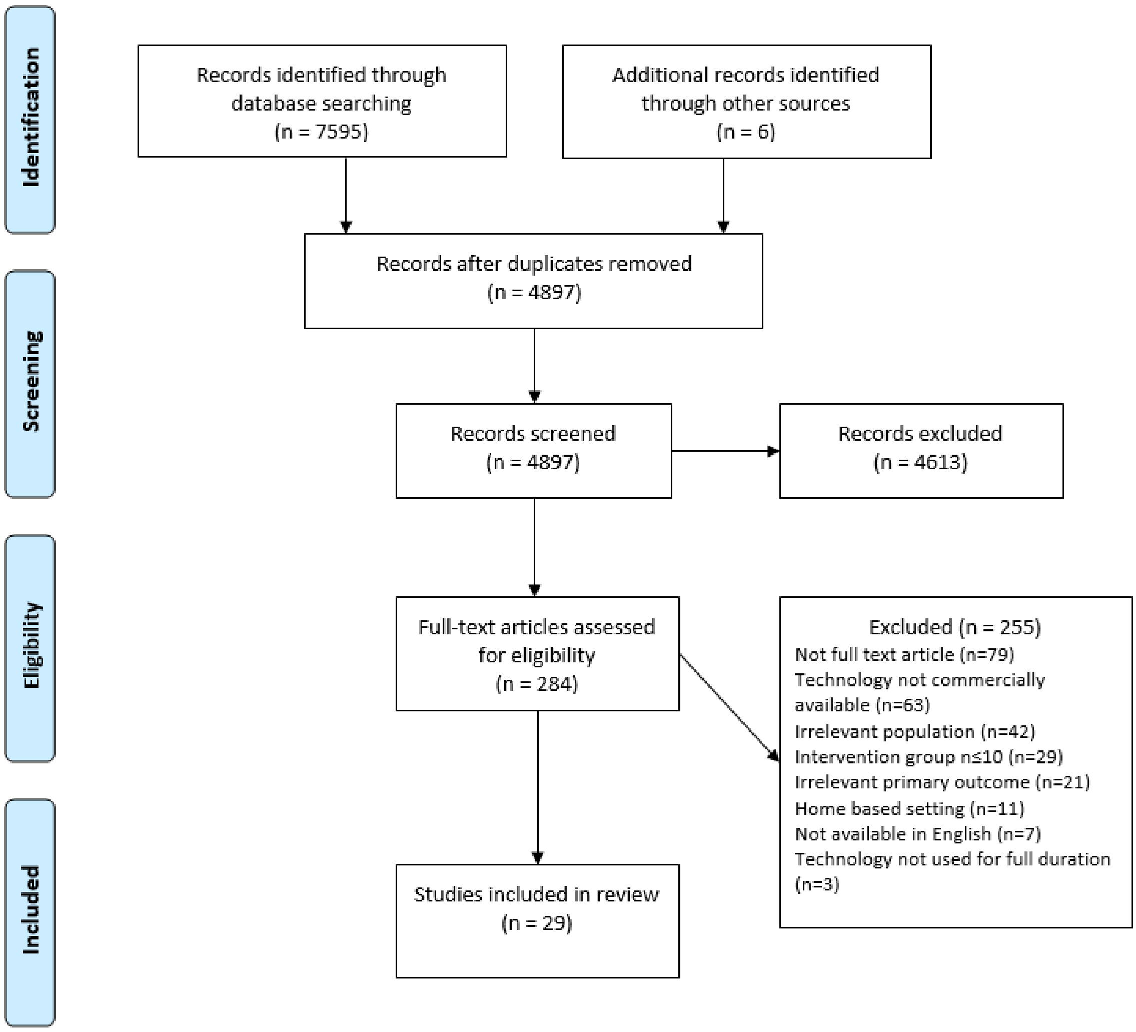

Figure 3-2 PRISMA diagram of flow of studies through the review

3.3.2 Characteristics of the included studies

Table 3-2 provides details of the study characteristics and assigns each study with a study number from 1-29 in alphabetical order. These study numbers are used in the reporting of the results.

The majority of studies (n=26; Studies 1-9, 11-12, 14-27 and 29) aimed to investigate the effect of a VR rehabilitation intervention, and the remaining three (Studies 10, 13 and 28) aimed to evaluate feasibility. Most studies (n=23) reported more than one outcome (Studies 1-2, 5, 7-8, 10-13, 15-17 and 19-29), with balance measures being the most studied outcome (n=20; Studies 2, 5, 8, 10-13, 27, 16-17 and 19-29) and gait second most studied (n=16; Studies 1, 5, 7-10, 12, 15-16, and 20-26).

Study designs used included single blind RCTs (n=23; Studies 2, 4-18, 20, 22-24, 26-27 and 29), quasi-experimental with non-randomized allocation (Studies 1 and 3) and cohort studies (Studies 19, 25 and 28). Sample size ranged from 18 (Study 3) to 84 participants (Study 20) (median=33). Participant mean age, specified in 28 studies, ranged from 28.6 years (Study 2) to 85.2 (Study 13). Study populations included primarily people with neurological disorders, with stroke being most common (n=11; Studies 5-6, 11-12, 14, 16, 18, 22, 25, 27 and 29). Eighteen studies were conducted in an outpatient setting (Studies 1-4, 7-11, 17, 19-24 and 27-28) with community patients attending a local clinic or community centre for the VR rehabilitation and in five studies (Studies 6, 18-19, 22 and 29) the setting was not explicitly stated. Five different technologies were studied (Wii [Nintendo Wii, Nintendo, Kyoto, Japan], Xbox [Xbox Kinect, Microsoft, Redmond, WA], IREX [GestureTek, Toronto, Canada], Biodex [Biodex Balance System, Biodex, NY, USA], and Jintronix [Jintronix, Seattle, WA, USA]), with 26 studies using one technology only (Studies 2-24, and 27-29) and three studies looking at more than one specific technology, either in a multi-technology intervention (Study 25) or studied in comparison to each other (Studies 1 and 26). The characteristics of the included studies are presented in Table 3-2.

Table 3-2 Characteristics of the included studies

First Author (Year)	Study number	Aim of study	Participant demographics (n=, Age mean (SD), population) α=age of all participants ϕ=age of VR group only	VR rehabilitation technology group(s)	Non-VR rehabilitation group(s) *as described by the authors	Primary functional outcome measure	Overall study quality
RCT's - Outpatient Settings							
Baltaci (2013)	2	Compare the outcomes of Nintendo Wii Fit with those of conventional rehabilitation	30, 28.6 (6.8)ϕ ACL	Nintendo Wii	Conventional rehabilitation	Modified Star Excursion Balance Test	Medium
Brichetto (2013)	4	Assess the effectiveness of visual feedback exercises (Wii) versus traditional rehabilitation strategies in improving balance	36, 40.7 (11.5)ϕ MS	Nintendo Wii	Tailored exercise program	BBS	High
de Melo (2018)	7	Evaluate the effects of gait training with VR (Kinect) on walking distance and physical fitness	37, 60.25 (9.28)ϕ PD	Xbox Kinect	Conventional rehabilitation, treadmill training	6MWT, gait symmetry and speed	Medium
Eftekharsadat (2015)	8	Investigate the efficacy of a short-term VR program on balance	30, 33.4 (8.1)ϕ MS	Biodex	No intervention	TUG and BBS	High

Ferraz (2018)	9	Compare the effects of functional training, bicycle exercise and exergaming on walking capacity	72, 69 (5)α PD, >60 years old	Xbox Kinect +stretching, calisthenics and breathing exercises	Stretching, calisthenics and breathing exercises + functional training or bicycle exercise	6MWT	High
Fung (2012)	10	Determine whether Nintendo Wii Fit is an acceptable adjunct to physiotherapy treatment in the rehabilitation of balance, lower extremity movement, strength and function	50, 67.9 (9.5)ϕ TKR	Nintendo Wii +physiotherapy	Lower extremity exercises + physiotherapy	2MWT	High
Hung (2014)	11	Compare the effects of exergaming with conventional weight shift training on balance function	30, 55.38 (9.95)ϕ Stroke	Nintendo Wii + routine rehabilitation	Conventional weight shift training + routine rehabilitation	TUG and FRT	High
Kim (2009)	12	Examine an additive effect of VR on balance and gait function	24, 51.96 (8.4)α Stroke	IREX + conventional physiotherapy	Conventional physiotherapy	BBS, 10mWT, MMAS	High
Lee (2015)	14	Investigate the clinical effects of VR-based training and task orientated training on balance performance	24, 45.91 (12.28)ϕ Stroke	Nintendo Wii + conventional physiotherapy	Task oriented training + conventional physiotherapy	FRT	Medium

Morone (2016)	17	Evaluate the efficacy of a supervised exergame performed with the Wii Fit compared to conventional exercises on balance function, quality of life, fear of fall and well being	38, 67.8 (2.98)ϕ Bone loss and BBS<45	Nintendo Wii	Conventional training	BBS	High
Nilsagard (2013)	20	Evaluate the effects of a Nintendo Wii Fit balance exercise program on balance function and walking ability	84, 50.0 (11.5)ϕ MS	Nintendo Wii	No training	TUG	High
Pedreira da Fonseca (2017)	22	Investigate the therapeutic effect of virtual reality associated with conventional physiotherapy on gait balance and the occurrence of falls	30, 53.8 (6.3)ϕ Stroke	Nintendo Wii + stretching and mobilizing activities	Conventional physiotherapy	DGI	High
Robinson (2015)	23	Examine the effects of exergaming on: (1) postural sway, (2) gait, (3) technology acceptance and (4) flow experience	56, 52.6 (6.1)ϕ MS	Nintendo Wii	Traditional balance program, no intervention	Gait parameters	Medium
Silva (2017)	24	Analyze the effects of a Wii-based exercise program on physical fitness, functional mobility and motor proficiency	27, "adult"α Down Syndrome	Nintendo Wii	Usual activities at occupational center	Eurofit Test Battery	Medium

Utkan Karasu (2018)	27	Investigate the efficacy of Nintendo Wii Fit-based balance rehabilitation as an adjunctive therapy to conventional rehabilitation	23, 62.3 (11.79)ϕ Stroke	Nintendo Wii + conventional rehabilitation	Conventional rehabilitation	BBS, FRT, PASS, TUG	High
RCT's – Inpatient, mixed, or undefined settings							
Cannell (2018)	5	Compare the efficacy of interactive, motion capture-based rehabilitation (Jintronix) to usual care stroke rehabilitation on functional outcomes	81, 72.8 (10.4)ϕ Stroke	Jintronix + individual physiotherapy	Individualized exercise program + individual physiotherapy	FRT	High
Cho (2012)	6	Investigate the effects of rehabilitation using a virtual reality game (Wii) on static and dynamic balance abilities	24, 65.26 (8.35)ϕ Stroke	Nintendo Wii + standard rehabilitation	Standard rehabilitation	BBS and TUG	Medium
Laver (2012)	13	Assess the feasibility of a physiotherapy intervention using an interactive gaming program compared with conventional physiotherapy	44, 85.2 (4.7)ϕ Older adults admitted to GEM unit for inpatient rehabilitation	Nintendo Wii	Conventional physiotherapy	TUG	High

Liao (2015)	15	Examine the effects of VR-based training in improving muscle strength, sensory integration ability, and walking abilities	36, 67.3 (7.1)ϕ PD	Nintendo Wii + treadmill training	Traditional exercise +treadmill training, fall prevention education	Gait velocity, stride length and functional gait assessment	High
McEwen (2014)	16	Determine whether an adjunct VR therapy improves balance, mobility and gait	59, 62.2 (14.1)ϕ Stroke	IREX (standing balance exercises) + standard therapy, IREX (sitting exercises) + standard therapy.	N/A	TUG	Medium
Morone (2014)	18	Investigate the efficacy of balance training using video game-based intervention on functional balance and disability	50, 58.4 (9.6)ϕ Stroke	Nintendo Wii + conventional physiotherapy	Usual balance therapy + conventional physiotherapy	BBS	Medium
Straudi (2017)	26	Test the effects of a commercially available video game therapy on balance and selective attention	21, 30.5 (16)ϕ TBI	Xbox Kinect + multidisciplinary rehabilitation program, Biodex + multidisciplinary rehabilitation program	N/A	CB&M, UBS, TUG	Medium

Yatar (2015)	29	Compare the effects of Wii Fit balance training and progressive balance training approaches on balance functions, balance confidence and ADLs	33, 62.8 (10.9)ϕ Stroke	Nintendo Wii + neurodevelopmental training program	Progressive balance exercises + neurodevelopmental training program	BBS, TUG, DGI and FRT	Medium
Other study types							
Alves (2018)	1	Compare the relative effects of Nintendo Wii and Xbox Kinect with regard to motor and cognitive performance, anxiety levels and perceived quality of life changes	27, 61.07 (10.74)α PD	Xbox Kinect, Nintendo Wii	No training	Gait performance (TUG, 10mWT, 30sec walk test - simple and dual task)	Medium
Bateni (2012)	3	Determine the effectiveness of Wii Fit training on balance control compared with physiotherapy training	18, 79, (13)ϕ Falls	Nintendo Wii, Nintendo Wii +PT	PT only (PT = tailored physiotherapy exercises)	BBS	Low
Negrini (2017)	19	Compare the effectiveness of 10 vs 15 sessions of Nintendo Wii Fit for balance recovery	27, 66(8)α PD	Nintendo Wii (10 sessions), Nintendo Wii (15 sessions)	N/A	BBS and Tinetti Scale	High

Ozgonenel (2016)	21	Explore the efficiency of a game console as an adjunct to an exercise program in treating incoordination	33, 65 (not reported)α PD	Xbox Kinect + standard rehabilitation program	Standard rehabilitation program (included exercise, hot pack and electrotherapy)	BBS and TUG	Low
Singh (2013)	25	Determine whether there were any changes in physical function and ADLs when substituting a portion of the standard physiotherapy time with VR games	36, 65.4 (9.8)ɸ Stroke	Nintendo Wii +Xbox Kinect + standard physiotherapy	Standard physiotherapy + additional standard physiotherapy	TUG, 30sec STS, 10mWT, 6MWT, Barthel Index	Medium
Williams (2010)	28	Determine whether the Nintendo Wii Fit was a feasible and acceptable intervention	21, 76.8 (5.2)ɸ At least one fall in past year and >70 years old	Nintendo Wii	Usual care (physiotherapy exercise/education program)	BBS and Tinetti Scale	Low

Abbreviations: Parkinson's Disease (PD), hamstring ACL reconstruction (ACL), Multiple Sclerosis (MS), Total Knee Replacement (TKR) Geriatric Evaluation and Management (GEM), Traumatic Brain Injury (TBI) Falls (2 or more falls in previous year), Berg Balance Scale (BBS), Timed Up and Go (TUG), Dynamic Gait Index (DGI), Postural Assessment Scale for Stroke Patients (PASS), Functional Reach Test (FRT), Six Minute Walk Test (6MWT), Two Minute Walk Test (2MWT), 10 meter Walk Test (10mWT), Community Balance and Mobility Scale (CB&M), Unified Balance Scale (UBS), Modified Motor Assessment Scale (MMAS), Activities of Daily Living (ADL)

The methodological quality, as assessed by the pre-defined criteria, was rated as high for 14 studies (Studies 4-5, 8-9, 10-13, 15, 17, 19, 20, 22 and 27), medium for 12 studies (1, 2, 6-7, 14, 16, 18, 23-26, 29) and low for the remaining three (3, 21, 28). Full details of the methodological quality assessment are presented in Table 3-3.

Table 3-3 Methodological quality of the included studies

	Did the trial address a clearly focused issue?				Were the participant groups appropriately recruited or randomized to minimise selection bias?				Were all of the patients who entered the trial properly accounted for at its conclusion?				Was the outcome assessor blinded to minimize bias?				Were the groups similar at the start of the trial?				Aside from the experimental intervention were the groups treated equally or were confounding factors accounted for?				**Overall rating (high if 5 or 6 highs, med if med or high in 5/6, otherwise low),**
First Author (Year)	no	unclear	yes	**Rating**	high bias risk	medium bias risk	low bias risk	**Rating**	no	per protocol analysis/unclear	intention to treat analysis	Rating	no	unclear	yes	**Rating**	no	partially	appropriately	**Rating**	no	unclear	yes	**Rating**	
Alves (2018)			x	high	x			low		x		med			x	high		x		med			x	high	med
Baltaci (2013)			x	high			x	high		x		med		x		med			x	high			x	high	med
Bateni (2012)			x	high	x			low		x		med		x		med	x			low			x	high	low
Brichetto (2013)			x	high			x	high		x		med			x	high	x			high			x	high	high
Cannell (2018)			x	high			x	high			x	high			x	high			x	high			x	high	high
Cho (2012)			x	high			x	high		x		med		x		med		x		med			x	high	med
de Melo (2018)			x	high			x	high		x		med		x		med		x		med			x	high	med
Eftekharsadat (2015)			x	high			x	high			x	high			x	high			x	high			x	high	high
Ferraz (2018)			x	high			x	high		x		med			x	high			x	high			x	high	high

Fung (2012)	x	high			x	high			x	high			x	high			x	high		x	high	high
Hung (2014)	x	high			x	high		x		med			x	high			x	high		x	high	high
Kim (2009)	x	high			x	high			x	high			x	high			x	high		x	high	high
Laver (2012)	x	high			x	high			x	high			x	high			x	high		x	high	high
Lee (2015)	x	high		x		med			x	high		x		med			x	high		x	high	med
Liao (2015)	x	high			x	high		x		med			x	high			x	high		x	high	high
McEwen (2014)	x	high		x.		med		x		med			x	high		x		med		x	high	med
Morone (2016)	x	high			x	high			x	high			x	high		x		med		x	high	high
Morone (2014)	x	high			x	high		x		med			x	high			x	high	x		med	med
Negrini (2017)	x	high	x			low			x	high			x	high			x	high		x	high	high
Nilsagard (2013)	x	high			x	high		x		med			x	high			x	high		x	high	high
Ozgonenel (2016)	x	high	x			low	x			low			x	high	x			low		x	high	low
Pedreira da Fonseca (2017)	x	high			x	high	x			low			x	high			x	high		x	high	high
Robinson (2015)	x	high			x	high		x		med	x			low			x	high		x	high	med
Silva (2017)	x	high			x	high		x		med			x	high		x		med		x	high	med

Singh (2013)	x	high	x			low	x		med		x	high		x		med		x	high	med
Straudi (2017)	x	high			x	high	x		med	x		med		x		med		x	high	med
Utkan Karasu (2018)	x	high		x		med		x	high		x	high			x	high		x	high	high
Williams (2010)	x	high	x			low	x		med	x		med	x			low	x		med	low
Yatar (2015)	x	high	x			low	x		med	x		med		x		med		x	high	med

3.3.3 Reported Items of VR Rehabilitation

Reported VR rehabilitation in each trial was extracted using the TIDieR reporting checklist (Hoffmann et al., 2014). Based on the headings of the TIDieR checklist (see Appendix C), data extracted included the why, what, who, how, where, when, how much, tailoring, modifications, how well, and therapist role within intervention. Details are reported in Table 3-4.

Why

The rationale presented for use of the VR intervention was related to previous research in 27 of the 29 studies (Studies 1-2, 4-27 and 29). A total of 22 studies reported the potential for advantages of increased engagement and motivation related to the technology use (Studies 1-14, 20, 22-26 and 28-29) compared to conventional rehabilitation and 16 studies referred to the feedback provided by the technology as a potential benefit for mobility rehabilitation (Studies 1-2, 4-5, 7-8, 10-13, 15, 17-18, 26-27 and 29). Eight studies extrapolated this further to mention the potential for home or other independent use (Studies 1, 3, 5, 13, 18, 25-26 and 29) and for increased rehabilitation dosage (n=6; Studies 5, 8, 11-12, 18 and 29). Low cost was another justification mentioned in nine studies (Studies 1, 3, 5, 27, 14, 18, 19, 26-27 and 29), with researchers referring to the inexpensive nature of several commercially available technologies as well as the potential to reduce therapy costs if the technology could be used independently.

Clinical reasoning used for specific game selection for the study population or for each individual participant (if tailored) was rarely reported. Most studies reported a basic premise behind choosing exercises e.g. “These games were selected because they resemble dynamic balance exercises performed in standard exercise therapy” (Study 25) or “chosen for their potential to influence physical and functional movement, cognitive functioning, and driving” (Study 2). Two studies reported using a specific intervention protocol to guide activity selection (Studies 8 and 13), however, these protocols were not published. One study (Study 14) referred to using a previously published guide for game selection.

What

Recreational VR technologies were utilised in 25 studies (Wii=21; Studies 1-4, 6, 10-11, 13-15, 17-20, 22-25 and 27-29, Xbox=6; Studies 1, 7, 9, 21 and 25-26), while rehabilitation-specific VR technologies were involved in 5 (Biodex=2; Studies 8 and 26, IREX=2; Studies 12 and 16, Jintronix=1; Study 5).

Seventeen studies (Studies 3, 5-6, 9-12, 14-16, 18, 21-22, 25-27 and 29) incorporated conventional rehabilitation into their intervention in addition to the technology-based therapy, while in 13 studies

(Studies 1-4, 7-8, 13, 17, 19-20, 23-24 and 28) involved an intervention group receiving the technology intervention only.

Who

In the majority of studies, the therapist providing the intervention was a physiotherapist (or physical therapist) (n=15; Studies 1-3, 5, 9, 13, 17-23, 26 and 29), with one study utilising an occupational therapist (Study 11). The remaining 13 studies did not specifically state the profession or professional background of the person providing or supervising the intervention, using terms such as "therapist", "therapy assistant" or "researcher" or not stating the profession at all. Further details such as the therapists' expertise, background and specific training in the VR rehabilitation was rare, with only three studies reporting specific intervention training (Studies 13, 20 and 22) and one study reporting the clinical experience of the interventional therapist: "physiotherapist with Post-Graduate training and more than 10 years of clinical experience in the management of neurological disease" (Study 19).

How

Technology interventions were delivered as individual one to one sessions in seven studies (Studies 1, 20, 22-23, 25-26 and 28). One study (Study 24) reported using both paired and individual sessions for intervention delivery. The remaining 21 studies did not specifically report how the intervention was delivered (Studies 2-19, 21, 27 and 29).

Where

Whilst the intervention primarily occurred in outpatient rehabilitation facilities, further location information was rarely provided. One study reported the Wii intervention took place in a quiet room (Study 6) and another study described that the Wii intervention was delivered in an activity room on the inpatient unit (Study 13). Only one study provided a detailed description of the intervention space reporting it was $20m^2$ and "free from external noise" (Study 22).

When and how much

The program length, predetermined in 25 studies (Studies 1-4, 6-9, 11-12, 14-15 and 17-29), ranged from four weeks (Studies 3-4, 7, 12, 18, 23, 27 and 29) to 12 weeks (Studies 2, 8, 11 and 28) (mean 6.6 weeks). In three studies program duration was dependent on the length of admission (Studies 5, 10 and 13) and in one study duration was unclear (Study 16). Intervention session frequency ranged from two times (Studies 1, 8, 10-11, 15, 17, 19-20, 22-23, 25 and 28) to five times a week (Studies 5, 13 and 27) (mean 2.8 times a week), and in one study this was unclear (Study 16). The total number of sessions where stated (n=13; Studies 1, 4-5, 7, 15-16, 18-20, 22, 24-25 and 29) or derived from provided data (n=14; Studies 2-3, 6, 8-9, 11-12, 14, 17, 21, 23, 26-27 and 28) varied from eight (Study 23) to 36 sessions (Study 2) (mean 16.8).

The majority of studies (n=26; Studies 1-2, 4-20, 22-27 and 29) reported overall session time, without differentiating between active and rest time. One study (Study 21) reported only active time, describing the duration of each component game. In this case, these figures were summated to calculate total session duration although this does not allow for rest breaks, instructions or navigating the menu system. Across these 27 studies, the shortest session time was 15 minutes (Study 10) and the longest 60 minutes (Studies 2, 4, 17, 22, 24 and 26), with the mean of all reported session times 35.3 minutes.

Where total amount of VR rehabilitation time was reported (n=2; Studies 16 and 19) or could be reasonably inferred (n=21; Studies 1-2, 4, 6-9, 11-12, 14-15, 17-18, 20-23, 25-27 and 29), the time ranged from 200 (Study 16) to 2160 (Study 2) minutes.

Tailoring

Six studies reported individually tailoring the exercises or games prescribed for each participant (Studies 5, 11, 13-14, 20 and 26), according to individual goals or needs. Fourteen studies explicitly reported using the same games or exercises with all intervention participants (Studies 1-3, 7, 12, 17-19, 21-23, 25, 28 and 29), while one study reported the games were “randomly presented” (Study 4). The remaining eight studies did not report whether the game selection was tailored (Studies 6, 8-10, 15-16, 24 and 27).

The intensity or difficulty level of each game or exercise was the same for all participants in one study (Study 21). A total of 10 studies reported some or all aspects of intensity or difficulty were individualised (Studies 5, 7, 9, 13-14, 20, 23, 25, 26 and 28) and the remaining 18 studies did not report this aspect at all (Studies 1,-4, 8, 10-12, 15-19, 22, 24 27 and 29).

Six studies reported individual progression of game or exercise selection and intensity, tailored to individual performance (Studies 5-6, 12-13, 20 and 26). Three described some progression of activities (Studies 9, 10 and 28) over the course of the intervention and seven described some progression of intensity (Studies 7, 9, 14-15, 23, 25 and 28) during the intervention period. One study explicitly ruled out any program progression (Study 21). Fourteen studies did not report any progressions (Studies 1-4, 8, 11, 16-19, 22, 24, 27 and 29).

Modifications

None of the included studies reported modifications to the original intervention protocol over the course of the study.

How well

Three studies reported measures were in place to ensure intervention fidelity, by reviewing the compliance of the intervention therapists with the protocol (Studies 8, 12 and 13).

Most studies reported on participant adherence to the intervention, with nine studies reporting all intervention participants completed the intervention (Studies 2, 8, 10, 12, 15, 18-19, 21 and 27), and 12 studies reporting small numbers of drop outs, mostly for reasons unrelated to the interventions (Studies 7, 9, 11, 13, 16, 20, 22, 24-26, 28 and 29). One study reported actual VR rehabilitation time, with protocol planned as "10-12 sessions of 20 minutes" and actual time reported as 176.6min (+/- 27.8SD) (Study 16). Seven studies did not report on intervention fidelity or adherence at all (Studies 1, 3-4, 6, 14, 17and 21).

Table 3-4 Reported VR intervention attributes of included studies

First Author (Year)	Brief Name	WHY	WHY	WHAT	WHAT	WHAT	WHO			HOW	WHERE	WHEN and HOW MUCH		TAILORING	PROGRESSION	HOW WELL – Planned and Actual
		Rationale for VR	Rationale for specific choice of VR intervention	Specific VR intervention	Protocol guiding procedures	Procedures	expertise	background	Specific training	Mode of delivery	Room e.g., bedside	Duration	Frequency			
												Total number of sessions	Time for each session			
												Total minutes of VR therapy				
										1:1 = individual		^=stated, *derived Where intervention included a non-VR component, only VR component was included				
Alves (2018)	Wii vs Xbox for PD	Feedback in enriched	Xbox and Wii vary in human	Wii: rhythm parade,	Experienced clinicians	Familiarisation session with	Physiotherapist			1:1	University lab	5 weeks^	2/wk^	Standardised program	Not stated	Not stated

		environment, increased engagement and home use at low cost.	movement measurement and input.	obstacle course, tightrope walk, basic step Xbox: hurdles, river rush, reflex ridge, light race	chose games with “similar motor and cognitive demands” to use for all participants.	manual and verbal cues. Each session lasted 45–60 minutes. In the last attempt, the participants played without any help, except for verbal motivation.	not stated	not stated	not stated			10^ 450-600 min*	45-60 min^			
Baltaci (2013)	Wii in ACL rehab	See next column	Wii is low cost and potentially provides increased feedback and motivation, potentially improving motor rehabilitation and function.	Wii: Boxing, football, bowling, skiing	Unclear	“Each game was tried for 15 min. Each subject participated in 1-h rehabilitation sessions and accomplished 3 sessions per week.”	Physiotherapist not stated	not stated	not stated	Not stated	Not stated	12 weeks^ 36* 2160 min *	3/wk^ 60 min^	Standardised program content	Unclear	All participant completed the intervention
Bateni (2012)	Wii training for older adults with fall history	Low cost and ease of use in the home.	Wii is low cost, readily available and has been found to	Wii: ski slalom, ski jump and table tilt	Unclear	Each game was repeated three times.	Physiotherapist licensed	not stated	not stated	Not stated	Not stated	4 weeks^ 12*	3/wk^ Not stated	Not stated	Not stated	Not stated

			provide benefit in other studies.									Could not be determined				
Brichetto (2013)	Wii exercises on balance in MS	"Interactive balance exercises could improve the effects of balance disorder rehabilitation treatments in older adults."	Wii can offer visual feedback	Wii: soccer heading, slalom skiing, table tilt, snowboarding, tightrope walking and zazen	Not stated	One hour of supervised Balance Board, exercises randomly presented.	Not stated not stated	not stated	not stated	Not stated	Not stated	4 weeks* 12^ 720 min*	3/wk^ 60 min^	Not stated	Not stated	Not stated
Cannell (2018)	Motion capture rehabilitation (Jintronix) on subacute stroke	Increase dose and provide visual feedback to increase engagement with potential for greater independence.	Not stated	Jintronix	Published protocol and individualized prescription of repetitive exercises… aimed to enhance balance, function, strength, and endurance.	Up to 1 hour, dependent upon the endurance of the participant. "Assistance was available to participants during balance-challenging activities."	Physiotherapist or rehabilitation assistant monitored by physiotherapist not stated	not stated	not stated	Unclear	"Out of sight of control group participants"	LOS 8-40^ Dependent on LOS	5/wk ^ Up to 60min^	Individualised program	Program reviewed daily	Planned aspects partially reported

Cho (2012)	Wii balance training on chronic stroke	VR has been found to improve UL function in patients with stroke, is low cost and may provide motivation.	Not stated	Wii: balance bubble, ski slalom, ski jump, soccer heading, table tiling, penguin slide	Not stated	Each session was 30 min (excluding set-up and rest time). "To prevent subjects from experiencing a fall during training, a therapist stood within arm's reach of the subject."	"Therapist" not stated	not stated	not stated	Unclear	"A quiet room"	6 weeks^ 18* 540 min*	3/wk^ 30 min^	Not stated	Progressive intensity not stated by whom	Not stated
de Melo (2018)	Gait training with Xbox for PD	Feedback for motor learning and repetitive practice.	Not stated	Xbox: run the world	Based participant simulating walking or marching by lifting the knees in a stationary march to maintain HR within target range.	The participant stood two to three meters in front of the motion sensor of the Kinect Xbox.	Not stated not stated	not stated	not stated	Not stated	Not stated	4 weeks^ 12^ 240 min*	3/wk^ 20 min^	Personalised intensity - maintaining HR range, not stated by whom	Not stated	One of 13 VR intervention participants did not complete due to "personal reasons"
Eftekharsadat (2015)		VR has shown promising	Not stated		Protocol referred to	Participants performed	"Therapist"			Not stated	Not stated	12 weeks^	2/wk^	Standardised program	Not stated	All participant

	VR balance training in MS	results in other neuromuscular diseases and provides repetitive practice, feedback, and motivation for motor learning.		Biodex Balance System SD		"postural stability training", using weight transfer on a balance platform to manipulate an onscreen cursor.	not stated	not stated	not stated			24* 480 min*	20 min^			completed the intervention as planned
Ferraz (2018)	Xbox training for PD	Enriched environments increase patient engagement and motivation.	Xbox uses whole body vs handheld controller.	Xbox: river rush, reflex ridge, 20,000 leaks	"Full-body motion allows the player to engage in a variety of mini-games. Each mini-game lasts about 3 minutes."	Each 30 min session comprised different intensities of 1-2 games. The physiotherapist motivated the patients to use correct posture and promote the best exercise performance.	Physiotherapist not stated	not stated	not stated	Not stated	Not stated	8 weeks^ 24* 720 min*	3/wk^ 30 min^	Standardised program with personalised intensity	Progressive intensity - not stated who progressed	Of 22 participants randomised into the exergaming group there were 2 dropouts (hypertension and non-adherence)
Fung (2012)							Not stated					LOS	2/wk^	Unclear		

	Wii training for TKR	Games "considered to be more fun and interesting than conventional exercise" and have been researched in other conditions.	Wii provides feedback based on weight distribution, encouraging movement and balance.	Wii: deep breathing, ski slalom, tightrope walk, penguin slide, table tilt, hula hoop, balance bubble, half moon, torso twist	Games selected that encourage weight shift, balance and postural control.	"Progression to other games once they demonstrated a plateau in scoring."	not stated	not stated	not stated	Not stated	"Separate treatment area"	Depend on LOS Dependent on LOS	15 min^		"Progressed to other games once they demonstrated a plateau in scoring" - not stated who	All participants completed the intervention
Hung (2014)	Wii training for chronic stroke	Increased motivation due to fun,	Wii can provide biofeedback in	Wii: table tilt, ski slalom, soccer heading, balance	Games were chosen "based on common balance	"The therapist chose 2 to 4 games for participants each session. A	Occupational therapist qualified	not stated	not stated	Not stated	Not stated	12 weeks ^ 24*	2/wk^ 30 min^	Tailored program by therapist	Not stated	Three participants (of 30) discontinued the study

		interactive systems.	an enjoyable way.	bubble, penguin slide, basic step, warrior	problems poststroke".	walker in front of the board was used for safety if necessary."							720 min*				protocol; all were from the Wii Fit group (severe ankle inversion, hospital transfer and medical issues)
Kim (2009)	IREX in chronic stroke	Increased motivation, and motor learning due to visual feedback.	Not stated	IREX: stepping up/down, sharkbait, snowboard	Protocol referred to; exercises chosen to improve skills using motor learning principles.	Each game was practiced five times, and depending on a game, within each game, there were three levels of 88–131 opportunities to perform the exercise.	Not stated	not stated	not stated	not stated	Not stated	Not stated	4 weeks^ 16* 480 min*	4/wk^ 30 min^	Not stated	Program progressed, not clear if therapist or technology	All participants and therapists completed the intervention as planned
Laver (2012)		See next column	Wii is fun and motivating and	Wii-specific games not	Protocol mentioned but not	Participants were closely supervised and	Physiotherapist	not stated	not stat	train ed	Not stated	"An activity room on the	LOS LOS	5/wk^ 25min^	Tailored program		All participants completed

	Wii for inpatient older adults		provides feedback.	reported by name	published; Physiotherapist selected games based on individual clinical goals.	able to use a support for safety if required.						inpatient unit”	Dependent on LOS			Program progressed by therapist	the intervention as planned
Lee (2015)	Wii for stroke	Low cost, interesting and previous research has shown benefit in stroke.	Not stated	Wii: sitting posture, knee bend and the other leg knee extend, tightrope walking, penguin teeter-totter seesaw, balance skiing, rolling marble board, balance	Program selected based on participant interests and levels based on previous research.	All 7 programs performed once and then games of their choice for the remainder of the session. In this study. Participant was flanked by a table and assistant for safety and physical assistance if tone increased.	“Assistant”	not stated	not stated	not stated	Not stated	Not stated	6 weeks^ 18* 540 min*	3/wk^ 30min^	“Selected depending on the subjects’ interests and motivation”	Progressed - unclear by who	Not stated
Liao (2015)	Wii for PD	Has been used in other	Previous research	Wii: yoga exercises,	Patients can adjust their	“In each Wii Fit exercise	Not stated				Not stated	Not stated	6 weeks^	2/wk^	Not stated	Not stated except “ankle	No dropouts from

		conditions to benefit mobility and postural control.	reported benefit from Wii in PD patients.	strengthening exercises, football game, marble balance, ski slalom and balance bubble	own movements according to the feedback in real time.	session, participants underwent 10 minutes of yoga exercise, 15 minutes strengthening exercise, and 20 minutes of balance game. "	not stated	not stated	not stated			12^ 540 min*	45 min^		weights for each leg were also used, starting from 1 kg and gradually increased to 2 kg for each leg”	intervention group
McEwen (2014)	IREX VR exercises in standing for inpatient stroke rehabilitation	Has been shown to be of benefit in other conditions.	Not stated	IREX: soccer goaltending, birds and balls, juggler, conveyor, shark bait, snowboarding, formula racer	Games chosen which trained mobility, lateral weight shifting and reaching.	“Participants were instructed to step and reach as far as they could.”	"Researcher" not stated	not stated	not stated	Unclear	Not stated	3 weeks^ 10-12^ 200-240 min^	3-4/wk* 20 min^	Not stated	Not stated	3 dropouts from intervention (1 headache, 2 early discharge) also reported actual VR time
Morone (2016)	Wii for balance in women with impaired	Feedback in many forms in an enriched environment,	Wii has been found helpful to improve balance in	Wii - breathing, yoga, strength and balance	Not stated	Exercises were supervised by two expert physiotherapists. The patients	Physiotherapist expert	not stated	not stated	Not stated	Not stated	8 weeks^ 16*	2/wk^ 60 min^	Not stated	Not stated	Not stated

	balance and bone loss	potentially improving both cognitive and motor function.	other conditions.	(single leg extension and lateral leg extension in single stance, squat exercise, balance bubble, ski slalom and table tilt)		received a positive audible or visual feedback when the exercise or the game was played correctly.							960 min*				
Morone (2014)	Video game therapy for balance in stroke	Readily available and inexpensive, provides extrinsic feedback with task orientated practice in an enriched environment. Difficulty can be tailored for home and clinic use.	Not stated	Wii: hula hoop, bubble blower and ski slalom	Protocol referred to	During the intervention, three games were carried out in order to train balance, coordination, and endurance under the supervision of a physiotherapist .	Physiotherapist	not stated	not stated	not stated	Not stated	Not stated	4 weeks^ 12^ 240 min*	3/wk^ 20 min^	Not stated	Not stated	All participants and therapists completed the intervention as planned
Negrini (2017)	10 vs 15 sessions of	See next column	Wii is a low cost, portable	Wii: table tilt, ski slalom,	Patients received a	The patients were treated	Physiotherapist				Not stated	Not stated	5 weeks^	2 or 3/wk^	Standard program	Not stated	No dropouts reported

	Wii for balance in PD		balance board system that could improve balance, mobility and function in people with PD.	balance bubble, ski jump and penguin slide	multimodal treatment intervention consisting of 20 min of Wii Fit game using the balance board; 10 min with the Wii Balance game.	by a physiotherapist with Post-Graduate training and more than 10 years of clinical experience.	Post graduatetraining	>10yr experience	not stated			10 or 15^ 200 or 300 min^	20 min^			
Nilsagard (2013)	Wii for balance in MS	See next column	Improvement in balance for other conditions using Wii already reported.	Wii: penguin slide, ski slalom, perfect10, heading, table tilt, tightrope tension, balance bubble, snowboard slalom, skateboard arena, table tilt+, balance bubble+	Study protocol used with standardised progression of exercises.	Tailored intervention started with easier games and therapists encouraged progression to more difficult games. Participants could choose games that they enjoyed the most.	Physiotherapist not stated	not stated	yes	1:1	Not stated	6-7 weeks^ 12^ 360 min*	2/wk^ 30 min^	Tailored program	Program progressed. Game progression encouraged by therapist, supported by patient while technology progressed intensity/levels	One dropout from intervention group, protocol to ensure intervention fidelity

Ozgonenel (2016)	Use of game console for PD	Previous research has considered video gaming in therapy.	Not stated	Xbox: Reflex Ridge, 20,00 Leaks and River Rush	Games used for coordination and static and dynamic balance.	Patients played all three games at every training session (three games per session, two trials of each game) at Beginner level only.	Physiotherapist	not stated	not stated	not stated	Not stated	Not stated	5 weeks^ 15* Not stated	3/wk^ total time not wstated , active time 16min*	Standard program	No progressions	Not stated - no dropouts apparent
Pedreira da Fonseca (2017)	Effect of VR on gait balance and falls in stroke	Can improve balance in stroke patients and can provide "more motivation and excitement".	Not stated	Wii: tennis, hula hoop, soccer and boxing	A protocol was used. Prior to using the technology participants stretched for 15 minutes. The games were used for weight shift, trunk and hip movement and balance reactions.	The exercises were performed under the direct and personal supervision of a previously trained physiotherapist .	Physiotherapist	not stated	not stated	previously trained	1:1	$20m^2$ quiet room	10 weeks* 20^ 900 min*	2/wk^ 45 min^	Standard program	Not stated	1 intervention al dropout, reason not reported

Robinson (2015)	Exergaming for MS	Benefit for other conditions in balance, gait and function, with increased enjoyment and immersion.	Not stated	Wii: soccer heading, ski slalom, table tilt, tightrope walk, rhythm boxing, basic step, hula hoop, torso twist and rowing squats	Bespoke exercise programs were developed for the study based on using games found to emulate conventional balance exercises.	All exercise sessions were completed on a one-to-one basis and under the supervision of the primary researcher.	Physiotherapist	not stated	UK qualified	not stated	1:1	Not stated	4 weeks^ 8* 320-480 min*	2/wk^ 40-60 min^	Not stated	Intensity advanced "upon request"	No drop outs reported
Silva (2017)	Exergaming for adults with DS	Exergames allow participants to perform aerobic exercise and	Wii games require physical activity.	Wii: free run, heading, table tilt, snowboard slalom, tightrope	"balance and isometric strength exercises" and sessions	Participants completed three 1-h sessions per week, half individually and	Not stated	not stated	not stated	not stated	1:1 and paired sessions	Not stated	2 months ^ "up to 22"^	3/wk^ 60min^	Not stated	Not stated	Out of 14 VR participants two dropped out (1 withdrew and 1 moved

		generally offer increased enjoyment which may in turn increase engagement and adherence.		tension, hula hoop, balance bubble, penguin slide, boxing, swordplay, cycling, table tennis, Just Dance 2	for "aerobic endurance".	half with another participant.							Unable to be determined				to another city)
Singh (2013)	VR games for physical function outcomes in stroke	Previous research indicates benefit Motivating and may encourage self-management.	Not stated	Wii: balance bubble; Xbox: rally ball	"These games were selected because they resemble dynamic balance exercises performed in standard exercise therapy."	A familiarisation session prior to therapy commencement. A therapy assistant individually supervised the participants.	Therapy assistant	not stated	not stated	not stated	1:1	Not stated	6 weeks^ 12^ 360 min*	2/wk^ 30min^	Standardised program	Progressive intensity - technology	Out of 22 VR participants, seven dropped out
Straudi (2017)	Video game therapy for balance and	Low cost technology provides motivating,	Xbox is low cost and "feedback results are	Xbox –games selected that encompass a wide range of	Balance and mobility-related motor	First session tested a range of games, then chosen specific	Physiotherapist	not stated	not stated	not stated	1:1	Not stated	6 weeks^ 18*	3/wk^ 60min^	Tailored program	Tailored progression – unclear if	Out of 21 participants, one dropped out for

	attention in TBI	repetitive, task orientated therapy. Key factors are patient engagement and VR feedback.	more accurate and realistic compared with other devices with external controllers” and can be used at home.	motor activities in a standing position	tasks were trained.	to each patient. Each game was 2–5 min followed by rest if necessary. Physiotherapists supervised for safety and to provide external feedback.							1080 min*			therapist or technology	personal reasons
Utkan Karasu (2018)	Wii for static and dynamic balance in stroke patients	VR may “improve upper limb function, gait and balance, global motor function and cognitive function in stroke patients”.	Wii may “improve balance, strength, flexibility and fitness”, provides positive feedback and is low cost.	Wii: heading, ski slalom, table tilt, tightrope tension, balance bubble, penguin slide	Not stated	Not stated	Not stated	not stated	not stated	not stated	Not stated	Not stated	4 weeks^ 20* 400 min*	5/wk^ 20min^	Not stated	Not stated	All participants completed the intervention as planned
Williams (2010)	Wii for older fallers	See next column	Wii is “designed to improve balance and fitness, whilst	Wii: jogging, table tilt, step basics, ski slalom, ski jump, soccer	Standard program with specified repetitions in appendix;	A walking frame was placed in front of the balance board, if the	"Member of the research team”	not stated	not stated	not stated	1:1	Not stated	12 weeks^ 24*	2/wk^ Not stated	Standardised program except some options of increasing	Modified at weeks 4 and 8 according to set program	Of 15 participants initially in the intervention

			providing entertainment ”.	heading, hula hoop, breathing	balance and aerobic exercises.	participant deemed this necessary.							Unable to be determined		levels in later stages		group 13 completed the study (2 drop outs - due to knee pain and death of spouse)
Yatar (2015)	Wii for balance in chronic stroke	Potential for “enriched environment, task-specific goals, and repetitive practice”, potentially reducing 1:1 physiotherapy and allowing use at home.	Wii provides feedback, improving motor skills and postural control and is “interactive, motivating, useful and cheap”.	Wii: soccer heading, ski slalom, balance bubble	Exercises chosen to focus on “weight shift, quick motor responses, and improvement of postural control, attention and coordination by visual-auditory feedback”.	A user profile and Mii was created for each subject. The subjects played each game 3 times and had a 5 minute break in between games.	Physiotherapist	not stated	not stated	not stated	Not stated	Not stated	4 weeks^ 12^ 360 min*	3/wk^ 30min^	Standardised program	Not stated	Of 17 participants allocated to the intervention group, 2 were “drop-outs” due to “personal reasons”

Technologies: Biodex (Biodex Balance System, Biodex, New York, USA), IREX (*GestureTek*, Toronto, Canada), Jintronix (*Jintronix*, Seattle, USA), Wii (Nintendo Wii, *Nintendo*, Kyoto, Japan), Xbox (Xbox Kinect, *Microsoft*, Washington, USA)

Abbreviations: ACL (Anterior Cruciate Ligament), Down Syndrome (DS), HR (Heart Rate), LOS (Length of Stay), Multiple Sclerosis (MS), PD (Parkinson’s Disease), TKR (Total Knee Replacement), Traumatic Brain Injury (TBI), Virtual Reality (VR)

3.3.4 Therapist role in intervention

The therapist's role within the VR intervention planning and delivery was not explicitly stated in seven (Studies 2, 7, 10, 12, 15, 24 and 27) of the 29 studies, although descriptions were sometimes ambiguous where elements such as program progression and feedback were mentioned without specifying if provided by therapist or technology.

In the 22 papers that explicitly mentioned the role of the therapist, a variety of duties were described. The most commonly reported role (n=12; Studies 3-5, 9, 13, 17-18, 22-23, 25-26 and 28) was "supervision" and often this was not further elaborated upon. Safety was referred to in eight studies (Studies 1, 5-6, 14, 16, 19, 21 and 26), with concerns around falls most frequently mentioned. The therapist had a reported role in program selection and tailoring in five studies (Studies 5, 11, 13-14 and 20). Provision of external feedback by the therapist was mentioned in four (Studies 1, 9, 11 and 26) of the 29 studies, with some specified as manual guidance, and some verbal feedback. Other less frequently reported roles were providing training or education to participants (Studies 1, 19 and 21), motivating the intervention participants (Studies 1, 6 and 9) and recording the intervention (Studies 13 and 20).Table 3-5 provides quotes to illustrate each theme.

Table 3-5 Therapist role themes

Theme	Number of studies in which mentioned, n (%)	Studies	Quotes
Not explicitly stated	7 (24%)	Studies 2, 7, 10, 12, 15, 24, 27	N/A
Supervision	12 (41%)	Studies 3, 4, 5, 9, 13, 17, 18, 22, 23, 25, 26, 28	"During this study, participants performed three Wii Fit balance games under the supervision of a licensed physical therapist…" (Study 3) "Wii-group exercises consisted of one hour of supervised Nintendo® Wii® Balance Board® sessions, utilizing the standard software provided by Nintendo® Wii Fit,®…" (Study 4) "Exercises were supervised by two expert physiotherapists." (Study 17) "…under the supervision of a physiotherapist…" (Study 18) "The exercises were performed under the direct and personal supervision of a previously trained physiotherapist." (Study 22) "All exercise sessions were completed on a one-to-one basis and under the supervision of the primary researcher (JR, a UK-qualified physiotherapist)." (Study 23) "A therapy assistant supervised the participants performing the VR games on a one-to-one basis." (Study 25) "During the sessions, the patients were carefully supervised by a physiotherapist who monitored the safety of the patients (e.g., risk of falls, impulsive reactions) and provided external feedback." (Study 26) "The intervention group attended individual exercise visits supervised by a member of the research team" (Study 28)
Safety	8 (28%)	Studies 1, 5, 6, 14, 16, 19, 21, 26	"For clinical safety, we monitored participants' heart rates and blood pressure in all training sessions." (Study 1) ".. with spotting or supervision as required to ensure safety." (Study 5) "To prevent subjects from experiencing a fall during training, a therapist stood within arm's reach of the subject." (Study 6) "an assistant waited next to the

			affected side for the subject’s safety” “Participants stood in front of a green screen with a physio belt around their waist while being monitored by a researcher (behind the participant).” (from photo caption) (Study 16) “The physiotherapist attended to the treatment for safety purposes…” (Study 19) “Physiotherapists… observed patients during games for safety” (Study 21) “During the sessions, the patients were carefully supervised by a physiotherapist who monitored the safety of the patients (Study e.g., risk of falls, impulsive reactions) and provided external feedback.” (Study 26)
Program selection or review	5 (17%)	Studies 5, 11, 13, 14, 20	“Functional and repetitive exercise programs for all study participants were reviewed daily in order to optimize rehabilitation potential. “ (Study 5)” Participants in the Nintendo Wii Fit group participated in Wii Fit activities selected by the treating physiotherapist to match the patient’s individual abilities and treatment needs …” (Study 13)“The PTs were in charge of the remote control in order to maximise intensity” (Study 20)
Extrinsic Feedback	4 (14%)	Studies 1, 9, 11, 26	“During these first attempts, the physical therapist gave manual and verbal cues to the patient to promote a correct posture and perform movements required to interact with the game and achieve its goals.” (Study 1) “All treatments were carried out under the supervision of a physiotherapist who motivated the patients to use correct posture and promote the best exercise performance.” (Study 9) “During the sessions, the patients were carefully supervised by a physiotherapist who monitored the safety of the patients (e.g., risk of falls, impulsive reactions) and provided external feedback.” (Study 26)
Education and training	3 (10%)	Studies 1, 19, 21	“Before the start of the first virtual training session, the physical therapist explained the objectives and allowed each participant a trial attempt per game to familiarize themselves with the tasks and equipment.” (Study 1) “…aim to educate the patients in the use of Wii-Fit…” (Study 19) “Physiotherapists provided instructions to the patients on games…” (Study 21)

Motivation	3 (10%)	Studies 1, 6, 9	"In the last attempt, the participants played without any help, except for verbal motivation." (Study 1) "Subjects were encouraged to increase the challenge level and to try to improve their performance of each activity during the intervention period. " (Study 6) "All treatments were carried out under the supervision of a physiotherapist who motivated the patients to use correct posture and promote the best exercise performance." (Study 9)
Record keeping	2 (7%)	Studies 13, 20	"Physiotherapists providing the intervention kept records of treatment sessions, including the number of sessions completed, adherence, activities prescribed, participant reports of discomfort and adverse events." (Study 13) "The PTs… registered the games played, time (in minutes) needed to rest during sessions and made notes of the spontaneous comments regarding the progression." (Study 20)
Other	3 (10%)	Studies 8, 14, 29	Therapist followed "training protocol" (Study 8); "physical assistance" "If abnormal myotonus was noted in the affected limbs due to compensatory movements, the assistant lowered it with assistance before the initiation of the training." (Study 14) Physical assistance noted in photograph of intervention although not mentioned in description of intervention (Study 29)

3.4 Discussion

This systematic review has analysed how VR technology has been delivered in intervention studies addressing rehabilitation for mobility limitations, and what the reported role of the therapist entailed. Intervention protocols were heterogenous and generally lacked clinical reasoning for specific technology and activity selection, limiting the capacity to replicate the intervention in a clinical setting. The role of the therapist was also poorly defined. Whether limited intervention detail is due to incomplete reporting or shortcomings within intervention protocols is unknown.

None of the 29 studies included in this systematic review explicitly reported full details of all TIDieR components. Only 55% of the studies reported the profession of the person delivering the intervention. This is very similar to the results of Yamato et al. (2016) who assessed the completeness of physiotherapy intervention descriptions in 200 RCTs. The authors found that only 54% of the included RCTs reported who provided the intervention, indicating that lack of therapist detail in intervention reporting is not unique to VR rehabilitation studies. Delivery mode was another poorly reported TIDieR component in our review. Of the eight studies that reported delivery mode, seven described the intervention as one to one with the therapist, contradictory to the presented rationale that VR provides additional feedback and increased motivation, reducing the need for therapist involvement. It is surprising that none of the studies delivered VR rehabilitation in group format given that that it has been found a feasible way to increase exercise dose and facilitate task-specific improvements (van den Berg et al., 2016). Intervention dosage details related to frequency (97%) and duration (93%) were frequently reported; however, intensity and number of repetitions were seldom described. Most studies reported overall session duration time rather than active time. Previous studies have reported that active patient participation time in VR rehabilitation is reduced due to additional non-practice burdens such as technology set-up (Annema et al., 2012; Levac & Miller, 2013; Markus et al., 2009). Future VR intervention studies should report repetitions or active time, rather than overall session duration, to present a more accurate measure of intervention dose.

The issue of incomplete intervention reporting has been previously described in physiotherapy (Yamato et al., 2016) and other non-pharmacological studies (Hoffmann et al., 2013). In VR rehabilitation, incompleteness of intervention descriptions limits the ability to attribute outcomes to the use of VR technologies alone, and may hinder clinicians attempting to implement interventions in clinical practice. The review findings revealed that the level and type of therapist input in the intervention design and delivery lacked clear description despite evidence that therapist engagement in VR interventions may positively affect mobility outcomes (Brutsch et al., 2010; Pimentel Piemonte et al., 2017).

Detail of the therapist role was mentioned in 22 of the 29 studies, and these were grouped into seven themes. Supervision and safety, particularly falls prevention, were most frequently reported; however, details of what, or how much, input the therapist provided generally lacked description. The high prevalence of supervision and safety measures in VR-based rehabilitation intervention protocols has been previously noted (Skjæret et al., 2016), despite the lack of adverse events reported in VR-based rehabilitation studies (Canning et al., 2020; Laver et al., 2017; Zheng et al., 2020). Activities related to more complex therapist roles, such as clinical reasoning, program selection and modification, provision of feedback, and education and training, were rarely described.

In both conventional (Hubbard et al., 2009), and VR-based rehabilitation functional improvements are specific to the training task (Straudi et al., 2017; van den Berg et al., 2016), yet, in the included studies, the clinical rationale for the technology chosen and its relation to therapy goals and primary outcome measure was seldom reported. As an example, 10 studies using the Wii Balance Board platform used the TUG (Cho et al., 2012; Hung et al., 2014; Laver et al., 2012; Yatar & Yildirim, 2015) or gait parameters (Fung et al., 2012; Liao et al., 2015; Nilsagard et al., 2013; Pedreira da Fonseca et al., 2017; Robinson et al., 2015; Silva et al., 2017; Utkan Karasu et al., 2018; Yatar & Yildirim, 2015) as primary outcome measures, despite the Wii platform being primarily a stationary balance device. As rehabilitation technologies rapidly evolve, the understanding of why a particular technology was chosen for a specific population or individual may support and inform the direction of future developing technologies. Having available comprehensive descriptions of the intervention technology and the reasons for its use will allow findings to be extrapolated long after the technology is superseded.

Similarly, reasoning for specific exercise or game selection and tailoring of the program for individual patient needs were rarely reported. Of the five studies that reported therapist involvement in program selection and program review (Cannell et al., 2018; Hung et al., 2014; Laver et al., 2012; Lee et al., 2015; Nilsagard et al., 2013), all therapists were physiotherapists and occupational therapists, indicating the professional skill set required. In two studies (Nilsagard et al., 2013; Singh et al., 2013), intervention programs were reported as progressed automatically based on game achievements rather than on clinical judgment. It is possible that within the research protocols individual tailoring was restricted in an attempt to standardise interventions. However, providing autonomy for clinical judgment within the research protocol would accommodate appropriate clinical reasoning. All but three of the included studies based the intervention on the use of a single technology, possibly to simplify the study methodology. Recent studies have successfully incorporated the use of multiple technologies to provide scope for a more tailored approach resulting in improved outcomes such as task-specific balance (Hassett et al., 2016; van den Berg et al., 2016). Having access to a range of technologies may facilitate program tailoring, allowing the treating clinician to consider patient impairments, therapy goals, and personal preferences.

Only four (Alves et al., 2018; Ferraz et al., 2018; Hung et al., 2014; Straudi et al., 2017) of the studies included in this review explicitly mentioned therapist feedback in the description of the intervention procedures. Two studies (Hung et al., 2014; Yatar & Yildirim, 2015) discussed the importance of therapist guidance to ensure optimal movement patterns, stating that relying on the use of technology feedback solely is insufficient. In rehabilitation, extrinsic feedback is particularly important, as intrinsic motor learning abilities may be impaired in many individuals (Carr et al., 2011). VR technologies provide opportunity for practice in an enriched environment, which through the provision of additional extrinsic feedback may facilitate motor learning (Levac et al., 2016a). To date, the optimum use of interventions using technology feedback, therapist feedback, or a combination of both and their effect on motor learning has not been investigated. Recreational systems have been suggested to require more therapist input to optimize movement patterns (Fritz et al., 2013) as well as supplementary therapist feedback to negate the primarily negative feedback provided by the technology (Levac, Miller, et al., 2012). Future studies should consider this aspect carefully to inform the optimal involvement of therapists in VR rehabilitation.

Strengths of this systematic review include an extensive systematic search and comprehensive data extraction using the TIDieR checklist (Hoffmann et al., 2014). This study also has some limitations. Only studies published in English with more than 10 intervention participants using commercially available technologies were included. Studies investigating prototype technologies and those conducted in the home setting were excluded, therefore the results should not be extrapolated to these circumstances.

This review has established that the reporting of VR interventions generally lacks detail, hindering the translation of the research into clinical practice. Whether this lack of detail is due to underreporting or incomplete intervention protocols remains unknown. The therapist role in the provision of the VR intervention was poorly reported but, where stated, indicated the role was mainly undertaken by physiotherapists and concerned supervision and safety. Few studies reported more complex clinical skills such as tailoring of the intervention and provision of additional feedback by the therapist. Future studies utilising VR should explicitly report all intervention details and specifically include the therapist role in the design and delivery of the intervention informing best clinical practice.

CHAPTER 4: CONCURRENT VALIDITY OF AN AFFORDABLE WEARABLE SENSOR 3D MOTION CAPTURE SYSTEM FOR GAIT ANALYSIS

Preface:

The systematic review in Chapter 3 assessed how VR rehabilitation interventions have been reported in the literature and the therapist role in the design and delivery of the intervention. The next chapters aimed to explore how VR rehabilitation affects patient movement and therapist practice.

The purpose of Chapter 4 was the first step in establishing the feasibility of the use of a wearable sensor system to capture patient movement in VR intervention studies.

Specifically, this study sought to determine concurrent validity of a low cost commercial sensor motion capture system, the Notch. Two studies within the systematic review suggested that therapist feedback is required in order to address undesired patient movement patterns in VR rehabilitation. In order to investigate patient movement patterns during VR rehabilitation, and to allow for subsequent exploration of the relationship between patient movement and therapist feedback, a low cost, easy to use system was required to accurately capture complex patient movement in situ, without the need of a motion analysis laboratory.

This chapter specifically addressed the second research objective, to investigate the validity of a wearable sensor-based motion capture system to identify movement patterns in therapeutic rehabilitation settings. Initial results of this chapter were presented in a poster format at Flinders DOCFEST (Appendix D). This chapter was prepared for submission to the International Journal of Industrial Ergonomics. (Appendix E). The version within this thesis includes more focus on the clinical aspects that was not provided in the manuscript version submitted for publication.

4.1 Introduction

Motion capture refers to the objective recording, measurement and analysis of human movement and is widely used in various fields including rehabilitation and sport to provide detailed information on joint kinematics and kinetics. It can also be an important part of quantifying outcomes in clinical research. Assessment of movement quality is inherent to physiotherapy practice (Skjaerven et al., 2008). Objective motion capture and analysis can direct clinical decision making (Ferrarin et al., 2015) and inform physiotherapists when patients are using compensatory movements strategies (Kwakkel et al., 2008). Motion capture has particular application in gait analysis as observational gait analysis has been shown to lack reliability (Kawamura et al., 2007; Williams et al., 2009).

The current 'gold standard' of motion capture, three dimensional (3D) optical systems such as the Vicon Motion Capture System, requires expensive and laboratory-based optical 3D cameras and markers and yields highly accurate results (Dorociak & Cuddeford, 1995; Windolf et al., 2008). However, a laboratory setting may not be representative of a clinical setting, which may in turn influence the performance of the movement captured (Foucher et al., 2010). Additionally, when using these types of optical systems, the motion capture is limited to the area of camera view and by marker occlusion.

As an alternative to 3D optical systems for kinematic motion capture, video recording in 2D is relatively inexpensive and portable, allowing in situ measurement. However accurate data capture is limited to the video field of view, the movement plane perpendicular to the camera, and can be affected by parallax errors (Paul et al., 2016; Reinking et al., 2018; Schurr et al., 2017). In addition, manual data processing post-capture can be time and labour intensive. Markerless 3D video systems, such as the Microsoft Kinect, are another relatively low cost motion capture option, using an optical camera combined with depth sensing technology, but when used as a single camera as designed they currently lack accuracy for collecting kinematic data for research and clinical purposes (Muller et al., 2017; Pfister et al., 2014), and are also limited by field of view of the camera.

Wearable sensors are small, lightweight instruments capable of in situ measurement of joint kinematics and can capture data in a range of contextual environments (O'Reilly et al., 2018), including clinical settings. Each sensor within a wearable sensor system sends the data obtained to a computer via wired or wireless means to calculate the relevant motion capture variables. Motion capture within a rehabilitation setting allows for assessment of patient movement whist receiving therapy within the clinical environment, without requiring patient travel to a laboratory. Data can be processed via associated software or custom written algorithms. Validity of these systems has been shown to vary depending on the complexity and speed of the movement, the plane being studied, and the type of sensor used (Poitras et al., 2019).

Notch is a recently developed wearable sensor system, which uses up to 18 accelerometer and magnetometer-based sensors to provide a portable and user-friendly 3D motion capture in any environment. The Notch system is comparatively low cost (<$1000) to other sensor systems and offers a "plug and play" system with proprietary software available in both Apple and Android based App Stores. Wireless sensors are calibrated and operated via the Notch Pioneer mobile app employed on a smartphone or tablet, with real time processing and avatar visualisation of the motion (wearnotch.com). Further specialist skills in computer programming are not required. Whilst this system has been used in observational workplace ergonomic analysis research (Lenzi et al., 2019a, 2019b), and has been proposed to be used with Kinect cameras for upper limb workplace observation (Tarabini et al., 2018), the accuracy of the Notch system has not been independently evaluated. The aim of this study was to evaluate the concurrent validity of the Notch system against the Vicon system during gait in healthy adults, as a first step towards exploration of the suitability of the Notch to objectively record more complex patient movement in a clinical setting.

4.2 Methods

4.2.1 Study design

This study utilised a cross-sectional observational design to evaluate the concurrent validity of lower limb kinematics reported by the Notch system (Figure 4-1) against the gold standard Vicon system.

Notch sensor system

The Notch system comprises of small, lightweight and wireless sensors, which network together to record movement. Each sensor contains an accelerometer, gyroscope and a compass, and uses a Bluetooth connection to transfer data to the Notch app hosted on a smartphone or tablet.

To conduct a motion capture recording, sensors are first paired with the Notch Pioneer app and calibrated (see Figure 4-3 for full details). Following this, a sensor is attached to each body segment for which motion capture is required. The Notch system is orientated to anatomical position before recording is commenced. After recording is complete, the Notch app analyses the sensor output and provides the captured movement in an avatar representation on screen. Kinematic data can also be exported in Excel format.

Figure 4-1 Notch sensor system

4.2.2 Setting and participants

Participants were healthy adults recruited from students and staff at Flinders University, and were eligible to participate if they were over the age of 18 with no self-reported mobility impairment. Each participant attended a single session at a rehabilitation and motion analysis laboratory. Ethical approval was obtained prior to the study commencing (Appendix F) and all participants provided written informed consent (Appendix G).

4.2.3 Study procedures

A Vicon Bonita B10 ten camera system (Vicon Motion Systems, Oxford, UK) and a 13 sensor Notch system with firmware version 105 (Notch Interfaces Inc, New York, US) were individually calibrated in the motion analysis laboratory immediately prior to testing. The Vicon reflective markers were applied to the skin or tight-fitting clothing using double sided adhesive tape in a modified Helen Hayes full body marker set arrangement (Davis et al., 1991) with medial knee markers to further define the knee axis with a virtual Knee Alignment Device (Leboeuf et al., 2019).

The 13 Notch sensors were placed in a full body configuration. Upper and lower arm and leg midsegment sensors were attached directly to the skin using doubled sided tape, while head and torso sensors were attached to soft elastic straps wrapped around the segments (se Figure 4-2).

Figure 4-2 Participant with triangular Notch sensors and round reflective Vicon markers in situ

Markers and sensors were placed by an experienced research physiotherapist and further calibration procedures performed according to manufacturer instructions for both systems.

Participants performed a sit-stand-sit movement to allow synchronisation of the two systems before walking at a self-selected speed through the capture area until up to six clean walking trials were captured, three for each leg. Gait was chosen for analysis as it is cyclical and predictable in nature, with low variation between cycles and easily comparable to previously published motion analysis data (Picerno et al., 2008). Additionally, improvement in gait is one of the key goals in mobility rehabilitation (VanSwearingen et al., 2011).

A short video, available at this link: https://youtu.be/-F-rgE-liPk, provides footage of data collection, demonstrating how both motion capture systems simultaneously recorded the walking trials.

For both systems, calibration and quality assurance procedures were carried out in accordance with manufacturer instructions (Figure 4-3).

Calibration and quality assurance procedures

The Notch sensors were hard reset weekly during the testing period. To do this, sensors were taken into the centre of a football oval measuring approximately 190 metres by 180 metres. A level surface was constructed using a spirit level and the only electronic device within the vicinity was the tablet computer controlling the sensors. The Notch application on the tablet computer was used to reset the sensors according to manufacturer instructions.

On each occasion before the motion capture laboratory was used the Vicon optical system was dynamically calibrated using the Vicon Active Wand according to manufacturer instructions.

The Notch sensor system was calibrated within the motion capture laboratory prior to each participant visit to accommodate environmental factors as recommended by the manufacturers. This involved pairing the Notch sensors with the app via Bluetooth, then loading the sensors in the supplied dock. The dock was then rotated though space following the onscreen app instructions and ensuring a "calibration successful" message was provided.

Once the participant had the markers and sensors applied as detailed in the main text, further procedures were undertaken in order to increase the likelihood of accurate data collection.

The Vicon optical marker system was inspected for quality in with the participant in T-pose to ensure clear recording for each marker. Any marker not being recorded by the system (e.g. a dirty marker) was replaced to ensure quality.

The Notch sensor system was initiated to the person by asking them to stand in anatomical position while the motion capture recording was commenced from the app. During this time, participants were inspected to ensure joints were correctly aligned and then asked to stand perfectly still while the app started.

Figure 4-3 Calibration and quality assurance procedures

4.2.4 Data processing and analysis

Data was processed with each systems' proprietary software including Vicon "Plug-in Gait full body AI" model (Vicon Motion Systems, Oxford, UK) and the standard Notch skeleton android application (Version 1.9.33). Sagittal plane hip, knee, and ankle joint angles were exported from each system for analysis using Excel.

Each data set was normalised to 100% of the gait cycle (GC). A single GC was defined as from the time when the heel makes initial contact with the ground to the time when the same heel next contacts the ground. Maximal sagittal (flexion/extension) angles of the hip, knee, and ankle during clinically relevant phases of the GC (McLoughlin et al., 2016) were extracted and analysed; hip flexion (0-20% GC), hip extension (40-60% GC), knee extension (0-10%GC), knee flexion (60-80% GC), ankle dorsiflexion (0-10% GC and 40-60% GC) and ankle plantarflexion (50-70% GC) (see Figure 4-4). Sagittal plane angles were chosen as the plane with highest reliability (McGinley et al., 2009).

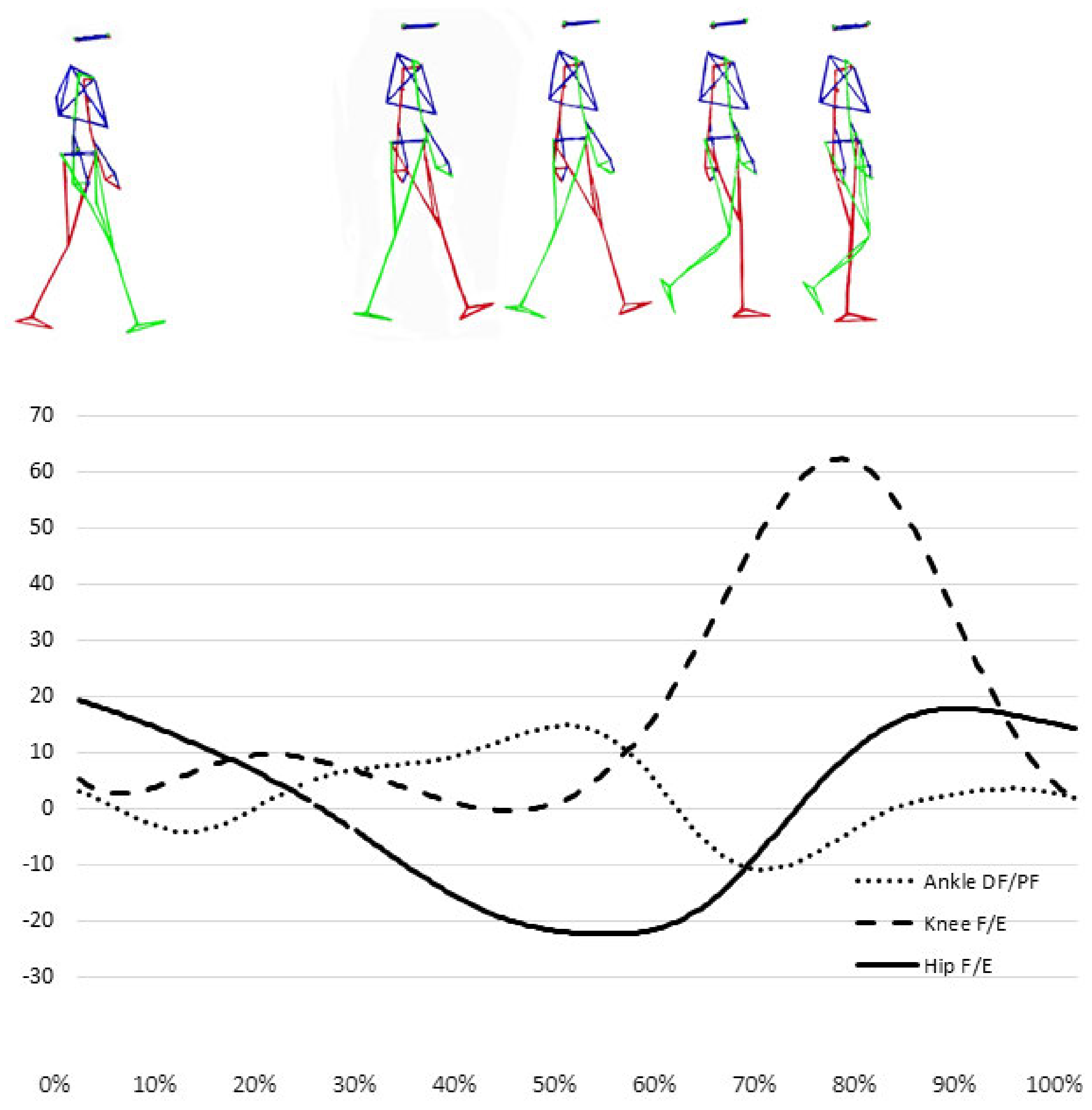

Figure 4-4 Sagittal plane hip, knee and ankle angles normalised to 100% of the gait cycle

4.2.5 Statistical methods

Statistical analysis was conducted using SPSS v25 (IBM, Chicago, US). Descriptive statistics were calculated for participant demographic data.

Data points were visually inspected and outliers were excluded from analysis by removing values more than 1.5 interquartile rankings (IQRs) below the first quartile or above the third quartile (Tukey, 1977). Data identified as potentially anatomically incorrect but within 1.5 IQRs of the inter quartile range were included in the analysis in order to evaluate the true accuracy of the device. Data was then assessed to confirm normal distribution before descriptive statistics and the coefficient of variance (CV; CV=standard deviation/mean*100) were calculated on each kinematic variable.

To determine the validity of the Notch system, the agreement and consistency of the Notch system with the Vicon system was assessed. The Pearson's Correlation Coefficient [r] was calculated to explore the relationships between each of the kinematic measurements taken by the two systems. Intraclass Correlation Coefficient (ICC) estimates were then calculated with a single rating, 2-way mixed-effects model for both absolute-agreement and consistency. For Pearson's correlations alpha was set to 0.05, and ICC was considered excellent for values greater than 0.90, good for 0.75–0.90, moderate for 0.5-0.75 or poor for 0.50 or lower (Koo & Li, 2016).

4.3 Results

4.3.1 Participants

Fifteen individuals (9 female), mean age 32.8 (SD 10.4), mean BMI 25.2 kg/m^2 (SD 4.26) with no self-reported mobility impairments were recruited into the study. From each participant three gait cycles from each leg were recorded, resulting in a total of 90 gait cycles. The Notch software failed to produce full data sets for eight gait cycles from three participants therefore 82 gait cycles were included for correlation analysis.

4.3.2 Kinematics

The results for each kinematic variable are summarised in Table 4-1. A total of 574 data points, (seven kinematic variables in 82 gait cycles) were analysed for each motion capture system. Thirty-five statistical outliers were removed, 22 from the Notch data and 13 from the Vicon data. The average peak sagittal joint angles reported by the Notch system were consistently within four degrees of the Vicon system but the CV was higher for the Notch.

Table 4-1 Summary of kinematic variables for both systems

	Notch sensor motion capture			Vicon optical motion capture		
	n	Mean (SD) In degrees	Coefficient of variance (CV)	n	Mean (SD) In degrees	Coefficient of variance (CV)
Maximum hip flexion (0-20%GC)	77	27.7 (7.5)	26.9	90	30.2 (7.9)	26.0
Maximum hip extension (40-60%GC)	81	-13.4 (6.5)	-48.1	90	-14.2 (6.8)	-48.0
Maximum knee extension (0-10%GC)	80	11.1 (7.2)	64.9	85	7.3 (3.9)	53.8
Maximum knee flexion (60-80% GC)	81	66.2 (9.4)	14.2	86	59.0 (5.3)	9.0
Maximum ankle dorsiflexion* (0-10% GC)	77	1.9 (7.6)	395.1	90	-1.1 (2.9)	-261.8
Maximum ankle dorsiflexion* (40-60% GC)	75	-11.4 (8.0)	-70.6	89	-14.3 (2.7)	-18.7
Maximum ankle plantarflexion* (50-70% GC)	81	11.0 (17.1)	155.2	88	13.1 (5.8)	43.9

* At the ankle a negative value indicates dorsiflexion and a positive value indicates plantarflexion.

4.3.3 Correlation between the Notch system and Vicon system

Pearson's correlation analysis showed that joint angles measured with the Notch and Vicon systems (Table 4-2) were significant and moderately correlated for maximum hip flexion (0-20% GC) (r=0.549), whereas maximum hip extension (40-60% GC), knee flexion (60-80% GC), ankle dorsiflexion (0-10% GC) and ankle dorsiflexion (40-60% GC) were all significant but weakly correlated (r<0.5). Both absolute and consistency ICC were moderate (ICC 0.5-0.75) for maximum hip flexion (0-20% GC) and poor (ICC<0.50) for hip extension (40-60% GC). No other significant relationships were observed.

Table 4-2 Correlation between the Notch system and Vicon system

	Pearson's correlation (r)	ICC absolute (95% CI)	ICC consistency (95% CI)
Maximum hip flexion (0-20% GC)	0.549**	0.539 (0.361-0.680)**	0.549 (0.371-0.687)**
Maximum hip extension (40-60% GC)	0.490**	0.489 (0.305-0.638)**	0.489 (0.304-0.638)**
Maximum knee extension (0-10% GC)	0.096	0.064 (-0.117-0.254)	0.078 (-0.149-0.297)
Maximum knee flexion (60-80% GC)	0.336**	0.179 (-0.050-0.395)	0.281 (0.062-0.474)
Maximum ankle dorsiflexion (0-10% GC)	0.422**	0.257 (0.047-0.448)	0.285 (0.066-0.477)
Maximum ankle dorsiflexion (40-60% GC)	0.275*	0.137 (-0.069-0.339)	0.151 (-0.077-0.364)
Maximum ankle plantarflexion (50-70% GC)	0.081	0.047 (-0.173-0.264)	0.047 (-0.174-0.265)

*Correlation is significant at the 0.05 level (2-tailed) ** Correlation is significant at the 0.01 level (2-tailed).

4.4 Discussion

This study investigated the concurrent validity of a low cost wearable motion capture system by simultaneously recording gait kinematics of healthy adults with the Notch and Vicon systems. Peak sagittal plane lower limb joint angles were compared during seven key phases of the gait cycle. The study findings showed that although the mean peak angles reported by the Notch were similar to the Vicon system, the weak correlation between the two systems in all but maximum hip flexion (0-20% GC) indicates the overall accuracy of the Notch is poor. Both absolute agreement and consistency ICC results were moderate or poor, implying this is not a systematic error. The results suggest that at present the validity of the Notch system does not provide a viable option for accurate quantitative motion capture of gait in healthy adults.

The Notch system does not appear as accurate as more costly sensor systems. Previous similar studies have reported moderate to excellent validity of several other wearable sensor systems, such as Xsens (Al-Amri et al., 2018; Cloete & Scheffer, 2008; Ferrari et al., 2010; Palermo et al., 2014; Seel et al., 2014), Physilog

(Rouhani et al., 2012) and Rehagait (Nuesch et al., 2017) in sagittal plane lower limb kinematics during gait. However, these systems are all substantially more expensive than the Notch system or are gait specific, limiting their clinical application. The difference in reported accuracy levels between the Notch and other systems may be attributable to variations in both hardware designs and software processing utilised, as well as the methodology employed in the reporting studies.

The biomechanical model used to calculate the kinematics of body movement can influence the accuracy of the measured joint angles (Ferrari et al., 2010; Robert-Lachaine et al., 2017). The Vicon system was used as the gold standard, however, although validated, the Vicon Plug in Gait model has some limitations (Schwartz & Dixon, 2018). The biomechanical model used by the Notch system is proprietary to the company making it difficult to compare the output of both systems without first extracting the raw data. Differences in measurements provided by the two systems in our study could be due to the software filtering and algorithms used to construct the joint angles. The present study utilised only the proprietary application provided by Notch to process the raw data. Motion capture validity results reported in the literature often utilise custom processing scripts written for the purpose of each project, rather than the commercial software supplied by the manufacturers (Petraglia et al., 2019). Previous studies have shown that optimising the filtering parameters can reduce joint angle errors (Saito & Watanabe, 2011), correct for soft tissue artefacts (Iosa et al., 2016) and increase accuracy (Takeda et al., 2009). Applying a custom processing script to the raw data obtained from the Notch sensors may have improved the correlations between the two systems, however using the proprietary app is reflective of how this system would be used in clinical practice. Soft tissue artefacts are a source of motion capture inaccuracy in sensor systems (Lebel et al., 2017; Seel et al., 2014), and optical systems (Fiorentino et al., 2017). As the sensors from the two systems were not placed on identical anatomical locations, differences in skin motion artefacts at different locations may have also influenced the results (Seel et al., 2014).

Statistical methods identified outliers greater than 1.5 IQR which were removed from our data prior to analysis, yet this did not remove all physically impossible results. Accuracy would improve with a handpicked selection of best trials, or whole cohort assessment by a clinician, however this study aimed to test the pragmatic accuracy of the system and therefore results were not manipulated by exclusion of poor-quality trial data.

There are a few study limitations that should be addressed. Further trials with more participants or more gait cycles per participant may provide different results, however six gait cycles per participant is similar to previously reported studies (Schreiber & Moissenet, 2019). Further system limitations also need to be considered. Metal interference from ferromagnetic materials, which influence the magnetometer within the Notch sensor, is known to limit accuracy of sensor-based motion capture systems, especially when placed within one metre (de Vries et al., 2009; Picerno, 2017). The data in this study was collected within a gait laboratory which likely resulted in electromagnetic interference. The accuracy of the Notch system may be improved in areas of less interference, but such interference is unavoidable in most clinical and research settings. Magnetic interference in motion laboratories is greatest 5cm above the floor (de Vries et al., 2009), which may explain the poor ankle joint correlations between the two systems. Magnetometer drift may also influence results (Lebel et al., 2015). Notch calibration procedures were followed, and recordings limited to 15 seconds each to minimise this, however, the difference in accuracy between the first and last trials was not assessed. Notch sensors are calibrated by securing the sensors in their provided docking station and performing a series of rotations. This process could be improved, consequently improving sensor accuracy, by using a low friction rotation rig to standardise movement, with care taken to keep rotations in the desired plane. Ensuring stationary subject positioning during participant calibration by using a rigid jig may also increase sensor accuracy (Kim & Lee, 2017), and combining Notch data with data collected from multiple Microsoft Kinect cameras has also been proposed to overcome the limitations of each system (Tarabini et al., 2018). Finally, it is possible that another set of Notch sensors may provide different results as there remains potential for individual sensors to perform differently, even within the same brand and type (Picerno et al., 2011).

This assessment of the Notch was conducted on an early hardware and software release and further updates and improvements may lead to more accurate reporting of joint angles. The Notch system investigated in this study lacked sufficient accuracy and consistency to allow it to be a useful tool for objective movement analysis in clinical practice. Overall, while there are many applications for an accurate and affordable portable sensor-based motion capture system, our results indicate that the accuracy of the Notch system used in this study is not within acceptable limits for use in research or clinical settings.

CHAPTER 5: OBSERVATIONAL STUDY PROTOCOL

Preface:

The literature review and systematic review presented in Chapters 2 and 3 have highlighted little is known about the practice of physiotherapy during virtual reality (VR) mobility rehabilitation. The next study presented in this thesis aimed to explore the similarities and differences in physiotherapy practice during usual mobility rehabilitation without active videogame and computer (AVC) technologies and mobility rehabilitation with AVC technologies. Specific areas of interest were the physiotherapist's focus of visual attention and physiotherapist instruction and feedback during rehabilitation intervention. As Chapter 4 established that the Notch wearable sensor-based motion capture system was not sufficiently accurate to be used in a research or clinical setting, this observational study did not incorporate the assessment of patient movement. Chapter 5 presents the study protocol for this observational study and provides detail of the AVC technologies used in the observational study and the procedures employed to compare the aspects of interest in physiotherapy practice during rehabilitation without and with AVC technologies.

Please note: it was at this point within the thesis that a shift in terminology from virtual reality (VR) technologies to active videogame and computer (AVC) technologies occurred, referring to non-immersive VR technologies that require active patient engagement.

5.1 Introduction

Mobility limitation can result from conditions such as stroke, brain injury, hip fracture and arthritis (AIHW, 2012). Rehabilitation programs can improve outcomes for people with mobility limitations, especially programs that effectively increase dosage by providing intensive repetitive exercises and programs that provide effective feedback to enhance motor learning (Kwakkel et al., 2004; Sigrist et al., 2013; Veerbeek et al., 2014). However, observational studies have found inpatients admitted to rehabilitation wards can be inactive for much of the day, with little time spent engaged in functional rehabilitation activities (West & Bernhardt, 2012). The use of technologies such as Nintendo Wii Fit and Xbox Kinect may be an effective, yet relatively inexpensive way to increase activity and therapeutic dose for people in rehabilitation (Bonnechere et al., 2016; Givon Schaham et al., 2018; Hassett et al., 2019).

Active videogame and computer (AVC) technologies are increasingly reported as an acceptable therapy tool in rehabilitation to increase dose of practice in an affordable way in various patient populations (Bonnechere et al., 2016; Kwakkel et al., 2004). Recreational examples include the Nintendo Wii and Xbox Kinect; rehabilitation-specific examples include Jintronix and the Humac Balance Board. AVC technologies utilise patient movement to interact with a screen-based virtual environment and have been shown to increase patient motivation and enjoyment of exercise (Mirelman et al., 2009). Moreover, when the person is discharged home from hospital these technologies can potentially be used in the home-setting to continue rehabilitation with a physiotherapist remotely monitoring the patient (Hassett et al., 2016; Miller et al., 2014; Sheehy et al., 2019).

In conventional rehabilitation, tailored extrinsic feedback is typically provided by the physiotherapist to the patient to facilitate motor learning as patients' own intrinsic feedback mechanisms may be impaired(van Vliet & Wulf, 2006). It has been advocated that AVC therapy can offer additional extrinsic feedback to the patient (Baranowski et al., 2013; Hassett et al., 2019; Tieri et al., 2018). During rehabilitation physiotherapists are known to observe movement patterns and patient facial expressions to guide the provision of therapy (Hayashi et al., 2020; Huhn et al., 2019; Liu et al., 2019). As AVC therapy feedback is predominately visual in nature (Lee et al., 2017), it is another potential location for physiotherapist focus of visual attention. The introduction of an additional feedback mechanism through the use of AVC therapy also has the potential to alter physiotherapist instruction and feedback, in addition to shifting physiotherapist visual attention from the patient. The exact nature of physiotherapist visual attention, instruction and feedback during conventional or AVC rehabilitation has not yet been investigated.

This observational study sought to examine physiotherapist focus of visual attention and physiotherapist instruction and feedback during rehabilitation for patients with mobility limitations, and compare these aspects of physiotherapy practice during rehabilitation without and with AVC technologies.

The research questions for this study were:

1. Where does a physiotherapist direct visual attention during usual care rehabilitation (without technologies) and how much attention is provided to the patient and equipment (conventional therapy equipment)?
2. Where does a physiotherapist direct visual attention during AVC rehabilitation and how much attention is provided to the patient and to the equipment (AVC technology and convention therapy equipment)?
3. What are the similarities and differences in physiotherapist visual attention during rehabilitation without and with AVC technologies?
4. What are the characteristics of the instruction and feedback provided by the physiotherapist to the patient during usual care rehabilitation?
5. What are the characteristics of the instruction and feedback provided by the physiotherapist to the patient during AVC rehabilitation?
6. What are the similarities and differences in physiotherapist instruction and feedback characteristics during mobility rehabilitation without and with AVC technologies?

5.2 Methods

5.2.1 Study design

This prospective observational study evaluated rehabilitation physiotherapy practice without and with active videogame and computer (AVC) technologies. Specifically, this study sought to determine and compare physiotherapist visual attention and physiotherapist instruction and feedback. The Strengthening the Reporting of Observational studies in Epidemiology (STROBE) checklist was used to guide reporting (von Elm et al., 2007).

Physiotherapist and patient dyads were observed whilst engaged in a usual mobility rehabilitation exercise and an AVC rehabilitation exercise, chosen to match the usual care activity as closely as possible. Each observation session comprised of both study conditions (rehabilitation without and with AVC technologies) undertaken in random order.

5.2.2 Study setting

This study was conducted within existing physiotherapy rehabilitation services of two major metropolitan Adelaide hospitals between September 2019 and March 2020. Both inpatient and outpatient settings were included and encompassed a specialist brain injury unit, as well as neurological, orthopaedic, and general rehabilitation wards. Neither hospital routinely used AVC technologies in physiotherapy rehabilitation as part of usual care.

5.2.3 Participants and demographics

Both physiotherapists and patients were considered participants in this study. Physiotherapists were convenience sampled between September 2019 and March 2020. Physiotherapists were eligible if currently providing rehabilitation services and willing to use technology in physiotherapy. Physiotherapists who agreed to participate were asked to identify eligible patients and obtain verbal consent for the researcher to approach these patients and explain the study. Patients were eligible to participate if they were currently receiving physiotherapy rehabilitation for mobility limitations due to any type of health condition (e.g., due to neurological or musculoskeletal disorders); able to provide own informed consent and willing to use technology in therapy. Patients were excluded if their physiotherapist thought they would be unable to participate for any reason including significant vision, cognitive or behavioural issues. Physiotherapists participated in up to 10 sessions, with each patient taking part no more than twice.

To minimise the potential effect of study observation on clinical practice participants were informed about the broad study aim without detailing specific research objectives. Physiotherapists and patient participants were each provided with a Participant Information Sheet (Appendices H and I) and provided written consent prior to study enrolment. Ethics approval was provided by the Southern Adelaide Human Research Ethics Committee (HREC/19/SAC/109 OFR 100.19) (Appendix J) and each hospital additionally provided site-specific approval (Appendix K).

In total 20 physiotherapists and 61 patients were recruited and a total of 95 sessions were observed. Physiotherapists completed a questionnaire regarding basic demographic data, clinical experience and experience with technology use in rehabilitation such as videogames and robotics. Demographic information was also collected from patients, including diagnosis, technology experience and current goals of therapy. These questionnaires are presented in Appendices L and M.

Physiotherapists had an average (SD) of 8 (8.4) years clinical experience and reported only occasional (55%) or no (45%) prior experience with using technology in rehabilitation. Patients predominately undertook rehabilitation for a neurological diagnosis and addressed a range of different mobility limitations. Table 5-1 below details the physiotherapist and patient demographic data.

Table 5-1 Participant demographics

	Physiotherapists (n=20)	Patients (n=61)
Age (years) mean (SD); range	31 (8.7); 21-56	65 (16); 19-91
Gender female n (%)	14 (70)	20 (33)
Clinical experience (years) mean (SD); range	8 (8.4); 0-33	
Prior experience in rehabilitation technology n (%)		
Yes, frequent	0 (0)	
Yes, occasional	11 (55)	
No	9 (45)	
Prior experience in gaming technology n (%)		
Yes, frequent	3 (15)	
Yes, occasional	15 (75)	
No	2 (10)	
Diagnosis n (%)		
Neurological		43 (70)
Non-neurological		18 (30)
Mobility limitation addressed n (%)		
Sit to stand		9 (15)
Standing balance		20 (33)
Stepping		9 (15)
Dynamic balance		23 (38)

5.2.4 Procedures

Prior to study commencement, consented physiotherapists were orientated to the AVC technologies during a session where they observed, experienced, and became familiar with the four different AVC systems available for this study. Examples of how AVC exercises could address the same clinical goals as usual care were provided. Physiotherapists were encouraged to consider how the technologies could be integrated into their clinical practice, but reassured that the technical support, including set up and navigating menu systems to each exercise would be provided by the researcher.

The completed observations focused on four common mobility limitations in people receiving physiotherapy rehabilitation, i.e., difficulties with: 1) sit to stand, 2) stepping (taking a step while standing) 3) standing balance (either maintaining static standing or intentional weight shift in standing) and 4) dynamic balance (walking in any direction). These mobility limitations were selected as task-specific exercises addressing each of these limitations could be performed with at least two of the study AVC technologies. Each data collection session was planned prior, and conducted as part of, the patient's usual care physiotherapy session. The physiotherapist proposed a task-specific exercise, tailored to and addressing a patient's mobility limitation as per usual practice. Following, the researcher matched this task-specific exercise with one of the AVC technology exercises, in discussion with the physiotherapist, taking into account use of walking aids, functional mobility level and goals of the activity. Descriptions of AVC technologies are in section 5.2.5, with detailed explanations of commonly used games in Appendix N. Examples of how AVC exercises were matched with usual, non-AVC-based rehabilitation exercises are presented in Table 5-2. The frequency of use for each AVC technology to address each mobility limitation is presented in Appendix O. A short video clip located at this link: https://youtu.be/PuGMNMsrhU4 provides two examples of matched usual rehabilitation and AVC rehabilitation exercises.

The order of study conditions (without and with AVC technologies), in which the exercises were undertaken was randomised with a 1:1 allocation using random block sizes of 2 and 4, stratified for recruitment site. An independent researcher generated this randomisation list using an online site (randomization.com) and subsequently placed allocation results into sequentially labelled opaque envelopes. The onsite study researcher opened each sealed envelope immediately prior to data collection and advised the physiotherapist and patient of the order in which to perform the exercises within the same session. It was not possible to blind either the physiotherapist or the patient to the exercise being undertaken.

All data collection sessions were undertaken with the physiotherapist and patient dyad in a therapy area with appropriate screening within the recruitment wards. Physiotherapists were not given any direction as to how to conduct the observed session except for the order of the exercises (without and with AVC technologies). During the session the researcher provided technical assistance if required but did not intervene in delivery of physiotherapy. Session duration, intensity, dose and rest breaks were all at the discretion of the physiotherapist. External supports such as plinths and parallel bars were used if clinically indicated. Usual care exercises without AVC technologies could also incorporate relevant customary small equipment such as mirrors, wobbleboards, markers, balls, and balance foam. Although each of the study AVC technologies had accompanying sound effects, all AVC exercises were undertaken without sound so as not to distract other people undertaking rehabilitation in the same space.

The data collection session was recorded with the physiotherapist wearing calibrated Tobii Pro 2 eye tracking glasses. The eye tracking glasses recorded the physiotherapist's eye gaze via inward-facing cameras and their field of view with an outward-facing camera, which were later combined in Tobii Pro Lab software to determine the location of physiotherapist visual fixations. These visual fixations were subsequently manually coded for area of interest, defined a priori as patient, equipment and other. This has been determined to be a valid method for establishing the distribution of visual attention over multiple areas of interest (Vansteenkiste et al., 2015).

A second video camera was used to record the physiotherapist and patient during the session. This camera was either placed on a tripod or was handheld by the researcher depending on the nature of the activity being recorded to optimise the field of view of the recording. The videos from the Tobii field of view camera and the second video camera were used to extract and code all instances of physiotherapist instruction and feedback during therapy. Video recording was chosen over direct observation due to its superior validity (Fini et al., 2015). A customised template was used to record the details of each session including mobility limitation addressed and technology type and game used.

5.2.5 AVC technologies

Four AVC technology systems were utilised in this study. Factors considered in selection of technologies included the availability of the system, cost, portability, and capacity to meet goals of patients undertaking mobility rehabilitation. Two recreational systems (Nintendo Wii and Xbox Kinect) were specifically chosen for their prevalence in rehabilitation settings (Levac, Glegg, et al., 2019; Thomson et al., 2016). Two rehabilitation-specific systems (Humac Balance Board and Intelligent Rehabilitation Solutions) were selected based on their affordability, and features permitting tailored exercise prescription for a variety of patient populations.

Each of these four systems requires patient movement input via one of two different devices (3D motion capture camera or force plate), displays resultant visual task-related feedback and have been used previously in research and clinical practice for mobility limitations (Hassett et al., 2020; van den Berg et al., 2016).

Humac Balance System

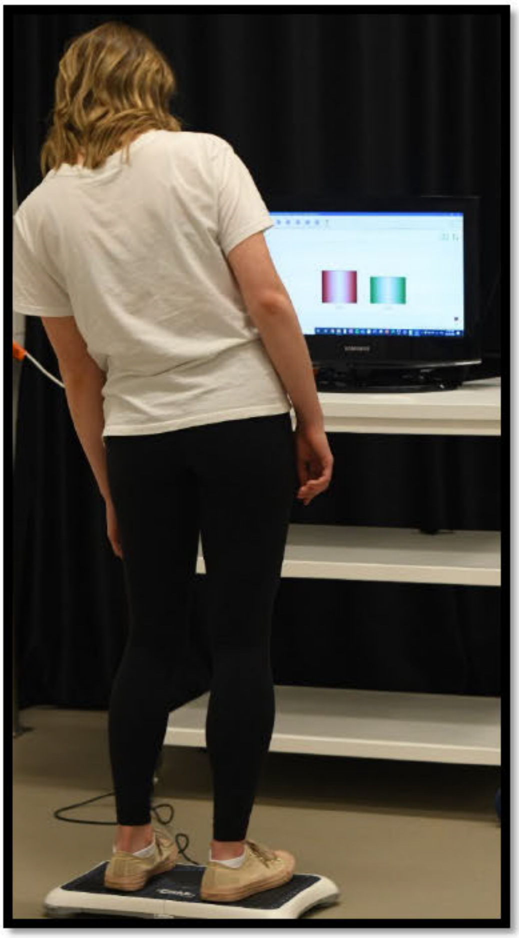

Figure 5-1 Humac Balance System

The Humac Balance System is a rehabilitation-specific system manufactured by Computer Sports Medicine Inc. (CSMi), Stoughton, Massachusetts, USA. It consists of the Humac Balance Board connected to a computer running Humac Balance software. In this study the software version in use was 15.000.0103. The user stands on the board and corner pressure sensors detect the user's centre of pressure (COP), which is displayed and used within the different software activities. Descriptions of the exercises commonly used in this study (weight bearing, centre of pressure, weight shift, limits of stability, snowboard, ski and balance) are in Appendix N.

Intelligent Rehabilitation Solutions

Figure 5-2 IRS system

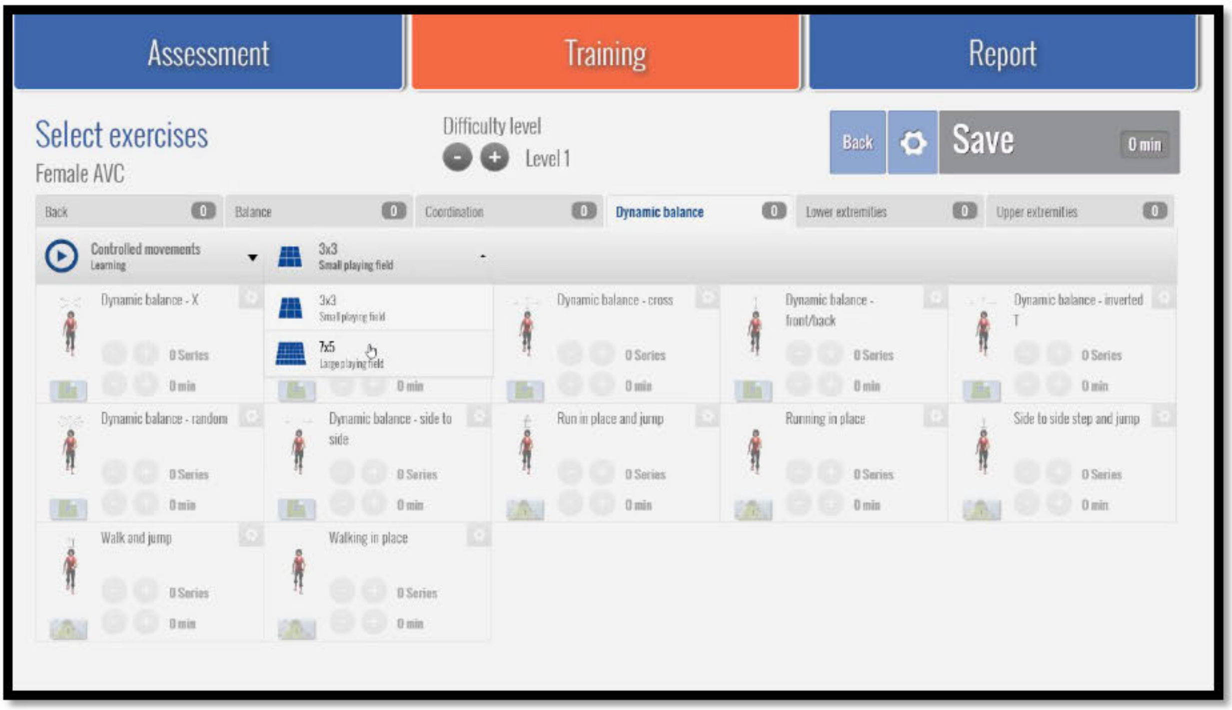

Figure 5-3 IRS exercise selection screen

Intelligent Rehabilitation Solution (IRS, formerly known as Fysiogaming) is a rehabilitation-specific system produced by Doctor Kinetic, Eindhoven, The Netherlands. Patient movement obtained by a Microsoft Kinect motion capture camera is used by the software for physical assessment and to control each game. The settings for each game are determined by the clinician prior to use and include level of difficulty (1-30), target range of movement (50%, 100%), side of the body (left, right or both), complexity and variability of practice (one task or different tasks within the same game). The software version used in this study was Version 2.4.3. The most frequently used exercises in this study (submarine, hip flexion, hip extension, knee lift, knee flexion, lunges, squats, sidestepping and dynamic stepping) are described in Appendix N.

Xbox One Kinect

Figure 5-4 Xbox Kinect system

Xbox One and Kinect motion capture camera is a videogame system produced by Microsoft, Redmond, Washington, USA and developed for a recreational market. Patient movement, captured by the camera, controls the avatar player in each game. Game characteristics such as speed of movement or game duration cannot be adjusted by the clinician. The game disc used in this study was Kinect Sports Rivals. Descriptions of two of the most frequently used exercises in this study, Bowling and Tennis, are further described in Appendix N.

Nintendo Wii Fit

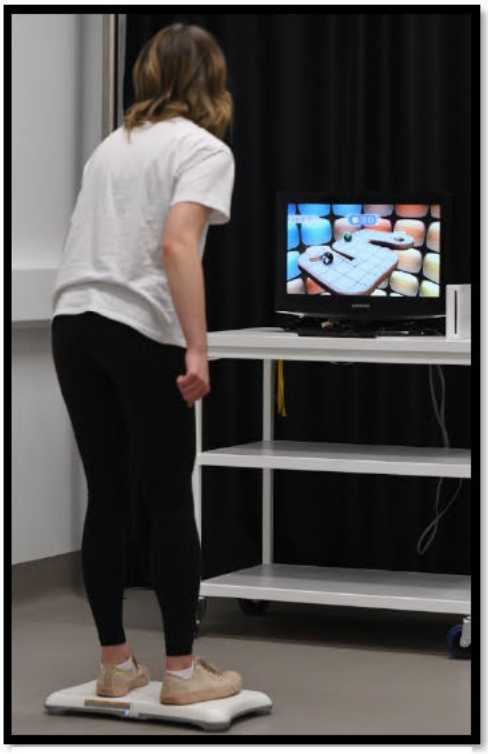

Figure 5-5 Wii Fit system

The Wii, in combination with the Wii Balance Board is a videogame system produced by Nintendo, Kyoto, USA. The Wii Balance Board captures the patient's standing centre of pressure (COP) to use for interaction with the various games. Games can be set to beginner, intermediate or advanced level, but are otherwise not tailorable by the clinician. This study used the Wii Fit disc, with games in the categories of Yoga, Strength training, Aerobics and Balance available. Descriptions of the two most commonly used games in this study, Table Tilt and Soccer Heading are available in Appendix N.

Table 5-2 Examples of matched usual care and AVC rehabilitation exercises

Mobility limitation	Examples of usual care exercises (without AVC technologies)	Examples of matched AVC exercises
Sit to stand (STS)	STS practice with feedback from physiotherapist, STS with mirror, STS with step or foam under one foot, STS with offset foot position, part practice e.g., squats.	STS practice with Humac Weight Bearing or Weight Bearing XY, STS with Humac COP, STS with IRS Submarine game, part practice e.g., squats with any of above.
Standing balance – maintaining static standing/small perturbations of COP	Standing practice while catching and throwing a balloon or ball, standing on an unstable surface (e.g., foam or wobble board), standing on an unstable surface and tapping a balloon	Standing practice on Humac with COP, Limits of Stability, Balance, or Ski (Humac calibrated to be sensitive to small movements) Standing practice on Wii performing Table Tilt or Tennis
Standing balance – weight shift in standing in preparation for stepping	Standing practice while encouraging weight shift with reaching for or transferring small equipment (e.g., shifting beanbags, moving pegs), standing practice while moving hip to touch a target (e.g., parallel bars, physiotherapist hand).	Standing practice on Humac with Weight Shift, Limits of Stability, Balance, or Ski (Humac calibrated to require larger movements) Standing practice on Wii performing Penguin Slide, Ski Slalom, Balance Bubble
Stepping	Single step in any direction (e.g., forward, sideways), lunge (same leg or alternating legs), single step with reach to a target, step and bowl.	Single step with IRS in any direction (e.g., forwards, sideways), lunges with IRS (same leg or alternating legs), Xbox bowling.
Dynamic balance – sidestepping	Sidestepping without targets, sidestepping to transfer objects or tap balloon or other target	Sidestepping with IRS at different levels (boat, car, dynamic balance in grid), Xbox tennis.
Dynamic balance – multidirectional walking	Multidirectional walking to targets around the patient, navigating flat walking course	Multidirectional walking to targets with IRS (dynamic balance)

5.2.6 Outcome measures

The two primary outcomes were physiotherapist focus of visual attention and physiotherapist instruction and feedback during active rehabilitation time without and with AVC technologies. Any adverse events occurring during the study rehabilitation sessions were also recorded.

Visual attention

To obtain visual attention data, each eye tracking file was processed in Tobii Pro Studio and inspected for completeness. Sessions with over 80% valid eye samples were selected for analysis, meaning each physiotherapist eye fixation during rehabilitation was manually viewed and coded for area of interest. Areas of interest were defined a priori in the categories of patient (head or face), equipment (AVC screen, AVC hardware, other), and other (researcher, physiotherapist own body, elsewhere in room). Each video file was viewed and each fixation coded for the area of interest, recorded on a custom Excel spreadsheet. Fixations were counted for each area of interest and divided by the total number of fixations for each session condition to report a percentage of number of fixations visually attending to each area. Similarly, the duration of each fixation was summated to report the total time visually attending to each area. The average duration of each fixation and the number of sequential fixations on each area was also calculated.

Physiotherapist instruction and feedback

Video files were viewed for the instruction and feedback provided to the patient by the physiotherapist. This included audible (e.g., spoken word and non-verbal sounds), visual (e.g., gestures, demonstration) and haptic instruction and feedback (e.g., physiotherapist touch for cueing and safety). Once coded by modality, visual and auditory instruction and feedback was further coded for content type (e.g., task instruction, performance instruction KP, KR, motivational statements) and auditory instruction and feedback for focus of attention (internal, external, mixed) and affective framing (positive, negative neutral). Coding was conducted per 15 second epoch, or in the event of continuous communication such as continual physiotherapist hands on support, was counted once in every epoch. The instruction and feedback provided by the AVC technology was also recorded. All data was recorded on a custom Excel spreadsheet. A second coder also viewed and coded 10 sessions until 80% agreement was reached.

5.2.7 Sample size

This study was powered to detect a moderate effect size (>0.5) with alpha of 0.05 and beta of 0.20. Thirty sessions were sufficient to detect a difference between study conditions with a moderate effect size for both the proportion of time visually attending to each area of interest, and the quantity of instruction and feedback provided by the therapist. Sessions were considered valid for eye tracking analysis if over 80% of eye tracking data were captured successfully. Sessions were recorded until a minimum of 30 valid data sets were collected, resulting in a total of 95 sessions.

5.2.8 Data management

All paper completed questionnaires, once entered into a custom Excel spreadsheet for analysis were kept in a locked cabinet. All Excel spreadsheets containing data were kept on a secured, password protected drive.

5.2.9 Statistical analysis

Demographic data

Demographic participant data and details of each session (n=95), including mobility limitation addressed and technology used, were descriptively analysed and reported.

Visual attention

Visual attention data were found valid in 32 sessions. Rehabilitation-specific technologies were used in 30 of these sessions, and subsequently analysed. The proportion of the total number of visual fixations, proportion of total fixation time, duration of each fixation and number of uninterrupted fixations was analysed with descriptive statistics and reported for each area of interest. Data was visually inspected for normality and was found to be not normally distributed, hence the Wilcoxon Signed Rank test was used to establish if significant differences existed in visual attention parameters between rehabilitation sessions without and with AVC technologies.

Physiotherapist Instruction and feedback

Instruction and feedback data from the same clinical sample (n=30) were analysed. Within each session, each 15 second epoch of active rehabilitation was coded for all instances of instruction and feedback. Coding classified key characteristics of instruction and feedback, including mode, content, focus of attention and framing. The amount of each instruction and feedback type was standardised to 5 minute periods of rehabilitation to allow for meaningful reporting. Data was analysed descriptively for each type of instruction and feedback. As data was not normally distributed the Wilcoxon Signed Rank test was used to compare characteristics of physiotherapist instruction and feedback between rehabilitation sessions without and with AVC technologies.

5.3 Discussion

This observational study was designed to investigate physiotherapist focus of visual attention and physiotherapist instruction and feedback during mobility rehabilitation, and compare these aspects of physiotherapy practice during rehabilitation without and with AVC technologies. AVC technologies can provide additional cueing, motivation and extrinsic feedback to the patient and may therefore impact upon the type and amount of instruction and feedback provided by the physiotherapist. The results of this research were to provide further insight into how physiotherapists practice is influenced by the use of AVC technologies.

An anticipated difficulty in this study was the matching of patients' usual care exercises with AVC technology supported exercises. However, to address this a range of different AVC technologies was included in the study protocol allowing for pragmatic, tailored prescription of exercises.

AVC technologies are increasingly used in rehabilitation, however to date, no studies have assessed physiotherapist focus of visual attention or physiotherapist instruction and feedback provided to the patient when completing AVC-based exercises. The knowledge gained from this study will provide further insight into how physiotherapists practice is influenced by the use of AVC technologies and a first step in determining optimal physiotherapist engagement in AVC technology-based rehabilitation therapies.

CHAPTER 6: PHYSIOTHERAPIST FOCUS OF VISUAL ATTENTION IN MOBILITY REHABILITATION WITHOUT AND WITH AVC TECHNOLOGIES

Preface:

As the literature review in Chapter 2 and systematic review presented in Chapter 3 have demonstrated, information on the practice of physiotherapy during AVC-based mobility rehabilitation is sparse. AVC technologies are inherently visual in nature, and provide a third component to the traditional patient-therapist dynamic in usual rehabilitation practice.

The purpose of this chapter was to investigate the focus of physiotherapist visual attention in usual care and AVC rehabilitation for mobility limitations, using the protocol presented in Chapter 5. The similarities and differences in visual attention between rehabilitation without and with AVC technologies were analysed, reported and potential reasons and clinical implications were discussed. This chapter addressed the research objective three: To examine physiotherapists' focus of visual attention during usual mobility rehabilitation without AVC technologies and AVC-based mobility rehabilitation and identify similarities and differences in physiotherapist focus of visual attention between rehabilitation without and with AVC technologies.

Results from this chapter were disseminated in a platform presentation at the World Physiotherapy Congress 2021 and will be presented in an oral presentation at the Australian Physiotherapy Association Thrive 2021 Conference. The abstracts for these presentations are in Appendix P and Q, and the recorded World Physiotherapy Congress presentation is available at this link: https://youtu.be/GwTejuNVdcA

6.1 Introduction

Physiotherapy rehabilitation is an effective intervention for people with mobility limitations (Binder et al., 2004; Pollock et al., 2014; Wade, 2020; Whitlock Jr & Hamilton, 1995). During mobility rehabilitation, physiotherapists primarily deliver individualised task-specific practice, frequently in the form of gait, balance and transfer training (Kimberley et al., 2010; Tole et al., 2014; Tyson et al., 2018). Interaction between physiotherapist and patient is central to physiotherapy practice, especially in rehabilitation where active patient participation is key (Bishop et al., 2019; Gyllensten et al., 1999; Kayes & McPherson, 2012). Non-verbal communication such as touch and eye gaze are key components of this interaction (O'Keeffe et al., 2016; Roberts & Bucksey, 2007).

Visual attention, defined as the process of selective focus and attending to viewed information, "turns looking into seeing" (Carrasco, 2011, p. 1484). Visual fixations, which occur when the eye stops briefly to observe a point of interest in the visual field long enough to allow for cognitive processing, infer visual attention (Duchowski, 2007; King et al., 2019; Orquin & Holmqvist, 2019). Visual attention of the physiotherapist during rehabilitation is important for information gathering, for example in assessment of movement quality (Hayashi et al., 2020; Liu et al., 2019) and in non-verbal communication (e.g. noting facial expressions) (Sze-Mun Lee et al., 2009). These observations can be used to inform clinical reasoning processes and guide the delivery of therapy (Huhn et al., 2019; Wainwright et al., 2011). The process of visual attention during clinical decision making has been studied in some clinical areas such as radiology and dermatology (Al-Moteri et al., 2017; Blondon et al., 2015; Brunye et al., 2019; Patel & Arocha, 2018), indicating that clinicians initially scan the entire scene for areas of interest, then fix upon these areas of interest to visually process them before responding/making judgement. Further research is needed to determine the focus of physiotherapist visual attention during active rehabilitation sessions.

The use of active videogame and computer (AVC) technologies, where patient movement is used to interact with a virtual, on-screen computer environment, introduces an additional dynamic element to rehabilitation, outside of the patient and therapist. As an inherently visual system, the introduction of AVC technologies may impact physiotherapist's focus of visual attention, but if, and to what extent this occurs is unknown. AVC technologies are increasingly being adopted in physical rehabilitation and have been demonstrated as a feasible alternative or supplement to conventional programs in populations such as people with stroke (Laver et al., 2017), spinal cord injury (Alashram et al., 2020), Parkinson's disease (Barry et al., 2014) and older adults (Skjæret et al., 2016; Zeng et al., 2017). One perceived advantage of AVC-based rehabilitation is the availability of additional extrinsic feedback, including visual, auditory and tactile feedback, to facilitate motor learning and stimulate neuroplasticity (Baranowski et al., 2013; Holden, 2005). How the introduction of technology affects physiotherapists' focus of visual attention during intervention delivery has not been researched. To address this current gap in knowledge, this observational study aimed to assess physiotherapists’ focus of visual attention while engaged in patient rehabilitation intervention without and with AVC technologies.

Specific research questions were:

1) Where do physiotherapists focus visual attention during usual rehabilitation without technologies and how much visual attention is focused on the patient?
2) Where do physiotherapists focus visual attention during AVC rehabilitation, how much visual attention is focused on the patient, and how much is focused on the technology?
3) What are the similarities and differences in physiotherapist focus of visual attention during rehabilitation without and with AVC technologies?

6.2 Methods

6.2.1 Design

In this observational study physiotherapists’ focus of visual attention was investigated in physiotherapy rehabilitation without and with AVC technologies. The detailed study protocol is described in Chapter 5. In brief, physiotherapist and patient dyads were observed performing a usual care exercise without technologies addressing a mobility limitation, as well as a matched AVC technology-assisted exercise, performed in random order.

6.2.2 Participants and setting

Participants in this study were physiotherapists and patients, both convenience-sampled from two Adelaide hospitals. Participants were eligible if they were currently providing or receiving rehabilitation for mobility limitations due to any health condition and willing to use technology in therapy. Patients additionally needed to be able to provide informed consent and were excluded if significant visual, cognitive or behavioural issues precluded them from being able to participate in therapy. Physiotherapists were excluded if they self-reported any visual conditions that could affect eye tracking (history of eye surgery, eye movement or alignment abnormalities, use of multifocal glasses during therapy). A Participant Information Sheet was provided to physiotherapist and patient participants and written consent obtained prior to study enrolment. All participants were broadly apprised of the study aims without explicitly informing them of the study objectives to minimise the influence of the research procedures on clinical practice. Ethical approval was obtained from the Southern Adelaide Human Research Ethics Committee.

6.2.3 Procedure

Prior to data collection, physiotherapists were familiarised with the AVC technologies used in this study. Demographic information was collected from physiotherapist participants (including clinical and previous technology experience) and patient participants (including diagnosis, goals of therapy and technology experience).

In each data collection session one patient and physiotherapist dyad was observed performing an exercise without and with AVC technologies, addressing one of the following four commonly observed mobility limitations: 1) sit to stand, 2) stepping 3) standing balance or 4) dynamic balance. The mobility limitation addressed was dependent on the patient's rehabilitation goals and usual physiotherapy care. The AVC technology exercise was chosen, in discussion with the physiotherapist, to match the usual care exercise as closely as possible and tailored to the participants' clinical rehabilitation goal. Data collection sessions with the patient and physiotherapist dyad were performed in an appropriately screened therapy area, and the order of exercises (without and with AVC technology) was randomised.

During the session the physiotherapist wore eye tracking glasses (Tobii Pro Glasses 2, Figure 6-1). Eye tracking glasses use near infrared light and inward-facing cameras mounted within the frame to record the position of each eye and a forward-facing camera to record the wearer's point of view. This data is combined to map eye gaze onto the viewed environment. Physiotherapists were only informed that the glasses recorded the session from their point of view and were not given any instruction on how to perform the exercises, except for the exercise order (without and with AVC technology). Prior to each recording the glasses were successfully calibrated to each participant's eye gaze following the manufacturer's instructions using Tobii Glasses Controller (Version 1.114.20033). Gaze data was recorded at 50Hz and exported to Tobii Pro Lab (Version 1.73.8622) software for processing.

The short video clip located at this link: https://youtu.be/-D1lr-cYdlM provides an example of a recording from the Tobii eye tracking glasses, showing the visual fixations mapped on the wearer's field of view.

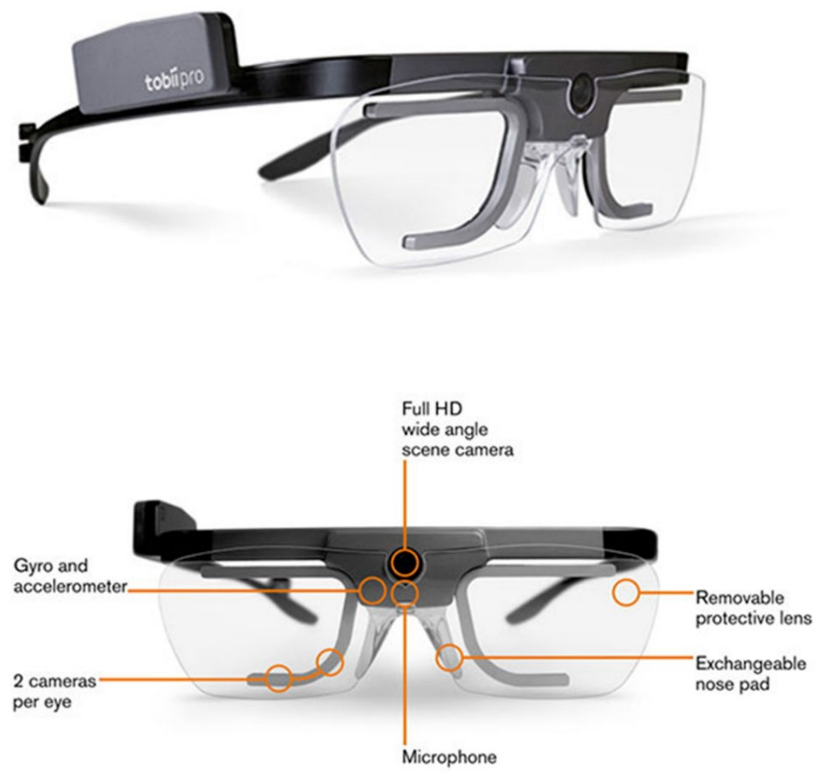

Figure 6-1 Tobii Pro 2 Glasses (Images reproduced by permission of Tobii AB)

6.2.4 Active Videogame and Computer technologies

To match usual care (without technology) exercises with AVC assisted exercises four low cost, commercially available, portable AVC systems were used; two recreational (Nintendo Wii Fit and Xbox Kinect) and two rehabilitation-specific (Humac Balance Board (Humac) and Intelligent Rehabilitation Solutions (IRS)). Each of these systems use a monitor to display task-specific feedback related to patient movement detected by a force plate (Wii and Humac) or 3D motion capture camera (Xbox Kinect and IRS). Chapter 5 and Appendix N contain further details about each AVC technology used in this study.

6.2.5 Data extraction

The physiotherapist eye gaze data was processed with the Tobii I-VT (Attention) filter, which identifies when the fovea of the eye is stabilised on an area of interest and uses a velocity threshold of 100 degrees/second to allow for movement in either the wearer of the eye tracking glasses (physiotherapist) or the subject of interest (e.g., patient). This filter captures and reports attentional stabilisations, including typical fixations, vestibulo-ocular reflex (VOR) movements, smooth pursuits and some slow saccades (Olsen, 2012). For the purposes of this study, these attentional stabilisations will be referred to as ‘fixations’ as they indicate continuous eye gaze on an area of interest. Specific parameters of the filter are detailed in Table 6-1.

Table 6-1 Tobii I-VT (attention) filter parameters

Parameter	Parameter function	Setting
Gap fill-in (interpolation)	Short periods of data loss (e.g., due to blinking) can be extrapolated or not	No gap fill-in
Noise reduction	Noise within the data can be removed with a low pass filter	Moving median; window size 3 samples
Velocity calculator	The window length is the duration of time over which the average gaze velocity is calculated	Window length 20ms
I-VT classifier	Eye gaze samples with a velocity below the threshold are classified as a fixation	Threshold 100°/s
Merging of adjacent fixations	Fixations that are within the maximum time and angle are merged together into one fixation	Maximum time between fixations 75ms Maximum angle between fixations 0.5°
Minimum fixation duration	Fixations shorter than the minimum fixation duration are discarded	60ms
		Table data sourced from (Olsen, 2012)

Eye gaze data files were initially inspected for completeness of eye gaze recording, as data loss can occur due to issues such as blinking, eye-gaze outside the recording zone and eyelash interference. Only recordings with more than 80% valid eye gaze samples were used in this analysis to ensure eye tracking data was representative of the observed session (Vansteenkiste et al., 2015). Each session was viewed and every fixation identified by the software during the rehabilitation exercises was manually coded for area of interest (AOI). The AOIs for this study were defined as patient face, patient body (including back of the head, neck, trunk and limbs), AVC technology screen, technology hardware (e.g., remote, force platform, motion capture camera, keyboard), other equipment in use by the patient (e.g., balls, cones, walking aid), physiotherapist own body, researcher or elsewhere in the room. Raw data was exported from Tobii Pro Lab to obtain each fixation duration.

6.2.6 Data analysis

Extracted data was imported into SPSS (Version 23) for data analysis. Descriptive statistics were used to present demographic data for physiotherapist and patient participants.

The number of fixations and durations of fixations for each AOI were collated for all study sessions. Number of uninterrupted fixations, defined as the number of sequential fixations on a single AOI before a fixation on a different AOI, were also determined. As the data was found to be not normally distributed, non-parametric statistics were used. Descriptive statistics including frequencies, proportions, medians, IQR and ranges were reported for the visual attention measures of number of fixations, fixation time, average fixation duration and number of uninterrupted fixations. For each metric of visual attention recorded, comparisons between the two conditions (rehabilitation without and with AVC technologies) were performed using Wilcoxon signed rank test. Significance was set to an alpha of 0.05.

6.3 Results

Data from 30 rehabilitation sessions with 11 physiotherapists and 27 patients was analysed. Eight physiotherapists and three patients participated in more than one session. The proportion of valid eye gaze samples for included recordings was mean (SD) 90.1 (4.2)%. Randomisation of the order of study conditions in which the exercises were undertaken resulted in an equal ratio (15 without AVC technologies first and 15 with AVC technologies first). All 30 sessions included for data analysis used either Humac (n=17) or IRS (n=13). Participant demographics are detailed in Table 6-2 below.

Table 6-2 Participant demographics

	Physiotherapists (n=11)	Patients (n=27)
Age (years) mean (SD); range	28 (5); 21-37	65 (19); 19-90
Gender female n (%)	6 (55)	10 (37)
Clinical experience (years) mean (SD); range	5 (4); 0-10	
Prior experience using rehabilitation technology n (%)		
Yes, frequent	0 (0)	
Yes, occasional	8 (73)	
No	3 (27)	
Prior experience using gaming technologies n (%)		
Yes, frequent	0 (0)	
Yes, occasional	11 (100)	
No	0 (0)	
Diagnosis n (%)		
Neurological		18 (67)

Non-neurological		9 (33)
Mobility limitation addressed n (%)		
Sit to stand		5 (19)
Standing balance		9 (33)
Stepping		2 (7)
Dynamic balance		11 (41)

6.3.1 Visual attention

During rehabilitation without AVC technologies, physiotherapists' primary focus of visual attention was the patient, with a median (IQR) of 76 (55-88)% of total number of fixations, and 79 (57-94)% of total fixation time spent looking at the patient's face and body. In rehabilitation with AVC technologies the primary focus of visual attention was the equipment, with a median (IQR) of 53 (41-72)% of total number of fixations and 77 (58-86)% of total fixation time, directed at the screen, hardware or other equipment. Physiotherapist focus of attention on the patient in rehabilitation with AVC technologies was comparatively little with a median (IQR) of 38 (17-47)% of total number of fixations and 18 (8-39)% of total fixation time.

Proportion of number of fixations and fixation time on each AOI

The physiotherapist focused on the patient's body half as often in rehabilitation with AVC technologies compared to rehabilitation without AVC technologies (proportion of total number of fixations on body; median (IQR) without AVC: 64 (49-79)%; with AVC: 32 (11-41)%, $p<0.001$)), and for a significantly smaller proportion of the total fixation time (without AVC 63 (46-81)%; with AVC: 14 (6-27), $p<0.001$). Although the proportion of total number of fixations on the patient's face was similar in each rehabilitation condition (without AVC: 6 (3-17)%; with AVC: 5 (1-9)%, $p=0.371$), the proportion of total fixation time on the patient's face was significantly lower in rehabilitation with AVC technologies than without AVC technologies (without AVC: 8 (2-19)%; with AVC: 3 (1-5)%, $p=0.037$). In both conditions physiotherapists spent only a small fraction of the total fixation time (median <10%) fixated elsewhere in the room, including the researcher, and this was not significantly different between conditions ($p>0.05$). Table 6-3 details the number of fixations and total fixation time on each AOI, expressed as a percentage of total number of fixations and total fixation time.

Average duration of fixations on each AOI

A significant difference in the proportion of total number of fixations on the patient was observed between the two study conditions (median (IQR) without AVC: 76 (55-89)%; with AVC: 38 (17-47)%, $p<0.001$), yet the average duration of each fixation on the patient was similar in both conditions (median (IQR) without AVC: 341 (259-492)ms; with AVC: 296 (243-524)ms, $p=0.339$). In contrast, the average duration of each fixation on equipment was more than double in rehabilitation with AVC technologies when compared to rehabilitation without AVC technologies (without AVC: 314 (258-418)ms; with AVC: (876 (617-1244)ms, $p<0.001$). Table 6-4 and Figure 6-2 display the average duration of each fixation for each AOI.

Table 6-3 Proportion of the total number of fixations and total fixation time on each AOI

		Proportion of the total number of fixations on each AOI			Proportion of total fixation time on each AOI		
		Rehabilitation without AVC technologies Median (IQR), range %	Rehabilitation with AVC technologies Median (IQR), range %	Wilcoxon signed rank test (p)	Rehabilitation without AVC technologies Median (IQR), range %	Rehabilitation with AVC technologies Median (IQR), range %	Wilcoxon signed rank test (p)
Patient		76(55-89), 38-99	38(17-47), 4-61	<0.001*	79(57-94), 40-100	18(8-39), 1-58	<0.001*
	Face	6(3-17), 0-36	5(1-9), 0-30	0.371	8(2-19), 0-44	3(1-5), 0-41	0.037*
	Body	64(49-79), 19-95	32(11-41), 0-56	<0.001*	63(46-81), 13-95	14(6-27), 0-57	<0.001*
Equipment		6(0-25), 0-48	53(41-72), 21-96	<0.001*	6(0-25), 0-59	77(58-86), 33-99	<0.001*
	Screen		51(39-69), 20-94			77(57-85), 32-99	
	Hardware		1(0-1), 0-8			0(0-1), 0-15	
	Other equipment	6(0-25), 0-48	0(0-0), 0-4	<0.001*	6(0-25), 0-59	0(0-0), 0-1	<0.001*
Other		12(5-23), 1-34	6(2-14), 0-24	0.003*	8(3-17), 0-33	3(0-5), 0-16	<0.001*
	Elsewhere in room	11(4-22), 0-33	5(2-11), 0-17	0.001*	6(2-16), 0-25	1(0-5), 0-11	<0.001*
	Researcher	0(0-1), 0-5	0(0-2), 0-12	0.054	0(0-1), 0-7	0(0-1), 0-9	0.205
	Own body	0(0-1), 0-7	0(0-0), 0-1	0.008*	0(0-1), 0-7	0(0-0), 0-1	0.002*

* Indicates a significant difference (p<0.05) between rehabilitation without and with AVC technologies.

Table 6-4 Average fixation duration on each AOI

		Average Duration of Each Fixation		
		Rehabilitation without AVC technologies Median (IQR), range ms	Rehabilitation with AVC technologies Median (IQR), range ms	Wilcoxon signed rank test (p)
Patient		341(259-492), 180-1125	296(243-524), 140-2222	0.339
	Face	398(246-623), 183-1390	290(238-421), 128-3087	0.581
	Body	304(262-444), 180-1125	297(199-421), 160-2222	0.177
Equipment		314(258-418), 175-670	876(617-1244), 196-2375	<0.001*
	Screen		900(653-1270), 196-2375	
	Hardware		200(110-285), 60-8241	
	Other equipment	314(258-418), 175-670	219(176-393), 100-600	0.401
Other		212(169-298), 128-389	217(132-299), 75-551	0.719
	Elsewhere in room	212(169-275), 128-378	191(120-278), 75-705	0.292
	Researcher	280(174-677), 80-980	273(180-448), 85-1020	0.310
	Own body	205(142-333), 60-693	200(128-220), 120-380	0.398

* Indicates a significant difference (p<0.05) between rehabilitation without and with AVC technologies.

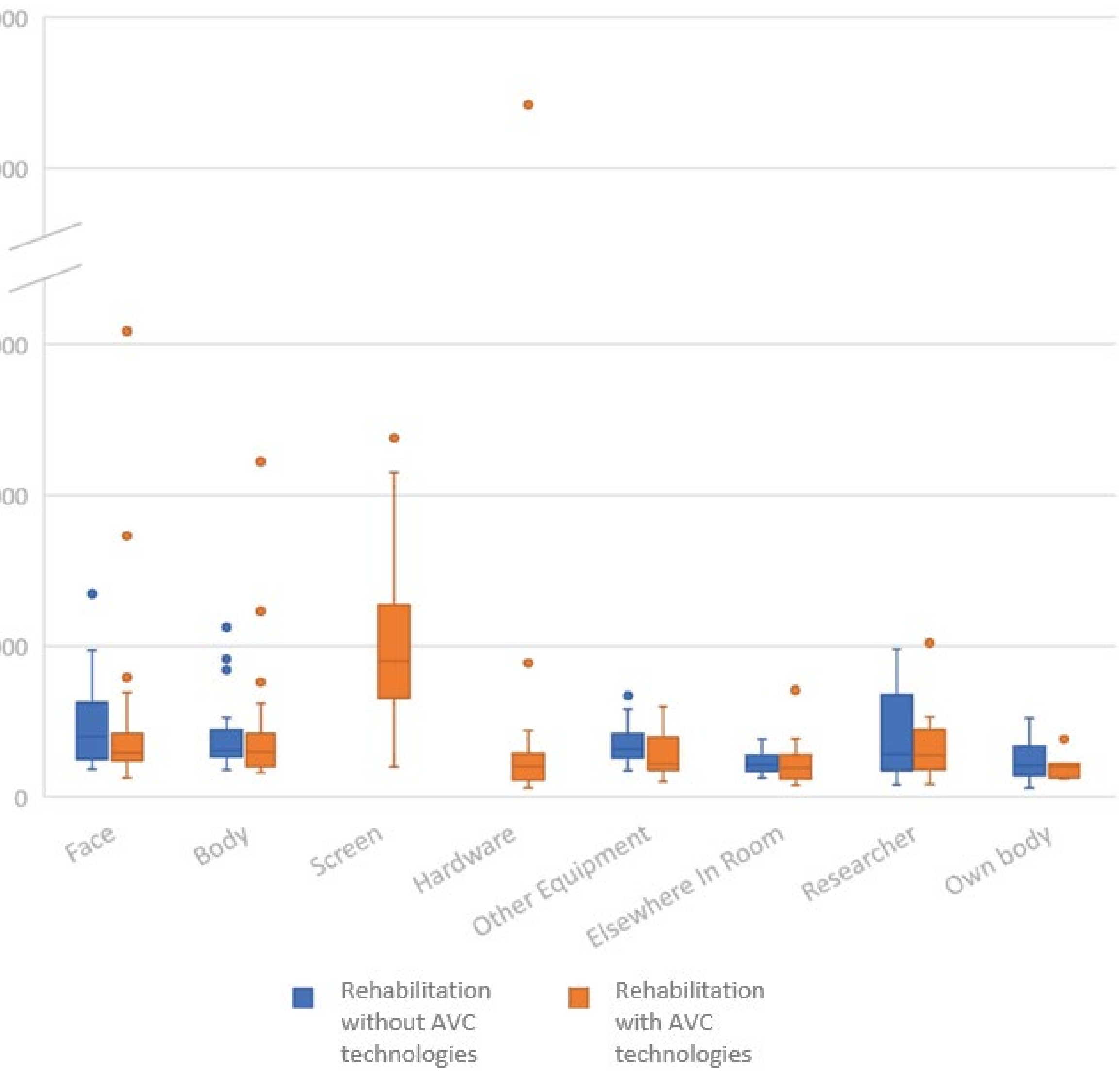

Figure 6-2 Average duration of each fixation

Number of uninterrupted fixations

In rehabilitation without AVC technologies the number of continuous uninterrupted fixations were greatest on the patient body (median (IQR) 5.1 (3.1-9.5) fixations), double the number of uninterrupted fixations on the patient body in rehabilitation with AVC technologies (median (IQR) 2.6 (1.7-3.5) fixations, p=<0.001). The number of uninterrupted fixations on patient face was similar in both conditions (without AVC: 1.8 (1.4-2.9); with AVC: 1.7 (1.2-3.0) fixations, p=0.453). In rehabilitation with AVC technologies, the number of uninterrupted fixations was greatest on the AVC screen (4.0 (2.8-5.8) fixations). Figure 6-3 illustrates the number of uninterrupted fixations on each AOI in each condition.

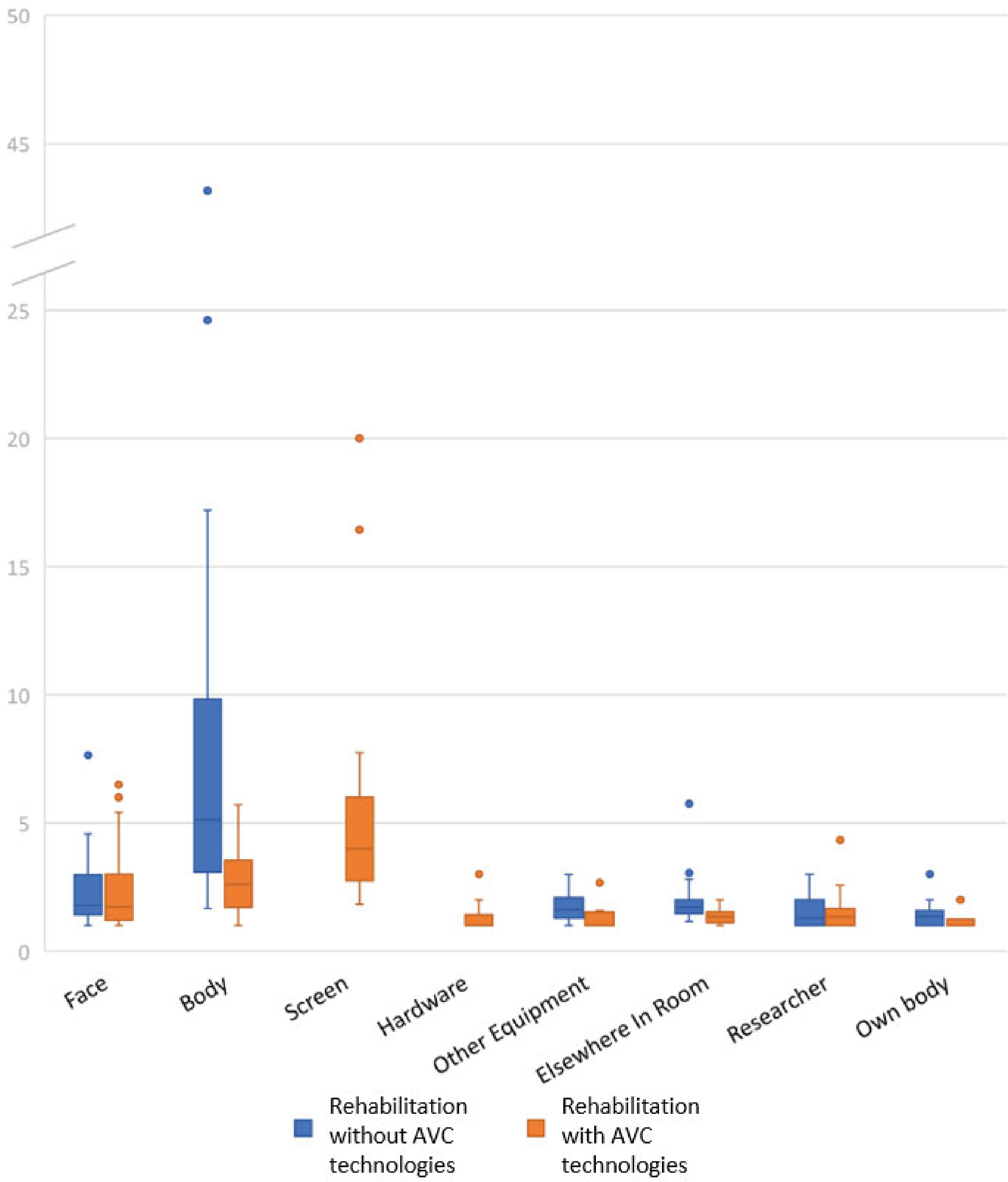

Figure 6-3 Number of uninterrupted fixations

6.4 Discussion

This study observed physiotherapists' focus of visual attention while providing rehabilitation without and with AVC technologies for patients with mobility limitations. The primary aim was to investigate and compare where physiotherapist visual attention was directed and how much visual attention was focused on the patient during mobility rehabilitation without and with AVC technologies. The results have indicated that during rehabilitation without AVC technologies physiotherapists' main focus of visual attention was the patient, particularly the patient's body. However, when incorporating AVC technologies, physiotherapist visual attention moved away from the patient towards the technology screen. When physiotherapists did visually attend to the patient their focus of attention was primarily on the patient's body, rather than on the face, like in rehabilitation without AVC technologies.

6.4.1 Rehabilitation without AVC technologies

The results of this study established that during rehabilitation without AVC technologies the physiotherapist's focus of visual attention, as measured by proportion of number of total fixations and proportion of total fixation time, was predominantly on the patient. Although the precise reasons for this are unknown, visual fixation patterns, and the fact that physiotherapists are drawn to observe patients during movement, could be explained by either top-down or bottom-up processes, or a combination of both (Orquin & Holmqvist, 2019). In a top-down approach, visual attention is task orientated, deliberately focused on the relevant area to the exclusion of others. Bottom-up visual attention is stimulus driven, where objects with salient characteristics, compared to the rest of the visual field, attract attention (Orquin & Mueller Loose, 2013). The explanation of why physiotherapists' primary focus of visual attention was the patient could be due to one or both of these processes. A top-down explanation would infer that physiotherapists were goal driven, and observed the patient to inform clinical reasoning (for example to provide feedback or assess movement) (Huhn et al., 2019; Wainwright et al., 2011). In contrast, a bottom-up approach suggests physiotherapists focused visual attention on the patient due to a lack of other distractions within the therapeutic environment. During rehabilitation without AVC technologies the patient was typically the only moving feature within the physiotherapist's field of view and therefore may have commanded visual attention for this reason alone, rather than for information-gathering purposes. A study exploring occupational therapists' focus of visual attention when viewing patient videos showed that visual attention was focused on features with movement, rather than on other clinically relevant aspects such as the patient's paretic limb (MacKenzie & Westwood, 2013). Our observational study assessed when the focus of attention was on the patient body and face during rehabilitation but did not subcategorise the body further to differentiate between clinically relevant aspects and other movements of the body. As there were minimal external moving distractions during the rehabilitation sessions without AVC technologies it cannot be determined from this section of the study if top-down or bottom-up processing was predominant.

6.4.2 Rehabilitation with AVC technologies

Laufer and Weiss (2011) and others have theorised that the use of AVC technologies as a therapeutic tool in physical rehabilitation allows the physiotherapist to focus more on patient movement (Laufer & Weiss, 2011; Levac & Galvin, 2013). This does not align with our study observations, illustrated by the fact that the proportion of total fixation time focused on the patient in rehabilitation without AVC technologies (79%) was similar to the proportion of total fixation time focused on the equipment in rehabilitation with AVC technologies (77%). However, since AVC feedback can be unreliable (Deutsch, Brettler, et al., 2011) and patients may compromise their movement pattern in order to achieve higher game scores (Lewis et al., 2011), it has been recommended that physiotherapists observe actual patient movement during AVC rehabilitation, to confirm the desired movement strategy is being performed (Hassett et al., 2019). Whether the small amount of time physiotherapists focused on the patient during AVC rehabilitation was sufficient to ensure patient movements were as intended is unknown.

Deliberate, top-down reasons for physiotherapists to focus the majority of fixation time on the screen include to intentionally use information displayed on the technology screen, as a surrogate for patient performance, considering that all technologies continuously provided knowledge of performance. Another potential top-down reason for physiotherapists to focus visual attention on the screen display is to inform supplementary feedback or cueing, complementary to the technology and in order to succeed at the game or technology task. For example, in a game where multidirectional walking is required, being aware in which direction the patient is prompted to walk allows the physiotherapist to provide congruent cueing and feedback. The next chapter of this thesis will investigate physiotherapist communication during these observed sessions and determine if and what differences exist in instruction and feedback between rehabilitation without and with AVC technologies.

A bottom-up approach to visual attention would suggest that the screen display may provide a distraction for physiotherapists as the graphics, designed to be visually attractive, unintentionally draw attention away from the patient. The fact that AVC technologies can divert attention from the AVC exercise itself has been previously reported by people participating in AVC-based exercise, with increased immersion associated with increased distraction (Faric et al., 2019; Natbony et al., 2013; Neumann & Moffitt, 2018). This distraction can be advantageous for the patient as any physical discomfort associated with rehabilitation exercise may be less prominent (Faric et al., 2019; Neumann & Moffitt, 2018), or may be a barrier to participating as the exercise becomes secondary (Natbony et al., 2013). Rehabilitation-specific technologies have been purported to provide less extraneous visual information than recreational systems (Yates et al., 2016), so recreational systems may potentially attract more of the physiotherapists’ focus of visual attention. Whether this is detrimental to patient outcomes is unknown. Physiotherapists should endeavour to focus their visual attention on locations providing the most relevant information to direct their clinical practice and maintain physiotherapist-patient interaction.

6.4.3 Future research

Research in the fields of radiology, dermatology and surgery have illustrated significant differences in visual attention between health professionals with varying levels of expertise (Al-Moteri et al., 2017; Blondon et al., 2015; Brams et al., 2019; Van der Gijp et al., 2017), with less experienced clinicians being more likely to pay more attention to visual locations not pertinent to the clinical task (Brunye et al., 2019). Recent research into physiotherapist visual fixations while viewing a short video of patient gait also indicate differences in visual attention with different levels of experience, with experienced clinicians fixating more frequently than novices (Hayashi et al., 2020). Potentially, physiotherapist visual behaviour in clinical practice may vary with both general experience and specific experience in the use of AVC technologies in rehabilitation. The physiotherapists in our study all reported occasional use of gaming technologies and 73% reported occasional use of rehabilitation technologies. This is a higher proportion of physiotherapists with AVC experience than reported in therapist surveys in Canada (46%) and US (64%) (Levac, Glegg, et al., 2019) and may be representative of previously reported high availability of gaming technologies in Australian stroke units (76% in 2012) (National Stroke Foundation, 2012). Further studies need to be carried out to establish if and how physiotherapists' focus of visual attention changes with AVC rehabilitation experience. Further areas of future research include the impact of the use of AVC on other aspects of physiotherapist behaviour, such as the provision of cueing and feedback, in order to broaden our understanding of how AVC technologies affect the delivery of rehabilitation. Additional studies are also needed to provide more insight into how the change in physiotherapists' focus of visual attention influences clinical practice, and how this impacts on patient outcomes. Such studies may need to incorporate mixed methodologies, such as eye tracking metrics combined with qualitative interviews (Al-Moteri et al., 2017).

6.4.4 Strengths and limitations

This study has various strengths and limitations. The use of eye tracking glasses to record visual attention allowed for unimpeded physiotherapist movement and therefore the reported results ought to be representative of actual clinical practice. Whilst eye tracking glasses can fail to capture samples due to issues such as blinking, eye gaze being outside the capture area, or glasses moving on the face after calibration, this study only included files with more than 80% valid eye gaze samples to ensure data captured was representative of the session (Orquin & Holmqvist, 2019). In addition, recordings were relatively short (mean (SD) 11.5 (3.8) min), and the brand of glasses used were reportedly less sensitive to moving on the face than other systems (Niehorster et al., 2020).

A limitation of this study is that the results are specific to the clinical setting in which data was collected. In this study the physiotherapists were very familiar with their rehabilitation setting, and the study area was screened from the rest of the gym area for privacy. In non-research settings, where rehabilitation gym spaces are commonly shared with multiple patients and physiotherapists, there may be more stimuli to attract physiotherapist attention. Secondly, whilst physiotherapists were not explicitly informed of the eye tracking nature of the glasses, participants were aware that they were being observed and the researcher was present for all sessions; this may have influenced physiotherapist behaviour and therefore had an indirect impact on their focus of visual attention. However, focus of visual attention on the researcher was minimal (proportion of total fixation time; median (IQR) 0.2% (0-1%)), and similar between conditions, indicating minimal impact on clinical practice. Thirdly, the results of this study could have been different if the accompanying sound effects from each of the AVC technologies had been used, possibly reducing the need for the clinician to visually attend to the technology. Finally, is should be acknowledged that the results are specific to the rehabilitation specific technologies used, and the employment of other AVC technologies, including recreational technologies, may deliver dissimilar results.

6.4.5 Conclusion

This is the first known study to record physiotherapist focus of visual attention during clinical practice. The results have established physiotherapists primarily focus on the patient's body during rehabilitation without AVC technologies. In rehabilitation with AVC technologies physiotherapists primarily focus on the technology screen, and the average duration of each fixation is significantly longer, resulting in a similar proportion of total fixation time on the screen in rehabilitation with AVC technologies as the patient in rehabilitation without AVC technologies. It is currently unclear if this change in visual attention is due to physiotherapists deliberately looking at the screen to obtain visual information to inform clinical practice, or if the technology inadvertently diverts visual attention away from the patient. Developers of AVC technologies should ensure information displayed on screen is pertinent to both physiotherapists and patients.

CHAPTER 7: PHYSIOTHERAPIST INSTRUCTION AND FEEDBACK IN MOBILITY REHABILITATION WITHOUT AND WITH AVC TECHNOLOGIES

Preface:

The previous chapter assessed physiotherapist focus of visual attention during rehabilitation without and with AVC technologies, following the protocol presented in Chapter 5. The results indicated that physiotherapist visual attention is primarily directed at the patient body during rehabilitation without AVC technologies. However, during rehabilitation with AVC technologies, physiotherapist visual attention is focused mainly on the technology screen. The reasons for this significant shift in visual attention are unknown, and the associated impact on physiotherapy practice has not been previously reported.

Next, analysis of physiotherapist communication during the same 30 matched rehabilitation sessions without and with AVC technologies was undertaken, with a detailed extraction of the amount and type of physiotherapist instruction and feedback. In addition, the relationship between the observed patterns in focus of visual attention and the observed patterns of instruction and feedback were explored.

The study presented in this chapter reports these findings and addresses research objective four: To analyse the provision of physiotherapist instruction and feedback during usual mobility rehabilitation without AVC technologies and AVC-based mobility rehabilitation and identify similarities and differences in physiotherapist instruction and feedback between rehabilitation without and with AVC technologies.

The findings from this chapter will be disseminated at a presentation at the Australian Physiotherapy Association Thrive 2021 Conference. The abstract for this is available in Appendix R.

7.1 Introduction

Conventional physiotherapy rehabilitation for mobility limitations involves motor learning to redevelop movement patterns (Carr & Shepherd, 1989), encouraging neuroplastic changes in people with musculoskeletal (Boudreau et al., 2010; Gokeler et al., 2019) and neurological disorders (Cramer et al., 2011; Sampaio-Baptista et al., 2018). In mobility rehabilitation, providing patients with individual, task-specific feedback to promote motor learning is a primary physiotherapist role (van Vliet & Wulf, 2006). Feedback can be classified as intrinsic (i.e. movement information from a person's own senses) or extrinsic (i.e. information from an outside source) (Schmidt, 2019). Extrinsic feedback, commonly provided by the physiotherapist, is particularly important in rehabilitation when intrinsic patient feedback mechanisms may be compromised, and may be visual, auditory or haptic in mode (van Vliet & Wulf, 2006). Feedback in motor learning can be classified as providing knowledge of performance (KP) or knowledge of results (KR) (Magill, 2017). KP promotes superior motor learning compared to KR in people with and without neurological impairments (Cirstea & Levin, 2007; Levin & Demers, 2020; Soares et al., 2019). Motivational statements are comments which reinforce and encourage patient participation without imparting specific movement knowledge (Stanton et al., 2015), although these statements may promote motor learning by encouraging additional practice and by reducing self-focus to allow for further attention on the movement task (Wulf & Lewthwaite, 2016). Therapist instruction and feedback can invoke an internal focus of attention (focus on body movement) or external focus of attention (focus of the effect of the movement on the environment) (Wulf et al., 1998), with an external focus superior for motor learning as it encourages movement mechanisms that are more implicit and automatic (Kal et al., 2019; Wulf, 2013). Previous observational research has found that physiotherapists in rehabilitation typically provide motivational statements and instructions more frequently than feedback (Carr et al., 2011; Durham et al., 2009; Talvitie, 2000), and verbal statements are the primary mode of delivery (Johnson et al., 2013; Talvitie, 2000). Feedback that is provided to patients with stroke during gait rehabilitation has been observed to be mainly internally focused (Johnson et al., 2013; Kal et al., 2018).

Active videogame and computer-based (AVC) rehabilitation technologies are being increasingly researched and implemented in clinical practice due to their potential to provide increased amounts of extrinsic feedback and enhance therapy engagement and dose (Hassett et al., 2016; Holden, 2005; Howard, 2017; Levin & Demers, 2020; Rohrbach et al., 2019; van den Berg, 2018). AVC systems register patient movement to engage with a virtual, onscreen environment and include both recreational systems, designed for the general population, and rehabilitation-specific systems, designed for use by patient populations.

The extrinsic feedback provided by AVC technologies in rehabilitation practice promotes motor learning through provision of information to the patient which may enhance performance, and inform the patient of successful attempts which may motivate participation (Baranowski et al., 2013; Darekar et al., 2015; Doyle et al., 2011; Hassett et al., 2019; Levin et al., 2015). AVC devices provide extrinsic feedback in a multitude of ways; for example, by displaying immediate on-screen visual feedback to illustrate weight shift in standing, or sounding a congratulatory noise when a movement target is reached. AVC technology interventions provide an external focus of attention for patients and systems may provide feedback, instructions and motivational encouragement (Imam & Jarus, 2014).

The reported effect of AVC technologies on physiotherapist instruction and feedback is mixed. In qualitative studies, some physiotherapists have reported that they provide more positive feedback when using AVC technologies, to negate the negative feedback from commercial game systems (Levac, Miller, et al., 2012) or to interpret the feedback provided by the technology (Hamilton, McCluskey, et al., 2018). Yet, others have reported giving less feedback when using AVC technologies in rehabilitation as they felt the volume of feedback delivered by the game was overwhelming (Levac, Miller, et al., 2012), or because patient attention appeared focused on the technology (Tatla et al., 2015). These studies have relied on physiotherapist self-report, which is known to be unreliable in observational therapist studies in usual rehabilitation (Durham et al., 2009; Stanton et al., 2015). Quantification of characteristics of instruction and feedback in rehabilitation without and with AVC-based interventions is required.

Although the use of AVC technologies is a rapidly expanding area in physical rehabilitation, little is known about how the use of AVC technologies changes the physiotherapist role in clinical practice, particularly the quantity and characteristics of physiotherapist instruction and feedback. The primary aim of this observational study was to investigate and compare instruction and feedback provided by physiotherapists during rehabilitation without and with AVC technologies for patients with mobility limitations. Specific instruction and feedback characteristics assessed were modality, quantity, content, attentional focus, and affective presentation (positive or negative).

The research questions were:

1. What are the characteristics of physiotherapist instruction and feedback provided during usual mobility rehabilitation without technologies?
2. What are the characteristics of physiotherapist instruction and feedback provided during AVC-based mobility rehabilitation?
3. What are the similarities and differences in physiotherapist instruction and feedback characteristics during mobility rehabilitation without and with AVC technologies?

In addition, the secondary aim of this study was to explore if there were any relationships between physiotherapist focus of visual attention reported in the previous chapter and the quantity and type of verbal instruction and feedback during mobility rehabilitation without and with the use of AVC technologies.

7.2 Methods

7.2.1 Design

This was a prospective observational study, evaluating physiotherapist instruction and feedback during rehabilitation without and with AVC technologies. Chapter 5 contains the detailed study protocol. In summary, physiotherapist and patient dyads were observed whilst engaged in a mobility rehabilitation exercise without and with AVC technologies, undertaken in random order. The AVC technology-based exercise was chosen to mimic the exercise without AVC technology as closely as possible.

7.2.2 Participants and setting

In this study, both physiotherapists and patients were considered participants, and were convenience sampled from rehabilitation services at two metropolitan Adelaide hospitals. To be eligible, physiotherapists had to be working within rehabilitation wards and willing to use technology in clinical practice, while patients were eligible if they were receiving rehabilitation for mobility limitations (regardless of diagnosis), able to provide own informed consent and also willing to use technology in rehabilitation. Patients were excluded if, in the opinion of their treating physiotherapist, they were unable to participate for any reason, such as significant visual, cognitive, or behavioural issues.

All participants were kept naïve to the specific research objectives, and only informed that the study was to investigate the use of AVC technologies in physiotherapy practice, to minimise the potential effect of study observation on therapy. Physiotherapists and patient participants were all provided with a Participant Information Sheet and provided written consent prior to study enrolment. Ethical approval was provided by the Southern Adelaide Human Research Ethics Committee (HREC/19/SAC/109 OFR 100.19).

7.2.3 Procedure

Prior to study commencement, consented physiotherapists were orientated to the different AVC systems available for this study. Physiotherapists completed a questionnaire regarding basic demographic data, clinical and technology experience. Demographic information was also collected from patients, including diagnosis, technology experience and current goals of therapy.

The observed session addressed one of four common mobility limitations in people receiving physiotherapy rehabilitation: 1) sit to stand, 2) stepping 3) standing balance or 4) dynamic balance. In planning for the session, the physiotherapist prescribed a task-specific exercise addressing one of the mobility limitations as per usual care, then the researcher, in discussion with the physiotherapist, matched this usual care exercise with an AVC exercise. Both exercises were performed in the same session, in random order. Data collection took place in an appropriately screened therapy area within the recruitment wards. Any sound effects from the AVC technologies were muted to avoid distracting other people within the rehabilitation area. If required, the researcher provided technical assistance during the delivery of therapy but did not otherwise intervene.

The data collection session was recorded with two video cameras to allow for subsequent review and coding. This was chosen over direct observation due to its superior validity (Fini et al., 2015).

7.2.4 Active Videogame and Computer-based technologies

The protocol for this study allowed for tailored selection of AVC exercises from one of four commercially available, inexpensive and portable systems, each which display visual task-related feedback on a screen. Two recreational systems (Nintendo Wii Fit and Xbox Kinect) and two rehabilitation-specific systems (Humac Balance Board and Intelligent Rehabilitation Solutions (IRS)) were selected for use in this study. A 3D motion capture camera is utilised for patient movement interaction with Xbox Kinect and IRS, while a force plate is employed for Wii Fit and Humac Balance Board. Further information about each AVC system is available in the study protocol described in Chapter 5 and description of the exercises used is in Appendix N.

7.2.5 Data extraction

Each data collection session was recorded by two video cameras for subsequent data extraction. One camera was worn by the physiotherapist as part of the eye-tracking glasses and the second camera was either mounted on a tripod or handheld by the researcher to ensure the physiotherapist was in view throughout the session. Analysis of the video recordings was coded with the use of a purposefully designed data extraction sheet (Appendix S). Each video recording was split into 15 second epochs and viewed for active patient rehabilitation time. Partial epochs at the start or end of active time were discarded, as were rest breaks. Within each remaining 15 second epoch the number and type of instructions and feedback provided by the physiotherapist were recorded. As physiotherapist touch is often continuous this was coded as either being present or not present for each epoch. Figure 7-1 illustrates how instruction and feedback was coded while Table 7-1 details the subcategories and definitions for each coding category and provides examples of each. Technology instruction and feedback, provided visually, was also documented, however as it was largely continuous it was counted once per epoch. To confirm accuracy and completeness, a second reviewer independently coded 10% of the data, where inter-rater comparison approached >80% agreement. Due to the nature of the intervention coders were not blinded to study condition.

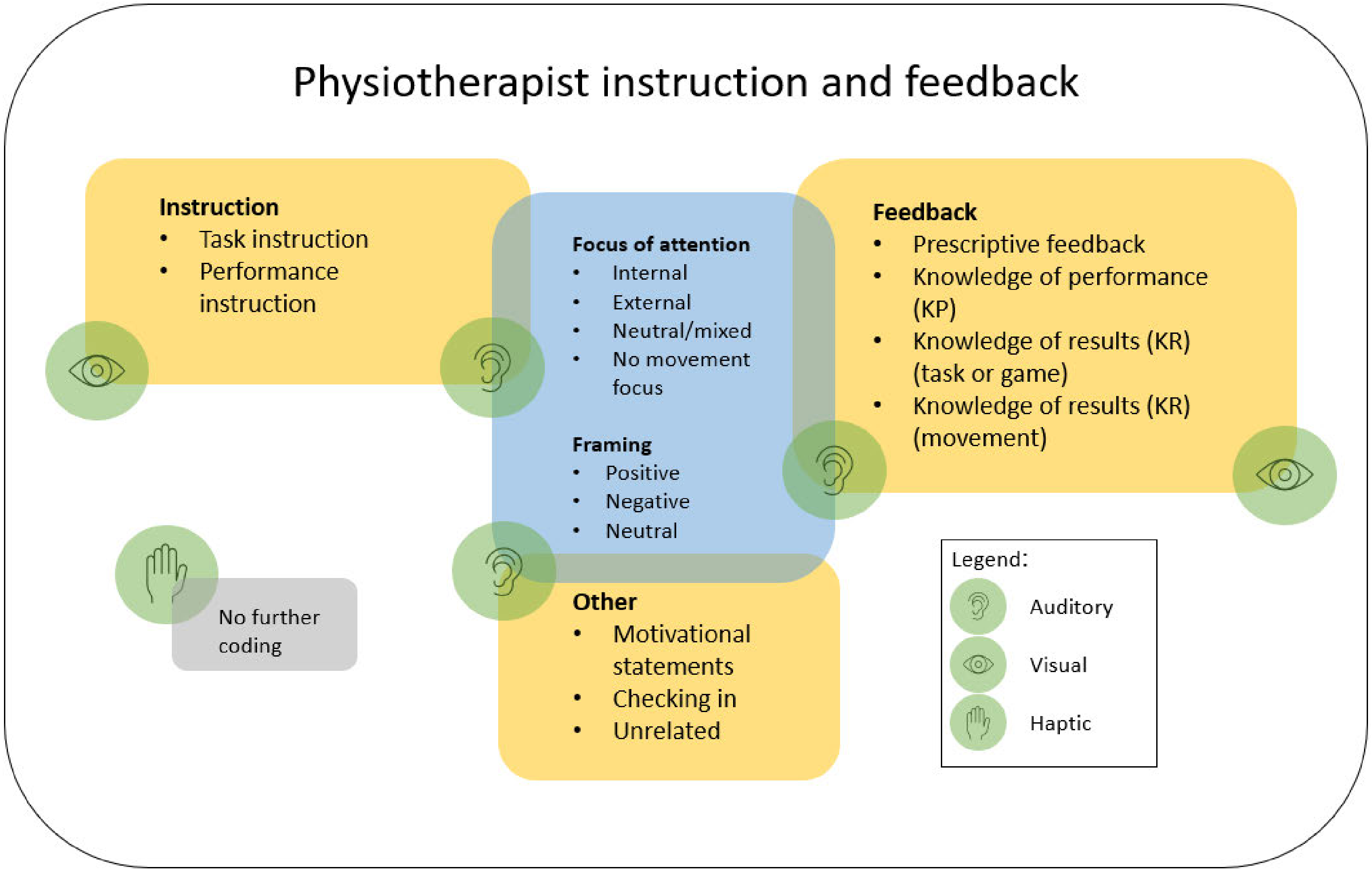

Figure 7-1 Coding of physiotherapist instruction and feedback.

Physiotherapist instruction and feedback was coded for modality (auditory, visual or haptic) and content (instruction, feedback and other). Auditory statements were further coded for focus of attention and framing.

Table 7-1 Definitions used in the coding of physiotherapist instruction and feedback

Section	Category	Sub-category	Definition	Examples	Notes
Time points	Start of active time		When the patient begins the intended movement	Commence sit to stand action	Partial epochs at start of active time discarded
	End of active time		When the patient ceases the intended movement/completes the last repetition	Complete final sit to stand action	Partial epochs at end of active time discarded
	Rest break		When the patient is not actively performing the intended exercise	Sitting and resting between sets of sit to stand	Can be at rest in any position including sitting and standing. Partial epochs due to rest breaks discarded
Modality	Haptic – physiotherapist instruction and feedback perceived by patient via touch		Physiotherapist using touch in order to improve movement quality or for safety	Tapping, positioning, guiding movement, supporting knee extension	Occasions only counted once per epoch, regardless of if continuous or repeated.
	Visual – physiotherapist instruction and feedback perceived by patient via vision		Physiotherapist providing hand gestures or demonstrations to provide instruction or feedback to the patient; Physiotherapist providing mirror for feedback	Pointing to cue a certain direction of movement, modelling an exercise to provide instruction or feedback, providing a mirror for continuous performance feedback	Excluded physiotherapist facial expressions. All occasions counted, regardless of whether patient appeared to be attending to the visual information provided Occasions only counted once per epoch, regardless of if continuous or repeated

	Auditory – physiotherapist instruction and feedback perceived by patient via hearing	Verbal	Therapist providing verbal, spoken word statements	"Let's stand up now" "Your posture is looking really straight today"	Each phrase coded separately
		Non-verbal	Therapist using non-lexical sounds as a replacement for spoken words	"ahhh" "mm-hmm" "uh-huh"	These only included when used as a replacement for a spoken phrase e.g., a deliberate, drawn out "uhm" to alert the patient to reconsider what was happening. Non lexical fillers within phrases were not coded.
		Non-vocal	Therapist directing other sounds at the patient	Clapping, tapping foot, clicking fingers	These only included sounds explicitly directed to the patient to influence behaviour.
Content (visual and auditory instruction and feedback only)	Instruction – communication directed at patient to elicit a desired action without reference to a previous action	Task instruction	Instruction about what to do without detail on performance quality	"Step forward", "left foot yellow", "2 more", "stand up".	These instructions imply patient will generate their own implicit movement patterns, and may have either internal or external focus of attention
		Performance instruction	Instruction on how to do the exercise; specific information on the performance quality	"Move your weight forward so your hips touch my hand as you stand up" "make sure you put your foot down slowly and quietly"	These instructions provide some form of explicit movement instruction, and may have either internal or external focus of attention

Feedback – communication directed at patient relating to a previous action	Prescriptive feedback	Instruction on how to perform the exercise with explicit reference to previous attempts	“Next time make it a bigger step with your left foot”	
	Knowledge of performance (KP)	Information on the performance of the exercise leading to the final outcome	“You’re moving your foot too quickly” “I think you’re leaning too far”	
	Knowledge of results (KR) – task or game	Information on the outcome of the task or game	“You knocked all the pins down” “that’s three reps done”	
	Knowledge of results (KR) – movement	Information on the outcome of the movement or skill	“Your step was long enough that time”	
Other – verbal statements directed at patient that is neither instruction or feedback	Motivational	Statements without specific informational content, intended to motivate or reinforce patient efforts	“That’s it” “great”	
	Checking in	Queries directed at patient to elicit information	“Feeling ok?” “shall we do some more?”	
	Unrelated	Statements not related to the patient performing the exercise	“It’s great weather today” “I heard your sister visited on the weekend”	These tended to be conversational in nature

Focus of attention (Verbal Statements only)	External	Statements directing patient attention to the effects of the movement on the environment	“Touch my hand”, “ski around that corner”, “walk to that gap”	
	Internal	Statements directing patient attention towards the movement itself	“Make sure you straighten your left knee” “you need to squeeze your bottom now”	
	Neutral/mixed	Statements regarding movement without a specific internal or external focus or with both foci within the same statement	“Ok, do the same again” “bend your knee more to get your foot onto the step”	
	No movement focus	Statements not directing attention to movement or body	“Good” “well done”	Typically motivational or unrelated statements
Framing (Verbal statements only)	Positive	Statements that is expressed in a positive manner; emphasis on what to do or reinforcing correct performance	“You’re doing a great job at getting more weight on your left side” “make sure you look ahead once you’re standing up”	
	Negative	Statements that is expressed in a negative manner; emphasis on what not to do or highlighting performance errors	“Your knee isn’t getting high enough” “Don’t look down once you’re standing up”	

Neutral/not applicable	Statements that is expressed in a way that is neither positive or negative	“That hole is a different size” “so you’re the blue ball”	Typically statements of fact

7.2.6 Data analysis

Extracted data was imported into SPSS (Version 25) for data analysis. Physiotherapist and patient demographic data, and the type and key characteristics of physiotherapist instruction and feedback (mode, content, focus of attention and framing) were descriptively analysed.

To allow comparison between study conditions, the amount of each instruction and feedback type was coded per 15 second epochs and then standardised to 5 minute periods of exercise for meaningful reporting. Data was tested for normality with the Shapiro-Wilk test and was found to be non-parametric. The non-parametric Wilcoxon Signed Rank test was used to compare instruction and feedback results between rehabilitation without and with the use of AVC technologies. The McNemar test was used to determine differences in dichotomous variables between the two conditions. Alpha was set to 0.05 for these tests.

Further statistical tests were conducted to explore emerging patterns in both visual attention (from Chapter 6) and the quantity and type of instruction and feedback provided between rehabilitation without and with AVC technologies. Data sets were coded into groups based on whether or not the physiotherapist provided different types of instruction and feedback (for example if they provided KP within a session). Mann-Whitney tests were performed to assess differences in patterns of visual attention (proportion of fixation time, proportion of number of fixations, average duration of each fixation and uninterrupted number of fixations) between these groups. Mann-Whitney tests were selected to treat the data as independent samples as outcomes were not consistent across all sessions. Spearman's correlations were used to explore relationships between measures of visual attention and the amount of instruction and feedback across both conditions. For these tests alpha was set to 0.01 to reduce the risk of type I errors.

7.3 Results

Data from 30 rehabilitation sessions, each with an exercise without AVC technologies and a matched exercise with AVC technologies, comprising a total of 11 physiotherapists and 27 patients, was analysed. Participant demographics were presented in Chapter 6 and are repeated in Table 7-2 below.

Table 7-2 Participant demographics

	Physiotherapists (n=11)	**Patients (n=27)**
Age (years) mean (SD); range	28 (5); 21-37	65 (19); 19-90
Gender female n (%)	6 (55)	10 (37)
Clinical experience (years) mean (SD); range	5 (4); 0-10	
Prior experience using rehabilitation technology n (%)		
Yes, frequent	0 (0)	
Yes, occasional	8 (73)	
No	3 (27)	
Prior experience using gaming technologies n (%)		
Yes, frequent	0 (0)	
Yes, occasional	11 (100)	
No	0 (0)	
Diagnosis n (%)		
Neurological		18 (67)
Non-neurological		9 (33)
Mobility limitation addressed n (%)		
Sit to stand		5 (19)
Standing balance		9 (33)
Stepping		2 (7)
Dynamic balance		11 (41)

Overall auditory physiotherapist instruction and feedback was provided a median (IQR) of 77.9 (66.2 - 101.8) times per 5 minutes of rehabilitation without AVC technologies, with the majority being task instruction, followed by motivational statements. In rehabilitation with AVC technologies, auditory instruction and feedback was similar, and provided a median (IQR) of 68.0 (41.5 - 79.5) times per 5 minutes, with the majority being motivational statements followed by task instruction. Full results are presented below. In summary, statistically significant differences in auditory instruction and feedback between rehabilitation without and with AVC technologies were observed; in rehabilitation with AVC technologies performance instructions, KR (task or game), internally focussed statements and neutrally framed statements were provided less frequently than in rehabilitation without AVC technologies. There were no significant differences in visual or haptic physiotherapist instruction and feedback.

7.3.1 Physiotherapist auditory instruction and feedback

In all sessions the physiotherapist provided instruction and feedback to the patient auditorily, predominately in the form of spoken verbal statements (median (IQR); without AVC: 76.9 (62.4-98.8); with AVC: 67.5 (37.8-79.3); per 5 minute session). Non-lexical sounds such as "aah" and "errr" as a replacement for lexical statements were observed less frequently (median <1 per session in both rehabilitation conditions). No observed sessions contained non-vocal auditory communication such as clapping or clicking fingers.

Physiotherapist verbal instruction and feedback content

Table 7-3 below details the number of sessions in which each type of physiotherapist verbal instruction or feedback was observed and the average number of physiotherapist verbal statements in each category during those sessions. The number of sessions in which KR (task or game) was provided, such as "you knocked all the pins down" or "that's 3 reps done" was significantly higher in rehabilitation with AVC technologies than in rehabilitation without AVC technologies (n (%); without AVC: 7 (23%); with AVC: 19 (63%), p=0.002), but no other statistically significant differences between rehabilitation/study conditions were observed.

Physiotherapists used verbal statements most frequently for instruction and motivational comments. Comparison of instruction and feedback frequency between rehabilitation conditions revealed task instruction (e.g. "pick up the cone") and performance instruction (e.g. "bend your knee as you step") both occurred nearly twice as often in rehabilitation without AVC technologies than in rehabilitation with AVC technologies, although this was only statistically significant for performance instruction (median (IQR): without AVC: 14.0 (6.9-22.7); with AVC: 7.7 (3.4-16.15), p=0.042; per 5 minute session). Non-specific, motivational statements (e.g., "yeah" and "great"), were observed at similar frequencies in both rehabilitation conditions.

Whilst KR (task or game) was provided in a significantly smaller number of sessions without AVC technologies, when it was offered it was done so more frequently than in rehabilitation with AVC technologies (without AVC: 8.0 (5.0-18.4); with AVC: 2.2 (1.6-4.0), p=0.003; per 5 minute session). Physiotherapists also provided significantly more performance instruction during rehabilitation without AVC technologies than in rehabilitation with AVC technologies (without AVC: 14.0 (6.9-22.65); with AVC: 7.7

(3.4-16.15), p=0.042; per 5 minute session). There were no other statistically significant differences between rehabilitation conditions.

Table 7-3 Physiotherapist verbal instruction and feedback content – number of sessions observed

	Rehabilitation without AVC technologies		**Rehabilitation with AVC technologies**	
	Number of sessions observed, n (%)	**Frequency per 5 minute session where observed, median (IQR)**	**Number of sessions observed n, (%)**	**Frequency per 5 minute session where observed, median (IQR)**
Task instruction	30(100)	31.8(12.4-42.8)	28(93.3)	17.5(7.9-33.9)
Performance instruction	22(73.3)	14.0(6.9-22.7)	22(73.3)	7.7(3.4-16.15)^
Prescriptive feedback	10(33.3)	3.2(2.5-5.8)	12(40.0)	3.5(2.1-4.0)
Knowledge of performance	13(43.3)	4.4(2.5-6.6)	20(66.7)	5.2(2.5-8.0)
Knowledge of results (movement)	3(10.0)	1.6 (-)	6(20.0)	1.4(1.2-1.7)
Knowledge of results (task or game)	7(23.3)	8.0(5.0-18.4)	19(63.3)*	2.2(1.6-4.0)^
Motivational statements	30(100)	21.7(11.9-33.1)	30(100)	20.9(13.6-34.9)
Checking in	20(66.7)	3.0(1.65-6.2)	13(43.3)	3.0(1.9-4.4)

Unrelated statements	24(80.0)	4.4(3.1-7.4)	26(86.7)	5.5(3.0-8.8)

Note: Data counted within each 15 second epoch and normalised for 5 minutes of rehabilitation.

* represents p<0.05 on related samples McNemar test; ^ represents p<0.05 on independent-samples Mann-Whitney U test

Focus of Attention

Statements with an internal focus of attention were observed in 23/30 sessions without AVC technologies and in 27/30 sessions with AVC technologies. When internal focus of attention statements were used this was done so significantly more frequently in rehabilitation without AVC technologies than rehabilitation with AVC technologies (median (IQR); without AVC: 20.0 (6.6-35.6); with AVC: (11.8 (3.4-16.6), p=0.003; per 5 minute session). Table 7-4 displays the focus of attention results, including the number of sessions and frequency within these sessions.

Table 7-4 Focus of attention

	Rehabilitation without AVC technologies		**Rehabilitation with AVC technologies**	
	Number of sessions observed, n (%)	**Frequency per 5 minute session where observed, median (IQR)**	**Number of sessions observed n, (%)**	**Frequency per 5 minute session where observed, median (IQR)**
Internal	23(76.7)	20.0(6.6-35.6)	27(90)	11.8(3.4-16.6)^
External	28(93.3)	13.8(6.6-21.9)	30(100)	13.6(7.9-26.2)
Mixed	17(56.7)	10.0(3.1-13.4)	16(53.3)	9.8(3.4-22.0)
No movement focus	30(100)	33.9(19.7-44.3)	30(100)	26.5(38.7-15.8)

Note: Data counted within each 15 second epoch and normalised for 5 minutes of rehabilitation.

^ represents p<0.05 on independent-samples Mann-Whitney U test

Framing

The majority of verbal statements in both rehabilitation conditions were positively framed (median (IQR); usual 67.9 (53.7-81.0); AVC 56.9 (32.1-77.9), p=0.165; per 5 minute session). Negative and neutral statements were observed considerably less often with statistically significantly fewer neutral statements used in rehabilitation with AVC technologies than in rehabilitation without AVC technologies (without AVC: 8.0 (4.0-15.0); with AVC: 4.0 (3.7-9.2) p=0.046; per 5 minute session). Results on framing of instruction and feedback are presented in Table 7-5.

Table 7-5 Framing of physiotherapist verbal statements

	Rehabilitation without AVC technologies		**Rehabilitation with AVC technologies**	
	Number of sessions observed, n (%)	**Frequency per 5 minute session where observed, median (IQR)**	**Number of sessions observed n, (%)**	**Frequency per 5 minute session where observed, median (IQR)**
Positive	30(100)	67.9(53.7-81.0)	30(100)	56.9(32.1-77.9)
Negative	14(46.7)	3.6(2.7-6.75)	17(56.7)	3.4(2.4-4.0)
Neutral	23(76.7)	8.0(4.0-15.0)	25(83.3)	4.0(3.7-9.2)^

Note: Data counted within each 15 second epoch and normalised for 5 minutes of rehabilitation.

^ represents p<0.05 on independent-samples Mann-Whitney U test

7.3.2 Physiotherapist haptic instruction and feedback

The use of physiotherapist touch for safety, instruction and feedback was observed in 18 (60%) rehabilitation sessions without AVC technologies and 19 (63%) rehabilitation sessions with AVC technologies. Where haptic instruction and feedback was provided this was done so either continuously or very frequently. There were no statistically significant between-group differences in how haptic instruction and feedback was used.

7.3.3 Physiotherapist visual instruction and feedback

Physiotherapists provided visual instruction and feedback during 18 (60%) rehabilitation sessions without AVC technologies and 12 (40%) rehabilitation sessions with AVC technologies, with infrequent provision within each session when provided (median per 5 minute session (IQR); without AVC: 4.3 (3.4-14.3); with AVC: 3.7 (1.9-6.2), p=0.241), and primarily for task instruction purposes, such as pointing or gesturing what to do (without AVC: 16 (53%); with AVC 12: (40%) sessions, p=0.424). Visual instruction to cue quality of performance, such as modelling the intended movement pattern was provided in only a small proportion of sessions (without AVC: 5 (16.7%); with AVC: 3 (10%), p=0.625), and where provided was infrequent (without AVC: 1.5 (1.5-3.3); with AVC: 1.8 (1.3-1.9), p=0.786). Feedback was rarely provided visually, with both types of rehabilitation sessions recording knowledge of performance in 3 (10%) sessions each. There was no statistically significant difference in presence or frequency of physiotherapist visual instruction or feedback between rehabilitation without or with AVC technologies.

7.3.4 AVC technology instruction and feedback

Of the 30 sessions analysed for this study, all used technologies designed for rehabilitation, either the Humac (n=17) or Intelligent Rehabilitation Solutions (IRS) (n=13). Screen content analysis revealed instruction to perform the exercise task was provided by the AVC technology in n=25 (83%) of sessions. Examples of this include a displayed target to walk to, maze to navigate via weight shift or coins to collect by sitting and standing. In three sessions the AVC technology provided the patient with specific additional instruction to correct performance, such as displaying an instruction to face the screen when a patient turned away while side stepping. During all sessions the AVC technology supplied continuous feedback in the form of knowledge of performance, with n=4 (13%) of sessions using an avatar for this feedback, and n=26 (87%) portraying patient movement via movement of an inanimate object, such as a ball, car or submarine. Knowledge of results was also provided in all sessions, with score and time continuously displayed. In addition to the score, several games also provided additional information each time a particular goal was reached, such as a large animated “+10” to indicate 10 more points were added, or by greying out an achieved goal.

7.3.5 Exploration of physiotherapist focus of visual attention and the provision of instruction and feedback

To explore emerging patterns between physiotherapist focus of visual attention (presented in Chapter 6) and instruction and feedback in both rehabilitation without and with AVC technologies, Mann-Whitney tests were performed to assess differences in the measures of visual attention in sessions without and with physiotherapist provision of each aspect of instruction and feedback. The relationships between visual attention and instruction and feedback across both conditions were explored further via Spearman’s correlations. Key findings are reported below with the full analysis available in Appendix T.

Instruction

When exploring patterns between type of instruction and visual attention, Mann-Whitney tests indicated that in rehabilitation without AVC technologies, the number of uninterrupted visual fixations on the patient face and body were greater in sessions where physiotherapists provided performance instruction (median (IQR) face 2.2 (1.5-3.0); body 6.2 (3.7-11.2)) than in sessions where physiotherapists did not provide performance instruction (face 1.3 (1.2-1.4); body 2.8 (2.2-4.6), $p=0.001$ and $p=0.005$ respectively). This pattern was not observed in rehabilitation with AVC technologies. In addition, correlational analysis demonstrated a moderate positive correlation between performance instruction and number of fixations on the patient body ($\rho=0.475$, $p=0.008$), and performance instruction and number of uninterrupted fixations on the patient body ($\rho=0.580$, $p<0.001$) in rehabilitation without AVC technologies.

Feedback

There were no significant differences in any of the measures of visual attention when analysed with respect to whether any type of feedback was present or absent. There were also no significant correlations between visual attention and feedback measures in rehabilitation without AVC technologies. In rehabilitation with AVC technologies, a moderate positive correlation between KR (task or game) and average duration of fixations on the patient body (ρ =0.486, p=0.008), and a moderate negative correlation between average duration of fixations on the screen and KR (movement) (ρ = -0.485, p=0.007) were observed.

Motivational and other statements

There were no significant differences in any of the measures of visual attention when analysed with respect to the provision or absence of motivational or other statements. In rehabilitation without AVC technologies, correlational analysis indicated a moderate positive correlation between number of checking in comments and proportion of total fixation time on the patient face (ρ=0.574, $p<0.001$) and a moderate positive correlation between unrelated comments and uninterrupted number of fixations on equipment (ρ=0.566, p=0.007). In rehabilitation with AVC technologies, a moderate negative correlation was demonstrated between unrelated comments and overall proportion of total fixation time on the patient (ρ=-0.505, p=0.008).

7.4 Discussion

In this study we observed physiotherapist instruction and feedback during mobility rehabilitation without and with AVC technologies. The findings have indicated that during rehabilitation with AVC technologies, despite substantial amounts of instruction and feedback provided by the technology, the overall amount of physiotherapist instruction and feedback remained largely similar to that observed in rehabilitation without AVC technologies. However, significant differences were observed in some types of instruction and feedback, with less frequent performance instructions, KR (task or game), internally focussed statements and neutrally framed statements within rehabilitation sessions with AVC technologies, although KR (task or game) occurred in more sessions with AVC technologies overall.

Verbal instruction and feedback

In rehabilitation without AVC technologies, verbal statements were frequently used by physiotherapists, with a median of 77.0 statements in a standardised 5 minute session. This is similar to Kal et al. (2018), who observed physiotherapists conducting gait rehabilitation following stroke and reported an average of 53.5 statements per 5 minutes, and consistent with high levels of physiotherapist statements previously reported in other observational studies (Durham et al., 2009; Johnson et al., 2013; Talvitie, 2000; Talvitie & Reunanen, 2002). Overall verbal statements were the most dominant form of communication, in line with reports from Finland (Talvitie, 2000) and England (Johnson et al., 2013), indicating this trend is not specific to a particular region.

Task instruction

The introduction of AVC technology did not significantly change the amount of task instruction provided by the therapist, despite the technology also providing task instruction in 83% (n=25) sessions. Although timing of instruction relative to movement was not explicitly examined it was observed that in AVC sessions physiotherapist task instruction was often provided concurrent with actual task performance, e.g., the physiotherapist stated “walk forward” when the patient was already walking forward in response to a task cue on screen. It is unclear as to whether the physiotherapist provided this as commentary, as motivation and reinforcement, or as a mechanism for continued communication when instructions are provided by the AVC technology. However, in rehabilitation where patient attention is a finite resource (Magill, 2017; Peters et al., 2015), and where physiotherapists may need to aid patients in the use of AVC technologies (Hamilton, McCluskey, et al., 2018), more specific performance instruction or informational feedback could be considered greater value.

Performance instruction

In the current study, physiotherapists provided about half the number of performance instructions such as “shift your weight slowly to your left foot as you reach for the cone” in sessions with AVC technologies compared to rehabilitation sessions without AVC technologies. It is possible that since AVC rehabilitation was novel, physiotherapists intentionally withheld performance instructions during AVC sessions in order to observe and assess patients’ own movement patterns first. However, as it has been suggested that the gamified nature and virtual environment of AVC technologies can encourage inferior movement patterns (Demers & Levin, 2020; Lewis et al., 2011; Liebermann et al., 2012; Tatla et al., 2015) patients may still require explicit movement instruction to correct these patterns (Hassett et al., 2019), and this warrants further investigation.

Feedback

Verbal statements to provide feedback were used only sparingly in both rehabilitation conditions; considerably less frequently than instructions and motivational statements (e.g., median (IQR) KP feedback without AVC: 4.4 (2.5-6.6); with AVC 5.2 (2.5 – 8.0); motivational statements without AVC: 21.7 (11.9-33.1); with AVC 20.9 (13.6-34.9)). Anecdotally it was noted that when a patient performed a successful exercise attempt the physiotherapist often provided a short motivational statement e.g., “well done”, rather than explicit informational feedback. After less successful attempts the physiotherapist often used performance instruction to elicit a movement change, in lieu of specific feedback, such as “I want you to really work on getting your left knee straight” rather than stating the left knee was flexed. This is also reflected in the fact that verbal physiotherapist statements were predominantly positively framed. This finding is similar to the results of Parry (2005), who found physiotherapists engaged in inpatient stroke rehabilitation avoided directly communicating performance errors to the patient, possibly to avoid slighting the patient (Parry, 2005). In our study feedback content was similar in both rehabilitation conditions in all categories except KR (task or game). Physiotherapists provided auditory KR (task or game) feedback referring to the task during more sessions with AVC technologies than sessions without AVC technologies, but when provided, the frequency of this feedback was significantly lower than in rehabilitation without AVC technologies. The KR feedback provided by the AVC technologies was largely task orientated, and related to scores, times and other game outcomes. Whilst not explicitly recorded, it was observed that the KR (task or game) feedback provided by the therapist during the AVC exercise was frequently reading the technology display, e.g., "you scored 100 points on that one". The feedback provided by the device relates to game performance which may not be an indicator of movement performance, (Deutsch, Guarrera-Bowlby, et al., 2011) and patients may be encouraged to achieve higher scores without regard for the therapeutic goal of the exercise (Lewis et al., 2011). In addition, patient movement was mostly represented by AVC technologies as a simple object within the virtual environment. As an example, in the IRS exercise "dynamic balance" the patient is depicted on screen as a ball, and only their gross movement within the defined game play area is represented, without providing feedback of individual limb or body section movements. Physiotherapists should consider providing movement feedback to complement task feedback provided by AVC technologies, ensuring they do not duplicate information already available to the patient.

Motivational statements

Non-specific motivational statements were observed in every session and comprised a substantial component of physiotherapist verbal statements in both rehabilitation conditions. Motivational statements have been previously noted to form a large proportion of physiotherapist communication during usual rehabilitation (Carr et al., 2011; Durham et al., 2009; Johnson et al., 2013; Stanton et al., 2015; Talvitie, 2000). The benefit of motivational statements may lie in encouraging additional practice, reducing self-focus (Wulf & Lewthwaite, 2016) and fostering positive therapeutic alliance (Talvitie, 2000), as patients have reported valuing statements of encouragement (Durham et al., 2009). However, physiotherapists should ensure motivational statements are not provided at the expense of informational instructions and feedback which may be more beneficial for motor learning (Talvitie, 2000; van Vliet & Wulf, 2006). Although AVC technologies have been shown to increase patient motivation and enjoyment of exercise (Mirelman et al., 2009; Rohrbach et al., 2019), in our study physiotherapists did not reduce the amount of motivational statements in rehabilitation with AVC technologies compared to rehabilitation without AVC technologies. The motive for this is unknown. Potentially the physiotherapist aimed to ensure the patient had a positive initial involvement with AVC technologies, as a study on physiotherapist experience using AVC technologies has reported that therapists feel it is important for patients to have a positive first AVC experience in order to foster long term patient engagement and uptake (Hamilton, McCluskey, et al., 2018).

Another explanation is that the therapists did not realise how much feedback they were providing, as research in usual rehabilitation has shown physiotherapists provide significantly more concurrent instruction and feedback than they perceive (Carr et al., 2011). Further research is required to determine the effect of physiotherapist motivational statements during AVC rehabilitation on patient outcomes.

Focus of attention

Internally focused statements were less frequently provided in rehabilitation with AVC technologies than in rehabilitation without AVC technologies, while externally focussed statements occurred at similar frequencies. In addition, the instruction and feedback delivered by the AVC technologies also provided patients with an external focus of attention. Directing patient focus externally may elicit superior motor learning outcomes in people undertaking rehabilitation (Chiviacowsky et al., 2010; Wulf, 2013), yet previous observational studies during gait retraining after stroke have reported physiotherapists predominately provide internally focused feedback (Johnson et al., 2013; Kal et al., 2018). In AVC rehabilitation in our study, the combination of both physiotherapist and AVC technology instruction and feedback meant the majority of instruction and feedback received by patients was externally focused.

Quantity of instruction and feedback

As the AVC technologies provided continuous KP and KR feedback and frequent task instruction, patients experienced more overall instruction and feedback during rehabilitation with AVC technologies compared to rehabilitation without AVC technologies. Although the optimal amount of instruction and feedback to patients has not been determined, research on concurrent feedback indicates motor learning is optimised when feedback is provided infrequently to ensure performance does not become dependent on the feedback provided (Magill, 2017; Schmidt, 2019; Winstein, 1991). Studies on motor learning also suggest that the presence of multiple sources of the same information renders some redundant (Buekers et al., 1992; Guadagnoli & Lee, 2004; Stanton et al., 2017; van Vliet & Wulf, 2006). Buekers et al. (1992) found erroneous verbal feedback can override a learner's own correct visual feedback, indicating the patient may prioritise the physiotherapist instruction and feedback over intrinsic feedback. When presented with physiotherapist and AVC technology information it is unknown which source the patient would give precedence to. In our study, all physiotherapist instruction and feedback was recorded and coded as provided, without inferring patient interpretation. However, it is unlikely that patients attended to every instruction and feedback from both physiotherapist and AVC technology, especially as patients undergoing rehabilitation may have limited attentional capacity (Peters et al., 2015). Reducing the information available to the patient, either by decreasing physiotherapist or AVC input may allow patients to focus on the most pertinent elements and improve rehabilitation efficacy.

Relationship between visual attention and provision of instruction and feedback

The exploration of the relationship between physiotherapists' focus of visual attention and provision of instruction and feedback demonstrated differences in rehabilitation without AVC technologies compared to rehabilitation with AVC technologies. In rehabilitation without AVC technologies increased visual attention on the patient were related to increased performance instruction, more attention to the face was related to more checking in comments, and more attention to equipment was related to more comments that were unrelated to the therapy.

In AVC sessions when more attention was on the patient's body more KR (task or game) and less unrelated comments were provided, but when attention was longer on the screen less KR (movement) was provided. In rehabilitation without AVC technologies, the positive correlation between performance instruction and uninterrupted fixations and overall visual fixations on the patient may potentially be explained by the physiotherapist observing the patient for the purpose of informing performance instruction. Therapist's use of instruction to change movement patterns, in lieu of feedback, has been previously reported (Parry, 2005) and extended visual observation may inform meaningful performance instruction. In rehabilitation with AVC technologies the moderate negative correlation between average fixation durations on the technology screen and KR (movement) may suggest physiotherapists were comfortable with the technologies during these sessions and able to attend more to providing the patient with feedback. However, given the substantial differences in physiotherapist focus of visual attention between rehabilitation without and with AVC technologies and yet the small differences in physiotherapist instruction and feedback, it would appear visual attention is not a large factor in physiotherapist instruction and feedback. Further research is needed to investigate the relationships between physiotherapist visual attention and the provision of instruction and feedback in mobility rehabilitation.

Study Limitations

There were some limitations to this study overall. It should be acknowledged that communication between physiotherapist and patient is inherently a complex task (Parry, 2005; Sondena et al., 2020), and quantitative analysis may have blunted some of the nuanced subtleties present in personal interactions. Whilst it was the intention of this study to only consider physiotherapist instruction and feedback, further research investigating patient perspectives would provide additional insight into the influence of AVC technologies on the physiotherapist-patient relationship. Secondly, individual factors such as physiotherapist preferences and experience, and patient preferences and stage of rehabilitation may all contribute to physiotherapist instruction and feedback. Physiotherapists have been observed to provide a greater proportion of externally focussed statements to patients with a longer length of stay and patients with a preference for internal focus, potentially due to therapists shifting towards encouraging more automatic movement patterns in patients further along in the rehabilitation process and in patients "over focused" on internal mechanisms (Kal et al., 2018). However, the methodology of our study compared the same patient and physiotherapist dyad on the same day to minimise these confounding factors. Thirdly, the AVC technologies in this study only provided visual instruction and feedback to participants; although each technology had sound effects, these were muted to avoid distraction to other people within the rehabilitation space. Also, none of the technologies used provided haptic feedback, and all were rehabilitation-specific technologies. Potentially the results observed could differ in the presence of other AVC technologies and other modalities of AVC instruction and feedback. An inherent limitation of observational research is that participants may change their behaviour in response to being observed (Kawulich, 2005). To minimise this potential bias, best practice guidelines for video collection of observed data were followed as participants were kept naïve to the specific study objectives, performed the activity in a familiar setting and were familiarised with the researcher beforehand (Haidet et al., 2009). Moreover, the same conditions were used for both rehabilitation without and with AVC technologies, so comparison between sessions remains valid. Physiotherapists recruited for this study did not regularly use AVC technologies as part of their clinical rehabilitation practice with patients, although most reported some prior experience doing so. Collecting data in a different clinical setting, where AVC technologies are integrated in clinical practice, may provide further insights into how physiotherapists practice with greater AVC experience. Whilst this study was limited to a sample size of 30 sessions with 11 physiotherapists with 27 patients, and therefore some therapists were represented in multiple sessions, this sample size is similar or greater than existing observational studies of physiotherapist practice (Carr et al., 2011; Durham et al., 2009; Johnson et al., 2013; Kal et al., 2018; Talvitie, 2000).

Future research

Future studies should investigate which aspects of both physiotherapist and technology instruction and feedback patients attend to during rehabilitation with AVC technologies. In addition, investigating the effects of different instruction and feedback provision during AVC rehabilitation on immediate patient movement patterns and longer-term mobility outcomes will further inform physiotherapists and technology developers about optimal AVC rehabilitation delivery.

Conclusion

This study has shown that although AVC technologies provide continuous feedback and frequent instruction, physiotherapist instruction and feedback during rehabilitation with AVC technologies remains largely unaltered when compared to rehabilitation without AVC technologies. Further research is required to investigate the reasons for the similarity in physiotherapist involvement and determine the ideal characteristics of physiotherapist instruction and feedback during AVC-based rehabilitation.

CHAPTER 8: DISCUSSION AND FUTURE RESEARCH

Preface:

To answer the four research objectives posed in this thesis a systematic review, a lab-based study, and a large observational study were conducted. In the following chapter the key research findings are summarised and brought together. Resultant insights in physiotherapy practice in rehabilitation without and with AVC technologies are discussed. Strengths and limitations of the thesis are acknowledged, and future avenues of research are outlined.

8.1 Introduction

AVC technologies are increasingly utilised in mobility rehabilitation, yet the influence of these technologies on the practice of physiotherapy has not been evaluated, including if and how AVC-based rehabilitation: 1) is being reported, 2) affects patient movement, 3) affects therapist focus of visual attention and 4) affects therapist instruction and feedback provided to the patient. To explore this field a series of four research objectives were identified.

1. *To characterise the delivery of VR-based mobility rehabilitation in published literature, including the reported role of the physiotherapist in this delivery*

Key findings:

- The systematic review of interventional VR rehabilitation studies in people with mobility limitations demonstrated that VR interventions were heterogenous and often poorly reported.
- All studies in the systematic review reported using non-immersive technologies.
- The therapist role in the delivery of the VR intervention was ill defined.
- Supervision and safety were the most commonly reported therapist roles.
- Therapist involvement in VR program prescription, as well as the delivery of extrinsic feedback and motivation was rarely described.
- Four of the 29 included studies explicitly stated the therapist provided additional external feedback during VR intervention.
- Two studies discussed the need for therapist guidance to ensure optimal movement patterns in VR interventions as the technology feedback was insufficient.

The next aim was to assess how the use of technologies affects patient movement. In order to do this, an accurate, inexpensive and practical method to quantify movement in situ was needed. Therefore the next research objective sought to validate a wearable sensor-based motion capture system, and determine the suitability for its use in a clinical setting.

2. *To investigate the validity of a wearable sensor-based motion capture system to identify movement patterns in therapeutic rehabilitation settings*

Key findings:

- Assessment of the concurrent validity of the Notch sensor system, investigated by simultaneously recording gait with the Notch sensor and Vicon optical motion capture systems, revealed correlation between the sagittal lower limb joint angles reported by the Notch and Vicon systems was significant but weak overall (r<0.5).

- Only maximum hip flexion angle reported by both systems was significantly and moderately correlated (r=0.549).
- The results of this study revealed the accuracy of the Notch sensor system, when used with the proprietary processing software, was inadequate for clinical or research use.

As identified by the literature review and systematic review, very little had been previously reported about physiotherapy practice during VR mobility rehabilitation, so an observational study was conducted to address this knowledge gap. The use of AVC technologies in rehabilitation, particularly screen-based technologies, introduces an extra dimension which may alter physiotherapist visual attention and potentially affect the physiotherapist and patient interaction. The first aspect of this observational study sought to investigate the focus of physiotherapist visual attention.

3. *To examine physiotherapists' focus of visual attention during usual mobility rehabilitation without AVC technologies and AVC-based mobility rehabilitation and identify similarities and differences in physiotherapist focus of visual attention between rehabilitation without and with AVC technologies*

Key findings:

- During rehabilitation without AVC technologies, visual attention was mainly focussed on the patient.
- Average number of uninterrupted fixations was greatest on the patient body in rehabilitation without AVC technologies.
- During rehabilitation with AVC technologies, the primary focus of physiotherapist visual attention was on equipment, specifically the AVC screen.
- Average number of uninterrupted fixations was greatest on the AVC screen in rehabilitation with AVC technologies.
- Average duration of each fixation on the patient was similar in rehabilitation without and with AVC technologies, but average duration of each fixation on equipment was significantly longer in rehabilitation with AVC technologies.

The findings of this chapter provided insight into the changes in physiotherapist visual attention in mobility rehabilitation without and with AVC technologies, Next, the influence of AVC technology on physiotherapist instruction and feedback was investigated.

4. *To analyse the provision of physiotherapist instruction and feedback during usual mobility rehabilitation without AVC technologies and AVC-based mobility rehabilitation and identify similarities and differences in physiotherapist instruction and feedback between rehabilitation without and with AVC technologies*

Key findings:

- Physiotherapist instruction and feedback was predominately provided as verbal comments in both rehabilitation without and with AVC technologies.
- The majority of physiotherapist verbal statements were instructions and motivational statements, while feedback was observed less often in both rehabilitation without and with AVC technologies.
- Between rehabilitation without and with AVC technologies, no significant differences were observed in the frequency with which task instruction, prescriptive feedback, knowledge of performance, knowledge of results (movement) or motivational statements were provided.
- Performance instruction was provided significantly less frequently in rehabilitation with AVC technologies compared to rehabilitation without AVC technologies.
- Knowledge of results (task or game) was provided in a significantly greater number of sessions with AVC technologies than rehabilitation sessions without AVC technologies, however, when provided it occurred less frequently per session in rehabilitation with AVC technologies.
- Internally focused verbal statements were provided less frequently in rehabilitation with AVC technologies than in rehabilitation without AVC technologies, while externally focused and mixed focus statements were provided at similar frequencies in both rehabilitation without and with AVC technologies.
- In both rehabilitation without and with AVC technologies, nearly all physiotherapist statements were positively framed.
- There was no statistically significant difference in physiotherapist visual or haptic instruction and feedback between rehabilitation sessions without and with AVC technologies.
- Exploration of the relationship between physiotherapists' focus of visual attention and provision of instruction and feedback found different relationships in rehabilitation without and with AVC technologies. In rehabilitation without AVC technologies, increased visual attention on the patient was related to increased performance instruction, while in sessions without and with AVC technologies increased visual attention on the patient body was related to increased KR (task or game) and less unrelated comments.

The final discussion chapter of this thesis will provide an overview of this research program and examine the results in a broader context, considering how the findings relate to each other and the clinical implications of this new knowledge. Strengths and limitations of the current research will be described before presenting the plans for future research to continue the advancement of knowledge in this field. The final conclusions of this thesis will complete this chapter.

8.2 Physiotherapy practice during rehabilitation for mobility limitations without AVC technologies

Physiotherapist focus of visual attention in rehabilitation without AVC technologies

The observational study presented in this thesis is the first to investigate physiotherapist focus of visual attention with eye tracking glasses during clinical practice. Prior to this study physiotherapist focus of visual attention had only been investigated while viewing short (<30 sec), pre-recorded patient videos with the aim of investigating the differences in visual attention during patient movement analysis between physiotherapists with different levels of clinical experience (Hayashi et al., 2020; McDuff et al., 2020). The visual attention study in this thesis recorded physiotherapist focus of visual attention in situ over several minutes and included areas of interest not previously reported, such as patient face, equipment, physiotherapist's own body and elsewhere in the room. This has provided a comprehensive understanding of physiotherapist visual attention in the context of clinical rehabilitation practice. The results showed that in rehabilitation without AVC technologies a median (IQR) of 79 (57-94)% of total fixation time was spent looking at the patient's face and body, with 6 (0-25)% on equipment, and 6 (2-16)% elsewhere in the room. Whilst there was wide variation between physiotherapists, the majority of time throughout all rehabilitation sessions without AVC technologies therapists visually focussed on the patient. This is likely due to a combination of top-down and bottom-up processes. Top-down visual attention refers to deliberate, task orientated visual attention, while bottom up is stimulus driven, reacting to salient objects within the field of view (Orquin & Holmqvist, 2019). It is important to note that visual attention suggests but does not automatically infer cognitive attention, so the interpretation that physiotherapists were actively engaged with the patient for the majority of time should be applied with caution. Further research is required to determine to what extent physiotherapists process and utilise this large proportion of visual attention on the patient and how this influences physiotherapist behaviour during rehabilitation practice.

The observational study within this thesis reported both average duration of fixations and average number of uninterrupted fixations on each area of interest, which allowed for an approximation of uninterrupted fixation time. In this study average duration of fixations on the patient body in rehabilitation without AVC technologies was median (IQR) 341 (259-492)ms, similar to the median (IQR) of 387 (331-533)ms average fixation duration reported in experienced physiotherapists by Hayashi et al. (2020) and the mean (SD) of 368.5 (80.8)ms reported in experienced therapists by McDuff et al. (2020). The duration of visual attention time needed to make clinical decisions in physiotherapy rehabilitation, a dynamic environment, is unknown. In the field of medical imaging one second has been proposed as the minimum duration to cognitively process a visual cue on a static 2-D image (Al-Moteri et al., 2017). As reported in Chapter 6, physiotherapists averaged 5.1 uninterrupted fixations on the patient in rehabilitation without AVC technologies, and multiplying average uninterrupted fixations by average fixation duration implies uninterrupted fixation time was in excess of one second, but further studies are required to understand the relationship between duration of physiotherapist visual attention and decision making in the clinical setting. Such studies could inform clinical training of student and novice physiotherapists by providing guidance on visual attention strategies for optimal clinical decision making.

*Physiotherapist instruction and feedback in rehabilitation with*out *AVC technologies*

Physiotherapists in the observational study provided large volumes of instruction and feedback within rehabilitation without AVC technologies, predominately provided in the form of verbal statements. During a standardised 5 minute session, physiotherapists provided patients with a median of 77 statements. Although this number of statements is similar to high volumes previously reported in observational physiotherapy studies (Durham et al., 2009; Johnson et al., 2013; Kal et al., 2018; Talvitie, 2000; Talvitie & Reunanen, 2002), the value of such frequent statements during rehabilitation is questionable. Whilst extrinsic feedback is an important tool in motor learning, particularly in rehabilitation where patient’s own intrinsic mechanisms may be impaired (van Vliet & Wulf, 2006), the ideal frequency of feedback is unknown. Patients may also have limited capacity to process high frequency instruction and feedback (Johnson et al., 2013) due to neurological and other deficits. Patients as learners may become reliant on feedback, detrimentally affecting retention of the new motor skill when asked to perform the action without the therapist (Cirstea & Levin, 2007; Goodwin & Goggin, 2018; Salmoni et al., 1984). Ideal quantities of motivational statements have not been studied, and may depend on individual patient needs and preferences (Chiviacowsky, 2020). It is important to acknowledge that only one exercise was observed in each rehabilitation session without and with AVC technologies, rather than an entire rehabilitation session with a variety of exercises. It is possible that physiotherapists, consciously or unconsciously, condensed instruction and feedback into this shorter observation, resulting in an artificially high volume of instruction and feedback compared to full length session.

Instructional and motivational statements were provided more frequently than feedback during rehabilitation without AVC technologies, a finding that closely replicates other studies observing physiotherapists in clinical practice (Durham et al., 2009; Johnson et al., 2013; Talvitie, 2000). In this thesis instruction was classified further, considering whether it was providing task instruction only or if it also contained movement instruction. This is distinct from the concept of explicit and implicit instruction. Explicit instruction articulates conscious components of a movement, providing knowledge of the components and rules; whilst implicit instruction encourages learning unconsciously with minimal instruction (Liao & Masters, 2001). The use of implicit instructions to encourage automatic movement patterns such as analogies (e.g. "think about keeping a big ball between your knees") has been associated with improved motor learning (Gokeler et al., 2019), as these instructions still involve some aspect of movement quality. Those instructions that were classified in the observational study as task instructions had no such quality, but simply referred to required action e.g., "walk to the red cone". Movement instructions containing information to direct movement quality e.g., "walk slowly to the red cone", or "lift your left foot high as you walk slowly forward" were provided half as often as task instructions during the observed rehabilitation. Several reasons could be speculated to explain this finding that has not been previously reported in the literature. Physiotherapists could provide frequent task instruction in order to continually tailor the task to the patient performance, such as changing to a more challenging task. Frequent task instruction may also have been provided to direct timing of the task, e.g., during sit to stand to sit exercise, directing "sit down" when the patient was perceived to have achieved a controlled standing position after standing up. Task instruction could have also been used as a commentary to the action already occurring, or used to direct patient cognitive attention towards the movement. Physiotherapists should reflect on how they use instruction and motivational statements during rehabilitation, and consider if these statements are of benefit to the patient. Potentially, reducing the amount of task only instruction and motivational statements, or replacing some with informational movement instruction or feedback, may further optimise patient motor learning if the amount of informational feedback is insufficient.

Summary of contributions to literature on physiotherapy practice in rehabilitation without AVC technologies

Comprehensive data extraction and exhaustive coding undertaken in this thesis revealed new findings which have significantly contributed to the existing literature on physiotherapy practice in rehabilitation without AVC technologies. Firstly, focus of physiotherapist visual attention during actual clinical practice had not been previously studied, and has established that the patient is the primary focus of visual attention during rehabilitation. Secondly, the study of physiotherapist instruction and feedback during rehabilitation without AVC technologies supports evidence from previous observational studies, highlighting that physiotherapists use large volumes of verbal statements, particularly to provide instruction and motivation. Thirdly, this study has identified the frequent use of task only instruction compared to instructions which include a component of movement quality. These findings have established an important foundation and a base of reference for the exploration of AVC-based rehabilitation practice.

8.3 Physiotherapy practice during rehabilitation with AVC technologies for mobility limitations

Differences in physiotherapist visual attention and provision of instruction and feedback in rehabilitation without and with AVC technologies

The study results have revealed that during rehabilitation with AVC technologies physiotherapists move their focus of visual attention away from the patient and towards the AVC screen, yet at the same time physiotherapists provide a similar volume of instruction and feedback as in rehabilitation without AVC technologies.

A possible top-down explanation for the majority of physiotherapist visual attention being focused on AVC technology is that physiotherapists were choosing to direct visual attention at the screen, potentially as a substitute for direct patient observation. As KR (task or game) was provided in more than double the number of sessions as rehabilitation without AVC technologies, visually focusing on the screen may have been a deliberate strategy to inform this physiotherapist feedback. Since AVC rehabilitation may encourage undesirable compensatory movement patterns (Demers & Levin, 2020; Lewis et al., 2011; Liebermann et al., 2012; Tatla et al., 2015), therapist instruction and feedback to correct these patterns may be critical to successful rehabilitation practice (Hassett et al., 2019; Hung et al., 2014; Yatar & Yildirim, 2015). Additionally, as AVC feedback is known to lack accuracy (Lewis & Rosie, 2012), it may be inferior to direct patient observation to inform physiotherapists of patient movement patterns. It is unknown if the relatively small proportion of fixation time physiotherapists spent visually focused on the patient during rehabilitation with AVC technologies (median (IQR) of 18 (8-39)% versus 79 (57-94)% in rehabilitation without AVC technologies) was sufficient to accurately inform the content of physiotherapist instruction and feedback. Further to this, based on an average fixation duration of 296ms and a median of 2.6 uninterrupted fixations, uninterrupted fixation time was less than one second. As discussed in the previous section on rehabilitation without AVC technologies, the length of visual attention time required for clinical decision making in rehabilitation practice is unknown, but this is considerably less than the uninterrupted fixation time on the patient observed in rehabilitation sessions without AVC technologies. In contrast, the results of physiotherapist visual attention on the screen in rehabilitation with AVC technologies, where the median (IQR) proportion of total fixation time was 77 (57-85)%, the median (IQR) average duration of each fixation was 900 (653-1270)ms, and the median number of uninterrupted fixations was 4.0, imply ample time for visual processing. Another possible bottom-up explanation for this increased visual fixation time is that the screen attracted visual attention due to the dynamic graphics. Once attention was drawn to the screen, further time may have been needed to cognitively process the novel display. Further research is required to ascertain how the content of physiotherapist instruction and feedback is determined in rehabilitation with AVC technologies and the influence of this instruction and feedback on patient movement patterns. Moreover, as this thesis has found that the type of instruction and feedback can change with the introduction of AVC technologies, further research to determine physiotherapist instruction and feedback patterns during AVC-based rehabilitation for optimal patient outcomes is required. This information will assist in both the training of physiotherapists in the appropriate use of these technologies, but also help optimise design features of the software used.

Quantity of feedback

The observational study has demonstrated that the addition of AVC technologies, which provide continuous KP and KR feedback and frequent task instruction, did not significantly change overall quantity of physiotherapist instruction and feedback. Physiotherapists should reflect why they provide this type and amount of instruction and feedback during rehabilitation, and consider if this is commensurate with evidence-based practice. Whilst the optimal feedback schedule for people undergoing rehabilitation for mobility limitations has not been determined, evidence in healthy populations suggests fading feedback frequency over time, particularly concurrent and internally focused feedback, promotes motor learning. Fading feedback reduces dependency on the feedback and encourages development of automatic movement strategies (Schmidt, 2019; van Vliet & Wulf, 2006). Each session within the observational study was a single exercise performed without and with AVC technologies, and it is unknown if physiotherapists would change their instruction and feedback over time. However, as therapist instruction and feedback remained at similar levels to rehabilitation without AVC technologies upon introduction of AVC technology, consideration should be made as to whether the addition of AVC instruction and feedback overloads the patient. Rehabilitation-specific technologies which can provide less extraneous visual information than recreational systems (Yates et al., 2016) may allow patients to focus attention on what is relevant. Simpler displays may be a required feature of AVC systems specifically designed for use in rehabilitation.

The study of physiotherapist instruction and feedback found that physiotherapists provide similar quantities of instruction and feedback during rehabilitation without and with AVC technologies. One of the frequently proposed benefits of AVC technologies in rehabilitation is that feedback provided by the technology may reduce the need for physiotherapist instruction and feedback, thereby decreasing health care costs and providing opportunities for self-led therapy (Levac & Galvin, 2013). However, this is called into question by the results of this thesis which suggest that physiotherapist instruction and feedback may only change in type during use of AVC technologies, rather than significantly reducing.

Reporting of physiotherapist role

A significant recommendation arising from the systematic review was that researchers should ensure AVC interventions are reported in full, including physiotherapist role in AVC-based rehabilitation delivery to ensure results can be replicated in clinical practice and to correctly attribute differences in outcomes. Observing the same patient therapist dyad in two different study conditions on the same day has demonstrated although overall amount of instruction and feedback is similar, there exist some significant differences in the type of instruction and feedback provided by physiotherapists between rehabilitation without and with AVC technologies. This finding that the role of the physiotherapist can be significantly different in rehabilitation without and with AVC technologies, even within the same patient-therapist dyad on the same day, suggests physiotherapists implement AVC-based rehabilitation differently to rehabilitation without AVC technologies. Whilst incomplete reporting of physiotherapy interventions has been previously reported (Yamato et al., 2016) and is therefore not unique to AVC-based rehabilitation, researchers should consider how the physiotherapist role (including instruction, feedback and motivation) is reported to provide sufficient detail for implementation of interventions.

Physiotherapist role in the systematic review compared to the observational study

The findings from the observational study were considered in the context of the therapist roles reported in the systematic review presented in Chapter 3. The observational study explicitly analysed physiotherapist provided instruction and feedback and found all rehabilitation sessions with AVC technologies contained physiotherapist motivational statements, while 93% (n=28) sessions contained instruction and 83% (n=25) included extrinsic feedback. These therapist roles were reported in 7/29 studies included in the systematic review, with one study reporting provision of extrinsic feedback, instruction and motivation (Alves et al., 2018), one study reporting feedback and motivation (Ferraz et al., 2018), and two studies reporting only feedback (Hung et al., 2014; Straudi et al., 2017), two studies only instruction (Negrini et al., 2017; Ozgonenel et al., 2016) and one study only motivation (Cho et al., 2012). The high rate of physiotherapist involvement in the observational study compared to therapist involvement reported by the systematic review studies may indicate that therapist role in the provision of AVC interventions may be underreported in the literature.

Potential effect on physiotherapist-patient relationship

Analysis of physiotherapist focus of visual attention revealed physiotherapists spent significantly less time visually attending to the patient’s face in rehabilitation with AVC technologies compared to rehabilitation without AVC technologies. This has potential to affect the patient-therapist relationship, as mutual eye gaze plays an important role in non-verbal communication in clinical practice (O'Keeffe et al., 2016; Roberts & Bucksey, 2007). While patient focus of visual attention was not recorded in this study, due to the nature of the intervention patient visual attention was likely to be mainly on the AVC screen, during which mutual eye contact was not possible. This study only analysed focus of visual attention during active exercise time, however it is conceivable that physiotherapists spent additional time focusing visual attention on the patient before or after the AVC-based exercise. Physiotherapists may need to allow for adequate eye-contact time outside of active AVC rehabilitation to ensure the therapeutic alliance is maintained.

Providing comparable amounts of instruction and feedback in rehabilitation without and with AVC technologies, in addition to the instruction and feedback provided by the AVC technology, may have been one such strategy to nurture the physiotherapist-patient relationship in the absence of eye contact. Other reasons for providing additional feedback have also been suggested, such as to encourage a positive AVC experience for patients (Hamilton, McCluskey, et al., 2018), to continue to feel involved in therapy (Tatla et al., 2015), or potentially, to ensure the physiotherapist role is not supplanted by technology (Flynn et al., 2019). Finally, as research has shown disparities between physiotherapist perception of their feedback and the actual feedback provided (Durham et al., 2009; Stanton et al., 2015), and other studies have noted physiotherapist instructions and feedback appear sometimes arbitrary it is possible that instruction and feedback were delivered without deliberate purpose (Talvitie & Reunanen, 2002). Further research is warranted to gain a full understanding of therapists' reasons for physiotherapists providing instruction and feedback.

Potentially, to ensure the instruction and feedback from the AVC technology is not duplicated by the therapist, AVC-based rehabilitation could be provided in in a format that is not individually based with a physiotherapist, for example with group supervision or with a physiotherapy assistant. The use of AVC technologies in group practice has been shown to be feasible and safe (Givon et al., 2016; van den Berg et al., 2016), and should be considered for appropriate patients as a feasible strategy to increase rehabilitation dose without individual physiotherapist attention. Use of a rehabilitation assistant instead of a physiotherapist during rehabilitation with AVC technologies may also be a model for providing increased dose with reduced cost (Cannell et al., 2018). AVC-based rehabilitation may be particularly useful as an adjunct to usual individual physiotherapy rehabilitation without AVC technologies (Levin, 2020), and group or assistant-supervised practice may be considered a cost effective way to implement this. This may also act as an intermediary stage leading to independent practice, either in the ward or at home, if this is a relevant patient goal.

AVC Technology selection and development

Four technologies were selected for use in this study, of which two were recreational and two rehabilitation-specific. These were chosen as all were commercially available, off the shelf systems and included the two most commonly found recreational systems in rehabilitation facilities (Levac, Glegg, et al., 2019). Which AVC exercise was used to match the usual care exercise was determined by the physiotherapist and researcher together, guided by the study protocol and individual needs of the patient. From the total of 95 data collection sessions, 86 sessions (91%) used rehabilitation-specific technologies, including all 30 reported in Chapters 6 and 7, as they were found to more closely match the functional PT exercises practiced in usual rehabilitation without technologies. The general difficulties in use of recreational technologies in rehabilitation, and specifically the lack of tailoring has been previously noted (Hassett et al., 2019; Levac, Huber, et al., 2019; Proffitt et al., 2019). Examples of parameters that could be customised in the Humac and IRS systems include movement range, speed and side of body to use. Potentially the focus of physiotherapist visual attention may be different in AVC rehabilitation sessions involving recreational technologies, which tend to have more superfluous graphics that may contribute more to a process of bottom-up visual attention

Physiotherapists visually attended to the AVC screen for the majority of active rehabilitation time. Although the reasons for this remain unknown, and visual attention may change with time, it reinforces that co-design of AVC technologies with therapists is important (Levac, Miller, et al., 2018; Proffitt et al., 2019). As the technologies develop in the future, ensuring AVC technologies provide a meaningful display that aids appropriate instruction and feedback without overloading the patient or physiotherapist with unnecessary information, and results in the desired patient movement will be critical.

Physiotherapist clinical and AVC experience

All physiotherapists in the observational study reported some prior experience with technology, and most had had some experience specifically with technology use in rehabilitation. However, AVC technologies were not routinely used in the rehabilitation settings from which we recruited, and both rehabilitation-specific technologies were novel to the physiotherapists observed. Physiotherapists' individual level of AVC experience and training in AVC rehabilitation may influence how they practice in AVC rehabilitation. Existing literature has shown when observing short patient movement videos physiotherapists with more clinical experience visually fixate more frequently and for shorter durations than novice physiotherapists (Hayashi et al., 2020; McDuff et al., 2020), suggesting that with experience physiotherapists learn to absorb clinical information more quickly and are able visually attend to more areas of interest. Likewise, studies on physiotherapist instruction and feedback suggest with experience physiotherapists may deliver different instruction and feedback patterns, such as providing more externally focused instruction and feedback (Kal et al., 2018). As this observational study has established the changes in physiotherapist visual attention and provision of instruction and feedback on immediate introduction of AVC technologies, further research is now needed to establish the differences in physiotherapist practice as physiotherapists develop AVC experience over time. For example, the average duration of visual fixation on equipment may shorten, broadening the number of areas visually attended to during rehabilitation; physiotherapist instruction and feedback patterns could adapt to accommodate the additional instruction and feedback provided by the AVC technology. This deserves further attention in order to inform optimal training practices when introducing AVC technologies to physiotherapists and physiotherapy students.

Summary of contributions to the literature on physiotherapy practice in AVC rehabilitation

This body of work contributes significant new knowledge to our understanding of physiotherapy practice in AVC-based rehabilitation. Firstly, the systematic review found VR interventions have been poorly reported, and the role of the physiotherapist in intervention planning and delivery is rarely meaningfully described. Secondly, observation of physiotherapists conducting mobility rehabilitation without and with AVC technologies revealed the focus of physiotherapist visual attention significantly shifts from patient to technology when AVC technologies are introduced. In addition, despite the technology providing frequent instruction and continuous feedback, overall amount of physiotherapist instruction and feedback remained largely unchanged, however a significant reduction in performance instructions and internally focussed statements were observed. In addition, KR (task or game) feedback was provided in more than twice as many AVC sessions although at a lower frequency within a session.

8.4 Strengths and limitations

There are some strengths and limitations within this thesis which should be acknowledged when considering the findings presented.

Firstly, the systematic review was conducted through a comprehensive search strategy and used standardised assessment tools, including the CASP and the TIDieR framework. This made it the first systematic review to date to use the TIDieR framework to synthesise the delivery and reporting of VR technology interventions in clinical studies. It is important to acknowledge however that the review only included studies using commercially available technologies, with more than 10 intervention participants in a supervised setting and therefore results cannot be extrapolated beyond this.

Strengths of the Notch study included the use of the 'gold standard' Vicon optical motion capture system as a tool to validate the Notch sensor system, and the use of the proprietary app to process the data, just as a typical clinician would operate the system. However, there is also a likelihood that the gait laboratory contributed to electromagnetic interference, limiting the accuracy of the sensors, and while the manufacturer's calibration procedures were followed, these could be improved with a jig to standardise movement patterns.

The observational study was strengthened by the pragmatic protocol design. The study was undertaken in an authentic clinical setting, with physiotherapists and patients currently involved in rehabilitation for mobility limitations. Participant inclusion and exclusion criteria remained as broad as possible and data was collected from six different clinical rehabilitation areas within two large metropolitan hospitals, so results may be indicative of clinical practice with a wide variety of patients. The physiotherapists within the study were not research therapists, but therapists employed within existing rehabilitation settings. The AVC technologies reported on in the observational study provided a variety of different exercises and games, utilising extrinsic feedback, motivation and engagement common to other AVC systems used in rehabilitation (Hassett et al., 2019) and therefore results could be extrapolated to other AVC rehabilitation technologies. Usual rehabilitation exercises were matched with AVC exercises using a detailed protocol which included a wide variety of AVC exercises and each could be further tailored to best align with usual rehabilitation. In addition, both exercises were undertaken by the same dyad on the same day, minimising confounding due to any changes in patient condition over time. All the above aspects within the protocol design contribute to the observational research findings being widely applicable. Another strength to the observational study was the objective analysis of physiotherapist focus of visual attention and instruction and feedback with a detailed coding framework. This is the first study to analyse physiotherapist visual fixations during clinical practice and to compare physiotherapist practice without and with AVC technologies. Furthermore, this observational study, with n=30 sessions, is the largest known eye tracking study in the field of physiotherapy. This use of eye tracking glasses and coding framework aimed to minimise bias from interpretation of the data such as may occur with studies attempting to interpret eye gaze from video recordings or record feedback provided with only field notes. The rigor applied to the data collection and extraction for study reinforces the validity of the results.

There remain some limitations to the observational study. Firstly, physiotherapy practice (focus of visual attention, instruction and feedback) was analysed only during 'active time', i.e., when the patient was actively exercising or moving. This means that therapist focus of attention, and provision of instruction and feedback, during assessment, exercise preparations or rest periods were not included in the analysis. As a result, the findings of this thesis are limited only to the active therapy time studied and should not be generalized beyond this.

Secondly, whilst the majority of physiotherapists reported previous occasional experience of using technology in rehabilitation, AVC technologies were not routinely used within the rehabilitation settings studied in this research. As a result, both physiotherapists and patients were less familiar with the AVC rehabilitation exercise than usual rehabilitation exercise without AVC technologies and this may have impacted the results.

8.5 Future Research

Multiple future research opportunities exist to build on the work presented in this thesis.

Firstly, a qualitative project exploring physiotherapists' perceived similarities and differences in their own physiotherapy practice during rehabilitation without and with AVC technologies is planned, using semi-structured interviews with consenting physiotherapists from the observational study. This will provide further insight into physiotherapists' motivations for their shift in visual attention from patient to technology in AVC rehabilitation as noted in the observational study, and also elucidate their rationale for providing similar amounts but different types of instruction and feedback in rehabilitation with AVC technologies compared to rehabilitation without AVC technologies. Secondly, further research should be conducted to assess the effect of different AVC technologies and level of physiotherapist clinical experience on physiotherapist practice in AVC rehabilitation. Thirdly, as AVC rehabilitation was found to significantly alter physiotherapist focus of visual attention, exploration of patient visual attention focus during AVC rehabilitation also warrants investigation, as well as the effect this has on patient movement patterns.

Fourthly, the study in this thesis on motion capture found the Notch sensor system lacked accuracy when compared to the Vicon optical sensory system. Hence the demand remains for an inexpensive, in situ, motion capture system for research and clinical purposes. Further research should be conducted to realise an accurate sensor-based motion capture system, validated within clinical populations and complete with consumer software which can be used in situ to record patient movement for research and clinical purposes. Finally, in order to understand how different AVC rehabilitation conditions affect motor learning, further studies which investigate the effect of different AVC rehabilitation conditions over a longer-term program of AVC rehabilitation on patient movement retention/outcomes will need to be undertaken.

8.6 Conclusions

This thesis has significantly contributed knowledge to what is already known with regards to the benefits and applications of AVC technologies in rehabilitation. As AVC technologies are increasingly introduced in mobility rehabilitation, knowledge of how AVC interventions are implemented and their impact on physiotherapy practice is essential in our understanding of the physiotherapist's role in AVC mobility rehabilitation. Existing literature has incompletely reported AVC interventions, and full reporting of interventions, including the therapist role will be essential as the field progresses.

AVC technologies are inherently visual in nature. This thesis has confirmed that the use of AVC rehabilitation does substantially shift physiotherapist visual attention from the patient to the screen. The study results have demonstrated that although overall volumes of instruction and feedback are similar in rehabilitation with AVC technologies when compared to usual rehabilitation, there are significant differences in the type of instruction and feedback provided to rehabilitation without AVC technologies. Compared to rehabilitation without AVC technologies, physiotherapists provided less frequent performance instruction and internally focused statements within an AVC rehabilitation session. KR (task or game) feedback was also provided less frequently within an AVC-based session, but occurred in more sessions overall. Further research is warranted to establish if the introduction of AVC technologies affect patient movement patterns.

The interaction between AVC technology, the physiotherapist and the patient is complex. The findings of this thesis have advanced our understanding of this relationship and can be used at the basis to refine the use of AVC technologies to optimise patient outcomes.

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APPENDICES

Appendix A: Prospero registration

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PROSPERO
International prospective register of systematic reviews

The reported therapy dose and role of the therapist in studies investigating virtual reality (VR) rehabilitation for adults with mobility limitations: a systematic review.

Heather Weber, Maayken van den Berg, Chris Barr, Claire Gough

Citation

Heather Weber, Maayken van den Berg, Chris Barr, Claire Gough. The reported therapy dose and role of the therapist in studies investigating virtual reality (VR) rehabilitation for adults with mobility limitations: a systematic review.. PROSPERO 2018 CRD42018105668 Available from: https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42018105668

Review question

1) What is the dose of therapy provided in studies investigating virtual reality rehabilitation intervention for adults with mobility limitations?
2) What is the reported role of the therapist in studies investigating virtual reality rehabilitation intervention for adults with mobility limitations?
Specifically: What type of therapist was reported to be involved? What was reported as the therapist background and specific training for the intervention? What was the mode of intervention delivery? What was the reported role during the therapy session? What was the reported role outside of the therapy session?

Searches

The systematic search will be conducted on MEDLINE (Ovid), CINAHL, Cochrane, Scopus and EMBASE databases to identify relevant studies. Reference lists of included studies will also be hand searched for eligible studies The searches will be re-run just before the final analyses and further studies retrieved for inclusion. The studies will be restricted to English language only and will include only terms relating to virtual reality or exergaming, mobility limitations and interventional trials. Articles published prior to 2007 will be excluded as the oldest currently available technologies was not available prior to then.

Types of study to be included

Inclusions:

Studies including randomised controlled trials, controlled trials, crossover trials and cohort studies.
Studies where the intervention group has greater than 10 participants.
Studies where the primary outcome measure is a functional mobility outcome measure.

Exclusions:

Studies where the methodology does not use a comparison group such as case studies.

Studies where the intervention group has 10 or fewer participants.

Studies utilising a primary outcome measure that is not related to functional mobility.

Condition or domain being studied

Virtual reality technologies are increasingly being used in rehabilitation to address mobility limitations in adults. However, the dosages prescribed and the role of the therapist is unclear. This review will investigate the dose and reported role of the therapist in studies investigating virtual reality rehabilitation interventions for adults with functional mobility limitations.

Participants/population

Inclusion: Adults with mobility limitations, including, but not limited to, gait disturbance, balance impairments and transfer difficulties. Any cause of these mobility limitations will be included including neurological disorders, degenerative conditions and musculoskeletal dysfunction.

Exclusions: populations under 18 years, populations without mobility limitations.

Intervention(s), exposure(s)

Inclusions: All supervised rehabilitation interventions for mobility limitations that incorporate commercially available virtual reality will be included. Virtual reality in physical rehabilitation may be defined as "any computer hardware and software system that generates simulations of real or imagined environments with which participants interact using their own movements" (Levac et al., 2016). Immersive and non-immersive technologies will be included as long as they are "plug and play" technologies readily available for purchase.

Rehabilitation for mobility limitation will be defined as studies using a functional mobility primary outcome measure.

Exclusions: Studies using prototype or custom technologies will be excluded, as will studies occurring in home environments, not using VR technology for the duration of the intervention and not being supervised for the duration of the trial.

Comparator(s)/control

Any alternate intervention or control group.

Main outcome(s)

Dose of virtual reality rehabilitation intervention:

1) type of intervention

2) number of sessions

3) frequency of sessions

4) duration of each session

5) duration of intervention
Reported role of the therapist in providing virtual reality rehabilitation intervention:
1) type of therapist (e.g. Physiotherapist, Occupational Therapist, Exercise Physiologist)

2) therapist background and specific training for intervention

3) mode of intervention delivery (individual or group)

4) reported role during therapy session ((a) patient related e.g. providing verbal feedback or manual guidance and (b) virtual reality related e.g. adjusting computer hardware or software)

5) reported role outside of therapy session (e.g. planning therapy or tailoring program)

* Measures of effect

None.

Additional outcome(s)

None.

* Measures of effect

None.

Data extraction (selection and coding)

Titles and/or abstracts of studies retrieved using the search strategy and those from additional sources will be screened independently by two review authors to identify studies that potentially meet the inclusion criteria outlined above. The full text of these potentially eligible studies will be retrieved and independently assessed for eligibility by two review team members. Any disagreement between them over the eligibility of particular studies will be resolved through discussion or independently by a third review author.

A standardised, pre-piloted form will be used to extract descriptive data from the included studies for evidence synthesis. Extracted information will include: study setting; study population and participant demographics; details of the intervention and control conditions; intervention dose including session duration, number and frequency; study methodology including data related to therapist type, expertise, background, training and role during and outside of therapy sessions. Data will be extracted by one author and verified by a second.

Risk of bias (quality) assessment

This review will use the appropriate CASP checklist to critically appraise all included studies. In addition, each study will be assessed for completeness of intervention reporting using the Template for Intervention Description and Replication (TIDieR) checklist. These assessments will be conducted by one author and verified by a second.

Strategy for data synthesis

We will provide a narrative and descriptive synthesis of the findings from the included studies, structured around the intervention characteristics including dose and the role of the therapist within the intervention. A table will provide a summary of each study and its intervention characteristics.

Analysis of subgroups or subsets

None

Contact details for further information

Heather Weber
heather.weber@flinders.edu.au

Organisational affiliation of the review

Flinders University
www.flinders.edu.au

Review team members and their organisational affiliations

Ms Heather Weber. Flinders University
Dr Maayken van den Berg. Flinders University
Assistant/Associate Professor Chris Barr. Flinders University
Ms Claire Gough. Flinders University

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Weber H, Barr C, Gough C, van den Berg M. How Commercially Available Virtual Reality-Based Interventions Are Delivered and Reported in Gait, Posture, and Balance Rehabilitation: A Systematic Review. Physical Therapy. 2020.
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Subject index terms
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Stage of review at time of this submission

Stage	Started	Completed
Preliminary searches	Yes	Yes
Piloting of the study selection process	Yes	Yes
Formal screening of search results against eligibility criteria	Yes	Yes
Data extraction	Yes	Yes
Risk of bias (quality) assessment	Yes	Yes
Data analysis	Yes	Yes

The record owner confirms that the information they have supplied for this submission is accurate and complete and they understand that deliberate provision of inaccurate information or omission of data may be construed as scientific misconduct.

The record owner confirms that they will update the status of the review when it is completed and will add publication details in due course.

Versions
03 September 2018
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Appendix B: Publication

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Weber, H., Barr, C., Gough, C., & van den Berg, M. (2020). How Commercially Available Virtual Reality-based Interventions Are Delivered and Reported in Gait, Posture, and Balance Rehabilitation: A Systematic Review. *Physical Therapy*. https://doi.org/10.1093/ptj/pzaa123

Review

How Commercially Available Virtual Reality–Based Interventions Are Delivered and Reported in Gait, Posture, and Balance Rehabilitation: A Systematic Review

Heather Weber, Christopher Barr, Claire Gough, Maayken van den Berg

Objective. Virtual reality (VR) technologies are increasingly used in physical rehabilitation; however, it is unclear how VR interventions are being delivered, and, in particular, the role of the therapist remains unknown. The purpose of this study was to systematically evaluate how commercially available VR technologies are being implemented in gait, posture, and balance rehabilitation, including justification, content, procedures, and dosage of the intervention and details of the therapist role.

Methods. Five databases were searched between 2008 and 2018. Supervised interventional trials with >10 adult participants using commercially available VR technologies to address mobility limitations were independently selected by 2 authors. One author extracted reported intervention characteristics into a predesigned table and assessed methodological quality, which was independently verified by a second author. A total of 29 studies were included.

Results. Generally, minimal clinical reasoning was provided to justify technology or activity selection, with recreational systems and games used most commonly (n = 25). All but 1 study used a single interventional technology. When explicitly described, the intervention was delivered by a physical therapist (n = 14), a therapist assistant (n = 2), both (n = 1), or an occupational therapist (n = 1). Most studies reported supervision (n = 12) and safeguarding (n = 8) as key therapist roles, with detail of therapist feedback less frequently reported (n = 4). Therapist involvement in program selection, tailoring, and progression was poorly described.

Conclusion. Intervention protocols of VR rehabilitation studies are incompletely described and generally lack detail on clinical rationale for technology and activity selection and on the therapist role in intervention design and delivery, hindering replication and translation of research into clinical practice. Future studies utilizing commercially available VR technologies should report all aspects of intervention design and delivery and consider protocols that allow therapists to exercise clinical autonomy in intervention delivery.

Impact. The findings of this systematic review have highlighted that VR rehabilitation interventions targeting gait, posture, and balance are primarily delivered by physical therapists, whose most reported role was supervision and safeguarding. There was an absence of detail regarding complex clinical skills, such as tailoring of the intervention and reasoning for the choice of technology and activity. This uncertainty around the role of the therapist as an active ingredient in VR-based rehabilitation hinders the development of implementation guidelines. To inform the optimal involvement of therapists in VR rehabilitation, it is essential that future studies report on all aspects of VR intervention design and delivery.

H. Weber, PT, College of Nursing and Health Sciences, Flinders University, GPO Box 2100, Adelaide 5001, Australia. Address all correspondence to Ms Weber at: heather.weber@flinders.edu.au.

C. Barr, PhD, College of Nursing and Health Sciences, Flinders University.

C. Gough, PT, College of Nursing and Health Sciences, Flinders University.

M. van den Berg, PhD, College of Nursing and Health Sciences, Flinders University.

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Mobility limitations affecting gait, posture, or balance can result from many conditions and are a primary cause of diminished ability to live independently.[1] Physical rehabilitation is an effective intervention for such mobility limitations, with higher intensity linked to greater recovery in a wide range of diagnoses such as stroke,[2] hip fracture,[3] and dementia.[4]

The use of virtual reality (VR) in rehabilitation is increasing in prevalence as it provides an opportunity for activity in an enriched environment, with resultant enhanced motivation and participation.[5] VR technology in physical rehabilitation has been defined as "any computer hardware and software system that generates simulations of real or imagined environments with which participants interact using their own movements."[6] The safe yet varied virtual environment can provide a stimulus for increased task repetition and dose intensity.[5] A further advantage lies in the additional external feedback provided by the technology, which may facilitate motor learning, especially in neurological conditions.[7]

Several different hardware systems have been used in rehabilitation therapies, with common movement input devices including hand-held controllers, balance boards, and full–body motion capture cameras. Display options vary in immersive qualities from flat 2D screens to fully immersive head-mounted displays and entire room displays.[8] Software systems are also diverse and include casual recreational gaming systems designed for entertainment through to rehabilitation-specific programs with modifiable task-specific goals.

Research into the benefits and efficacy of VR mobility rehabilitation has been conducted in several conditions, both neurological (eg, stroke,[9,10] cerebral palsy,[11] multiple sclerosis,[12] traumatic brain injury,[13] Parkinson disease[14]) and non-neurological (eg, falls and aging[15,16]). This growing body of evidence generally indicates that VR is safe and no less efficacious than usual care,[17] with higher levels of patient motivation and adherence.[18]

Although demonstrated to be an acceptable alternative or addition to usual care, variation in intervention methodology is considerable, preventing meaningful detailed synthesis of results and indicating the optimal interventional procedures are unknown.[10,19] While it has been argued that additional feedback and motivation provided by the technology may promote independence and reduce therapist involvement in technology-assisted therapy,[20] other research has indicated that the therapist may remain an "active ingredient,"[21–23] and therapists themselves report a need to be involved.[24] Guidelines to inform delivery of physical VR rehabilitation remain sparse, with resources for clinicians focusing on aspects such as game selection[25] with little consideration of dose parameters, mode of delivery, or therapist involvement. It remains unclear how therapists implement VR rehabilitation interventions in research.

The current information gap concerning the delivery of VR rehabilitation indicates further attention needs to be paid to knowing what is reported, including the what, why, who, how, and how much of VR therapy, with particular attention to how therapists are involved in supervised VR rehabilitation. Therefore, this systematic review aims to describe how commercially available VR technology is being used in clinical intervention studies addressing limitations in gait, posture, and balance. The objectives are to assess (1) how the technology is being reported and delivered, and (2) the therapist role in intervention design and delivery. Knowledge gained from this review will contribute to our understanding of how commercially available VR technologies are being used in clinical research and is the first step towards providing clinicians with further guidance for implementation.

Methods

This systematic review protocol was registered with PROSPERO (registration number CRD42018105668).

Data Sources and Searches

The systematic search was conducted on the following electronic bibliographic databases: MEDLINE (Ovid), CINAHL, Cochrane, SCOPUS, and EMBASE. Non-English articles and articles published prior to 2007 were not included. We defined the advent of currently commercially available body movement–controlled technology as the Wii, released at the end of 2006; therefore, only papers published post this date are considered as relevant.

Search terms covered the concepts of VR (including exergaming, serious gaming, and computer environments), mobility impairments (including gait, postural control, and balance), and interventional trials (randomized controlled trials, controlled trials, crossover studies). A full list of topic headings and keywords is presented in the Supplementary Figure. Reference sections of relevant articles were also hand searched to identify any further relevant studies.

Inclusion criteria are listed in Figure 1. Commercially available technology was defined as being currently easily accessible to purchase by either the general public or qualified therapists. Both immersive and non-immersive technologies were included provided they were "plug and play" technologies readily available for purchase. Novel and experimental technologies purposefully designed for specific research and not widely obtainable on the market were excluded. Similarly, specialist technologies requiring expert customized installation were also excluded.

Study design

- Interventional study design
- > 10 participants in intervention arm

Population

- Any mobility limitation including restrictions in balance, ambulation, and postural control
- > 18 years old
- Supervised inpatient or outpatient setting

Intervention

- Primary aim to achieve an improvement in an individual's functional mobility, reflected by a primary mobility outcome measure. By this standard, studies primarily aiming to examine change in cognitive or cardiovascular function were excluded.
- Intervention using a commercially available VR rehabilitation technology.

Outcome

- Reported intervention characteristics, including the role of the physical therapist during the design and delivery of the intervention

Figure 1.
Inclusion criteria.

Study Selection Process

Titles and abstracts were independently assessed by H.W. and C.G. against the inclusion and exclusion criteria. Subsequently full texts were obtained for potentially eligible studies and were independently reviewed by H.W. and C.G. for inclusion. Any discrepancies were resolved by author M.B.

Data Extraction

H.W. extracted the data from each study, and M.B. independently verified the data collection, with any discrepancies resolved by C.B. As the aim of this study was to assess reported information, study authors were not contacted for further information, but all published sources were used, including appendices, online supplements, and separately published protocols.

Study characteristics were extracted, including aim of study, study design, setting, sample size and participants, intervention (and control) type, and primary outcome measures. All information related to the intervention was extracted consistent with the Template for Intervention Description and Replication (TIDieR) checklist and guide,[26,27] including information on the justification, content, procedures and dosage of the intervention, and details of the supervision provided. Where an element of dosage was not specifically stated but could be reasonably derived, it was calculated such as if dosage was described in number of weeks and sessions per week; these figures were multiplied to obtain total number of sessions. Where any quantitative descriptors were reported as a range, the midpoint was used for calculating dose. If an item was not reported, this was stated; if an item was mentioned but not explicit or clear, this was also recorded.

Any mention or description of the role the therapist took in the design and delivery of the intervention session was extracted. Commonalities in the reported roles were sought and then grouped to synthesize the results.

Data Analysis and Quality Assessment

Methodological quality of the included studies was assessed based on a modified version of the CASP tool[28] for randomized controlled trials (RCTs) and cohort studies. Each of 6 assessment criteria was assessed as low, medium, or high quality. Studies rated as high quality in 5 or 6 criteria were rated as high quality overall, studies that were rated as medium quality or higher in 5 or 6 criteria were rated as medium quality overall, and all other studies were rated as low quality. These assessments were conducted by H.W. and verified by M.B.

Role of the Funding Source

The funder played no role in the design, conduct, or reporting of this study.

Results

Search Results

Initial database searching and hand screening identified 7601 studies. After duplicates were removed, 4897 titles and abstracts were independently screened for inclusion, and 284 articles were retrieved and assessed in full text. A total of 29 articles met the inclusion criteria and were

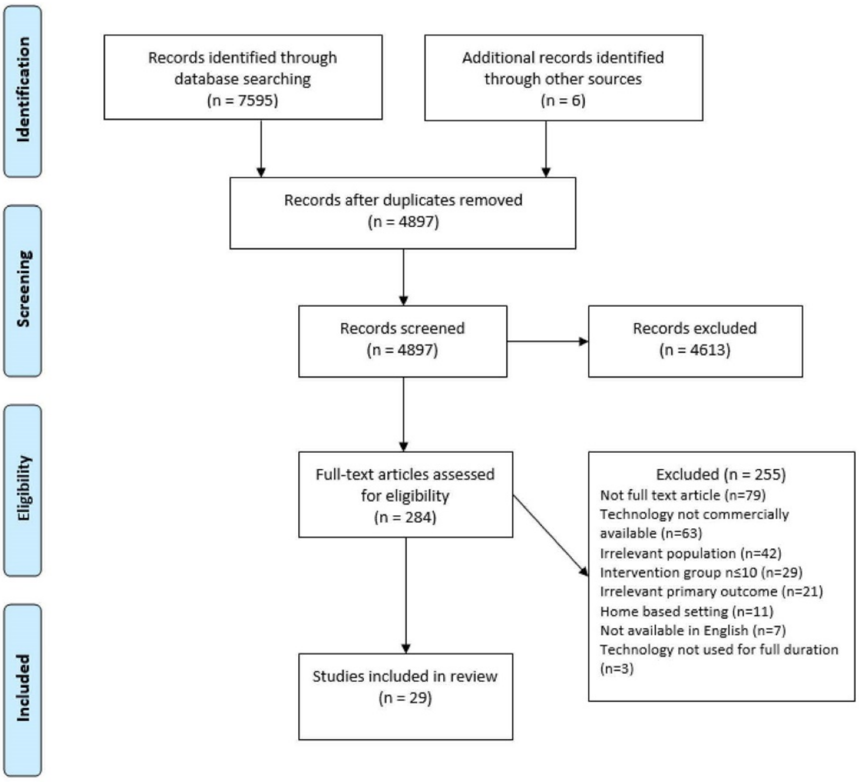

Figure 2.
PRISMA diagram of flow of studies through the review.

included in the review. The Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) flow diagram is presented in Figure 2.

Characteristics of the Included Studies

The majority of studies (n = 26)[29–54] had a stated aim of investigating the effect of the VR rehabilitation intervention, with the remaining 3[55–57] aimed at feasibility. Most studies (n = 23)[29,30,33,35,36,38–40,42–44,46–57] aimed to assess the effectiveness of the technology on improving more than 1 outcome, with balance measures being the most studied outcome (n = 20)[30,33,36,38–40,43,44,46–57] and gait the second most studied (n = 16).[29,33,35–37,40,42,43,47–53,55]

The study design in the included studies was single-blind RCTs (n = 23),[30,32–45,47,49–51,53–56] quasi-experimental with non-randomized allocation,[29,31] or cohort studies.[46,52,57] Sample size ranged from 18[31] to 84[47] (median = 33).

Participant mean age, specified in 28 studies, ranged from 28.6 years[30] to 85.2 years.[56] Study populations included primarily people with neurological disorders, with stroke being most common (n = 11).[33,34,38–41,43,45,49,52,54] Most studies were conducted in an outpatient setting (n = 18)[29–32,35–39,44,46–51,55,57] with community patients attending a local clinic or community center for the VR rehabilitation, and in 5 studies[34,45,46,49,54] the setting was not explicitly stated. Five different technologies were studied (Wii [Nintendo Wii, Nintendo, Kyoto, Japan], Xbox [Xbox Kinect, Microsoft, Redmond, WA], IREX [GestureTek, Toronto, Canada], Biodex [Biodex Balance System, Biodex, NY, USA], and Jintronix [Jintronix, Seattle, WA, USA]), with 26 studies using 1 technology only[30–51,54–57] and 3 studies looking at more than 1 specific technology either in a multi-technology intervention[52] or studied in comparison with each other.[29,53] The characteristics of the included studies are presented in Supplementary Table 1.

The methodological quality, as assessed by the predefined criteria, was rated as high for 14 studies,[32,33,36–40,42,44,46,47,49,55,56] medium for 12 studies,[29,30,34,35,41,43,45,50–54] and low for the remaining 3.[31,48,57] Full details of the methodological quality assessment are presented in Supplementary Table 2.

Reported Items of VR Rehabilitation Intervention

Reported VR rehabilitation in each trial was extracted using a modified TIDieR reporting checklist.[26] Data extracted were the why, what, who, how, where, when, how much, tailoring, modifications, how well, and therapist role within intervention. Details are reported in Supplementary Table 3.

Why. Twenty-seven[29,30,32–56] of the 29 studies cited previous related research to rationalize using VR rehabilitation as an intervention. A total of 22 studies reported the potential for advantages of increased engagement and motivation related to the technology[29–38,40,41,47,49–57] compared with conventional rehabilitation, and 16 studies reported the feedback provided by the technology was a potential benefit for mobility rehabilitation.[29,30,32,33,35,36,38–40,42,44,45,53–56] Eight studies extrapolated this further to mention the potential for home or other independent use[29,31,33,45,52–54,56] and for increased rehabilitation dosage (n = 6).[33,35,38,40,45,54] Low cost was further justification for 9 studies,[29,31,33,39,41,45,46,53,54] with researchers referring to the inexpensive nature of several commercially available technologies as well as the potential to reduce therapy costs if the technology could be used independently.

Clinical reasoning for game selection for the study population or for each individual participant (if tailored) was rarely reported. Most studies reported a basic premise behind choosing exercises (eg, "These games were selected because they resemble dynamic balance exercises performed in standard exercise therapy"[52] or "chosen for their potential to influence physical and functional movement, cognitive functioning, and driving"[30]). Two studies reported using a specific intervention protocol to guide activity selection[36,56]; however, these protocols were not published. One study[41] referred to using a previously published guide for game selection.[58]

What. Interactive games originally designed for recreational gaming consoles were utilized in 25 studies: Wii = 21[29–32,34,38,39,41,42,44–47,49–52,54–57] and Xbox = 6,[29,35,37,48,52,53] while rehabilitation-specific games incorporating PC technologies were involved in 5 studies: Biodex = 2,[36,53] IREX = 2,[40,43] and Jintronix = 1.[33]

Seventeen studies[31,33,34,37–43,45,48,49,52–55] incorporated conventional rehabilitation into their intervention in addition to the technology-based therapy, while 13 studies[29–32,35,36,44,46,47,50,51,56,57] involved an intervention group receiving the technology intervention only.

Who. In the majority of studies, the therapist providing the intervention was a physical therapist (or physiotherapist) (n = 15),[29–31,33,37,44–50,53,54,56] and/or therapy assistant (n = 3),[33,41,52] with 1 study utilizing an occupational therapist.[38] The remaining 11 studies did not specifically state the profession/professional background of the person providing or supervising the intervention, using terms such as "therapist" or "researcher" or not stating the profession at all. Further details such as the therapists' expertise, background, and specific training in the VR rehabilitation was rare, with only 3 studies reporting specific intervention training[47,49,56] and 1 study reporting the clinical experience of the interventional therapist: "physiotherapist with Post-Graduate training and more than 10 years of clinical experience in the management of neurological disease."[46]

How. Technology intervention was delivered as individual 1-to-1 sessions in 7 studies.[29,47,49,50,52,53,57] One study[51] reported using both paired and individual sessions for intervention delivery. The remaining 21 studies did not specifically report how the intervention was delivered.[30–46,48,54–56]

Where. While the intervention primarily occurred in outpatient rehabilitation facilities, further location information was rarely provided. One study reported the Wii intervention took place in a quiet room,[34] and another study described a Wii intervention was delivered in an activity room on the inpatient unit.[56] Only 1 study provided a detailed description of the intervention space, reporting it was 20 m^2 and "free from external noise."[49]

When and how much. The program length, predetermined in 25 studies,[29–32,34–42,44–54,57] ranged from 4 weeks[31,32,35,39,40,45,50,54] to 12 weeks (mean 6.6).[30,36,38,57] In 3 studies, program duration was dependent on the length of admission[33,55,56] and in 1 study duration was unclear.[43] Intervention session frequency ranged from 2 times[29,36,38,42,44,46,47,49,50,52,55,57] to 5 times a week (mean 2.8),[33,39,56] with 1 study unclear,[43] and total number of sessions where stated (n = 13)[29,32,33,35,42,43,45–47,49,51,52,54] or derived from provided data (n = 14)[30,31,34,36–41,44,48,50,53,57] varied from 8 to 36 sessions (mean 16.8).

The majority of studies (n = 26)[29,30,32–47,49–56] reported overall session time, without differentiating between active and rest time. One study[48] reported only active time, describing the duration of each component game. In this case, we have summated these figures to arrive at total session duration, although this does not allow for rest breaks, instructions, or navigating the menu system. Across these 27 studies, the shortest session time was 15 minutes[55] and the longest 60 minutes,[30,32,44,49,51,53] with the mean of all reported session times 35.3 minutes.

Where total amount of VR rehabilitation was reported (n = 2)[43,46] or could be reasonably inferred (n = 21),[29,30,32,34–42,44,45,47–50,52–54] the time ranged from 200 minutes[43] to 2160[30] minutes.

Tailoring. Fourteen studies explicitly reported using the same games or exercises with all intervention participants,[29–31,35,40,44–46,48–50,52,54,57] while 1 study reported the games were "randomly presented."[32] Six studies reported games were individually selected for each participant[33,38,41,47,53,56] according to individual goals or needs. The remaining 8 studies did not report whether the game selection was tailored.[34,36,37,39,42,43,51,55]

The intensity or difficulty of each game or exercise was the same for all participants in 1 study.[48] A total of 10 studies reported some or all aspects of intensity or difficulty were individualized,[33,35,37,41,47,50,52,53,56,57] and the remaining 18 studies did not report this aspect at all.[29–32,36,38–40,42–46,49,51,54,55]

Progression was another area of possible personalization with 6 studies reporting individual progression of game or exercise selection and intensity as best suited to the individual.[33,34,40,47,53,56] Three described some progression of activities[37,55,57] over the course of the intervention, and 7 described some progression of intensity[35,37,41,42,50,52,57] during the intervention period. One study explicitly ruled out any program progression.[48] Fourteen studies did not report any progressions.[29–32,36,38,39,43–46,49,51,54]

Modifications. None of the included studies reported modifications to the intervention over the course of the study.

How well. Three studies reported measures were in place to ensure intervention fidelity, usually by reviewing the compliance of the intervention therapists with the protocol.[36,40,56]

Most studies reported on participant adherence to the intervention, with 8 studies reporting all intervention participants completed the intervention[30,36,39,40,42,45,46,48,55] and 12 studies reporting small numbers of drop-outs, mostly for reasons unrelated to the interventions.[35,37,38,43,47,49,51–54,56,57] One study reported actual VR time, with protocol planned as "10 to 12 sessions of 20 minutes" and actual time reported as 176.6 min (±27.8 SD).[43] Six studies did not report on intervention fidelity or adherence at all.

Therapist Role in Intervention

The therapist role was not explicitly stated in 7 studies[30,35,39,40,42,51,55] of the 29, although descriptions were sometimes ambiguous where elements such as program progression and feedback were mentioned without specifying if provided by therapist or technology.

In the 22 papers that explicitly mentioned the scope of the therapist in the VR rehabilitation, a variety of duties were described. The most commonly reported role (n = 12)[31–33,37,44,45,49,50,52,53,56,57] was simply "supervision," and often this was not further elaborated upon. Safety was a factor in 8 studies,[29,33,34,41,43,46,48,53] with concerns around falls most frequently mentioned. The therapist had a reported role in program selection and tailoring in 5 studies.[33,38,41,47,56] External feedback from the therapist was mentioned in 4 trials[29,37,38,53] of the 29, with some specified as manual guidance and some verbal feedback. Other less frequently reported roles were providing training or education to participants,[29,46,48] motivating the intervention participants,[29,34,37] and recording the intervention.[47,56] The Table provides quotes to illustrate each theme.

Discussion

This systematic review has analyzed how VR rehabilitation is being delivered in clinical trials addressing gait, posture, and balance rehabilitation and what the reported role of the therapist entails. Intervention protocols generally lacked clinical reasoning for specific technology and activity selection, limiting the capacity to replicate the intervention in a clinical setting. It is unclear whether limited intervention information in included studies is due to poor reporting or the lack of detailed intervention delivery protocols. Meanwhile, there remains an uncertainty around the role of the therapist as an active ingredient in VR-based rehabilitation.

None of the included studies explicitly reported full details of all TIDieR components. Only 55% of studies reported the professional background of the person delivering the intervention. This is very similar to the study results of an evaluation by Yamato et al,[59] who assessed the completeness of the descriptions of physical therapy interventions in RCTs. The authors found that 54% of the included RCTs reported who provided the intervention, indicating that incomplete intervention reporting is not unique to VR use in rehabilitation. In our review, of the 8 studies that reported delivery mode, 7 described it as exclusively 1-to-1, contradictory to the presented rationale that VR provides additional feedback and increased motivation, reducing the need for 1-to-1 therapy. It is surprising that none of the studies delivered VR rehabilitation in group format given that that it has been found a feasible way to increase exercise dose and facilitate task-specific improvements.[60] Intervention session details related to frequency (97%) and duration (93%) were frequently reported; however, intensity and number of repetitions were seldom described. Most studies reported overall session duration rather than active time; however, previous studies have reported that active patient participation time in VR rehabilitation is curtailed due to additional non-practice burdens such as technology set-up.[61–63] We therefore recommend that VR intervention studies report repetitions or active time as it

Table.
Therapist Role in VR Intervention for Mobility Limitation

Theme	Studies n (%)	References	Quotes
Not explicitly stated	7 (24)	30,35,39,40,42,51,55	N/A
Supervision	12 (41)	31–33,37,44,45,49,50,52,53,56,57	"During this study, participants performed 3 Wii Fit balance games under the supervision of a licensed physical therapist..."[31] "Wii-group exercises consisted of 1 h of supervised Nintendo Wii Balance Board sessions, utilizing the standard software provided by Nintendo Wii Fit..."[32] "Exercises were supervised by 2 expert physiotherapists."[44] "...under the supervision of a physiotherapist..."[45] "The exercises were performed under the direct and personal supervision of a previously trained physiotherapist."[49] "All exercise sessions were completed on a 1-to-1 basis and under the supervision of the primary researcher (JR, a UK-qualified physiotherapist)."[50] "A therapy assistant supervised the participants performing the VR games on a 1-to-1 basis."[52] "During the sessions, the patients were carefully supervised by a physiotherapist who monitored the safety of the patients (eg, risk of falls, impulsive reactions) and provided external feedback."[53] "The intervention group attended individual exercise visits supervised by a member of the research team."[57]
Safety	8 (28)	29,33,34,41,43,46,48,53	"For clinical safety, we monitored participants' heart rates and blood pressure in all training sessions."[29] "... with spotting or supervision as required to ensure safety."[33] "To prevent subjects from experiencing a fall during training, a therapist stood within arm's reach of the subject."[34] "An assistant waited next to the affected side for the subject's safety." "Participants stood in front of a green screen with a physio belt around their waist while being monitored by a researcher (behind the participant)"(from photo caption).[43] "The physiotherapist attended to the treatment for safety purposes..."[46] "Physiotherapists... observed patients during games for safety."[48] "During the sessions, the patients were carefully supervised by a physiotherapist who monitored the safety of the patients (eg, risk of falls, impulsive reactions) and provided external feedback."[53]
Program selection or review	5 (17)	33,38,41,47,56	"Functional and repetitive exercise programs for all study participants were reviewed daily in order to optimize rehabilitation potential."[33] "Participants in the Nintendo Wii Fit group participated in Wii Fit activities selected by the treating physiotherapist to match the patient's individual abilities and treatment needs ..."[56] "The PTs were in charge of the remote control in order to maximize intensity."[47]
Extrinsic feedback	4 (14)	29,37,38,53	"During these first attempts, the physical therapist gave manual and verbal cues to the patient to promote a correct posture and perform movements required to interact with the game and achieve its goals."[29] "All treatments were carried out under the supervision of a physiotherapist who motivated the patients to use correct posture and promote the best exercise performance."[37] "During the sessions, the patients were carefully supervised by a physiotherapist who monitored the safety of the patients (eg, risk of falls, impulsive reactions) and provided external feedback."[53]
Education and training	3 (10)	29,46,48	"Before the start of the first virtual training session, the physical therapist explained the objectives and allowed each participant a trial attempt per game to familiarize themselves with the tasks and equipment."[29] "...aim to educate the patients in the use of Wii-Fit..."[46] "Physiotherapists provided instructions to the patients on games..."[48]

(Continued)

Table.
Continued

Theme	Studies n (%)	References	Quotes
Motivation	3 (10)	29,34,37	"In the last attempt, the participants played without any help, except for verbal motivation."[29] "Subjects were encouraged to increase the challenge level and to try to improve their performance of each activity during the intervention period."[34] "All treatments were carried out under the supervision of a physiotherapist who motivated the patients to use correct posture and promote the best exercise performance."[37]
Record keeping	2 (7)	47,56	"Physiotherapists providing the intervention kept records of treatment sessions, including the number of sessions completed adherence, activities prescribed, participant reports of discomfort and adverse events."[56] "The PTs… registered the games played, time (in minutes) needed to rest during sessions and made notes of the spontaneous comments regarding the progression."[47]
Other	3 (10)	36,41,54	Therapist followed "training protocol"[36]; "physical assistance" "If abnormal myotonus was noted in the affected limbs due to compensatory movements, the assistant lowered it with assistance before the initiation of the training."[41] Physical assistance noted in photograph of intervention although not mentioned in description of intervention.[54]

is a more accurate measure of intervention dose than overall session duration.

Incompleteness of intervention descriptions is not only problematic in VR rehabilitation. Reporting of complex interventions has previously been demonstrated to be challenging,[64] and poor description of interventions has been found a common problem in physical therapy research[59] and other non-pharmacological interventions.[65] In VR rehabilitation, incompleteness of intervention descriptions limits the ability to attribute the true value of the use of VR technology in rehabilitation and hinders the identification of the active ingredients within the intervention. In a special communication paper in 2013, Levac and colleagues stated that the ultimate active ingredient in VR rehabilitation is the therapist.[23] However, the level and type of therapist input in the intervention procedures of the included studies lacked clear description despite evidence that therapist engagement in VR intervention delivery may positively affect mobility outcomes.[22,66]

A reference to the specific role of the therapist was made in 22 studies. Seven therapist roles were identified with regards to intervention delivery. Supervision and safety, particularly falls prevention, were most frequently mentioned; however, details of what, or how much, input the therapist provided generally lacked description. Activities related to more complex therapist roles, such as clinical reasoning, program selection and modification, provision of feedback, and education and training, had very little mention. The literature has shown that, as in conventional rehabilitation,[67,68] functional improvements in VR-based rehabilitation are specific to the training task.[53,60,69] Yet, in the included studies, the clinical rationale for the technology chosen and its relation to therapy goals and primary outcome measure was seldom reported. As an example, 10 studies using the Wii platform used Timed Up and Go (TUG)[34,38,54,56] or gait parameters[39,42,47,49–51,55] as primary outcome measures despite the Wii platform being primarily a stationary balance device.

Similarly, reasoning for exercise or game selection and aspects of program tailoring to patients' needs were rarely reported. Only 5 studies reported therapist involvement in program selection and program review,[33,38,41,47,56] all of whom were physical therapists and occupational therapists, indicating the professional skill set required. In 2 studies, intervention programs were reported as progressed automatically based on game achievements rather than on clinical judgment.[47,52] A recent systematic review[18] evaluating the application of VR in the rehabilitation of balance and gait in specific neurological conditions found that half of the included studies lacked therapeutic validity, particularly due to the omission of rationale relating to dose and customization of therapy to individual needs. It is possible that within the confines of a VR intervention trial, the ability for the treating therapist to individualize and tailor the intervention is limited. A level of autonomy for clinical judgment should be built into the study design to accommodate appropriate clinical reasoning. All but 3 of the included studies based the intervention on the use of 1 technology only. Having access to a range of technologies may facilitate program tailoring, allowing the treating clinician to take into account patient impairments, therapy goals, and personal preferences.

Only 4 of the studies[29,37,38,53] included in this review explicitly mentioned therapist feedback in the description of the intervention procedures. Two studies discussed the importance of therapist guidance to ensure optimal movement patterns, stating that relying on the use of technology feedback solely is insufficient.[38,54] In rehabilitation, extrinsic feedback is particularly important, as intrinsic motor learning abilities may be impaired in many individuals.[70] VR systems provide opportunity for practice in an enriched environment, which through the provision of additional extrinsic feedback may facilitate motor learning.[7] To date, the optimum use of interventions using technology feedback, therapist feedback, or a combination of both and its effect on motor learning has not been investigated. Recreational systems have been suggested to require more therapist input to optimize movement patterns[71] as well as supplementary therapist feedback to negate the primarily negative feedback provided by the technology.[72] Future studies should consider this aspect carefully to inform the optimal involvement of therapists in VR rehabilitation.

This review has critically analyzed how VR interventions aimed at the rehabilitation of gait, posture, and balance are being delivered and described and the role of the therapist in the design and delivery of the intervention. Strengths of this review are an extensive systematic search and comprehensive data extraction using the TIDieR[26] checklist. Only studies published in English with a sample size of >10 intervention participants and using commercially available technologies were included. We also limited our research to studies that utilized technologies commercially available to therapists for immediate integration into a service without the requirement for specialist support. We recognize that studies investigating prototype technologies may have provided more detailed intervention information, resulting in different results.

This review has demonstrated that VR intervention reporting generally lacks detail. It is unclear whether this is due to poor intervention implementation or to incomplete intervention reporting. Where stated, VR interventions were primarily provided by physical therapists, with roles of supervision and safeguarding described most frequently. Few studies reported on the integration of complex clinical skills, such as clinical reasoning, intervention tailoring to specific needs, or use of feedback. Incomplete reporting makes replication difficult and hinders the translation of research into clinical practice. Intervention reporting in future studies should report all aspects of intervention design and delivery. At the design stage, researchers should consider protocols that allow therapists to exercise clinical autonomy during the delivery of the intervention. This level of detail will aid clinicians in how to best integrate VR intervention into clinical practice.

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Concept/idea/research design: H. Weber, C. Barr, M. van den Berg
Writing: H. Weber, C. Barr, M. van den Berg
Data collection: H. Weber, C. Gough
Data analysis: H. Weber, C. Gough, M. van den Berg
Consultation (including review of manuscript before submitting): C. Barr, C. Gough, M. van den Berg

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Systematic Review Registration

This systematic review protocol was registered with PROSPERO (CRD42018105668). PRISMA guidelines were followed, and the TIDier checklist was used to extract intervention details.

Disclosures and Presentations

The authors completed the ICMJE Form for Disclosure of Potential Conflicts of Interest and reported no conflicts of interest.

A poster was accepted for the APA Transform2019 Physiotherapy Conference, October 17–19, 2019. This presented a subset of the results, and no conference proceedings were published.

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Appendix C: TIDieR Checklist

Checklist removed for copyright reasons.

Full publication and checklist available here:

Hoffmann, T. C., Glasziou, P. P., Boutron, I., Milne, R., Perera, R., Moher, D., Altman, D. G., Barbour, V., Macdonald, H., Johnston, M., Lamb, S. E., Dixon-Woods, M., McCulloch, P., Wyatt, J. C., Chan, A. W., & Michie, S. (2014). Better reporting of interventions: template for intervention description and replication (TIDieR) checklist and guide. BMJ, 348, g1687. https://doi.org/10.1136/bmj.g1687

[redacted]

Appendix D: DOCFEST poster

Affordable wearable motion capture anywhere – but is it accurate?

Heather Weber, Chris Barr, Maayken van den Berg

Flinders University
Clinical Rehabilitation
College of Nursing and Health Sciences

Background

Motion capture objectively records human movement in 3D and is used for complex movement assessment in health, athletic performance feedback in sport and to create digital characters in film making.

Optical marker systems (e.g. Vicon), are the existing motion capture gold standard, however these systems are expensive, lab based, with limited capture volume (Windolf et al, 2008).

Wearable inertial and magnetic sensor systems offer in situ motion capture without these limitations but accuracy varies depending on movement, sensor type and software (Poitras et al, 2019).

Notch is a recently released sensor system promising affordable user friendly motion capture with an app interface that is yet to be validated.

If the Notch sensor system is accurate for motion capture there is widespread application in not only health, sport and film making, but also in new fields such as ergonomic workplace assessment and telerehabilitation.

This study aimed to assess the motion capture accuracy of the Notch motion capture system during gait.

Figure 1. Notch sensor and mobile app

Method

This study used a concurrent observational study design.

- Fifteen participants without self-reported mobility impairments
- Three recordings per participant, 1 gait cycle each leg, 90 gait cycles in total
- Simultaneous recording by Notch and Vicon systems
- Joint angle data processed with each systems proprietary software
- Peak flexion/extension angles of the lower limb during key portions of the gait cycle (GC) extracted from each system
- Data compared using Pearson's correlation coefficient (r) and ICC

Figure 2. Notch sensors and Vicon markers worn simultaneously

Results

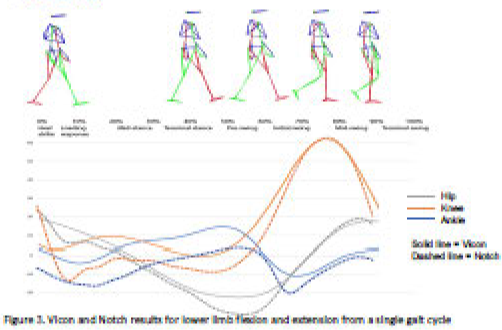

Figure 3. Vicon and Notch results for lower limb flexion and extension from a single gait cycle

Correlation, absolute, and consistency ICC between the Notch and Vicon systems was significant but weak (r<0.50) or poor (ICC<0.50) for hip flexion and extension, knee flexion and ankle dorsiflexion (0-10%GC).

Table 1. Correlation between Notch and Vicon sensor motion capture systems for key angles during gait

Maximum angle Gait cycle (GC)	r	ICC absolute (95% CI)	ICC consistency (95% CI)
Hip flexion (0-20% GC)	0.22*	0.21 (0.00 – 0.40)**	0.22 (0.00 – 0.41)*
Hip extension (40-60% GC)	0.49**	0.49 (0.31 – 0.64)**	0.49 (0.3 – 0.64)**
Knee extension (0-10%GC)	0.13	0.01 (-0.09- 0.28)	0.11 (-0.11-0.32)
Knee flexion (60-80% GC)	0.37**	0.21 (-0.05-0.44)**	0.33 (0.12 – 0.51)**
Ankle dorsiflexion (0-10% GC)	0.42**	0.24 (0.03 – 0.43)**	0.25 (0.03 – 0.45)*
Ankle dorsiflexion (40-60% GC)	0.08	0.03 (-0.19- 0.24)	0.08 (-0.19 – 0.25)

*Correlation is significant at the 0.05 level (2-tailed) ** Correlation is significant at the 0.01 level (2-tailed).

Discussion

As tested, the Notch sensor system does not currently provide results within acceptable limits for quantitative motion capture in gait.

This is in contrast to similar studies with different wearable sensor systems which have found moderate to excellent validity.

This could be due to:

- Differences in sensor types
- Potential ferromagnetic interference
- Differences in biomechanical models used to calculate the kinematics
- Using commercial proprietary software instead of custom processing scripts

Consumers of wearable motion capture systems should ensure systems have undergone validity testing that replicates settings and procedures relevant to their planned usage.

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INSPIRING ACHIEVEMENT

Appendix E: Notch Validity Study Submitted manuscript

Running Head: VALIDITY OF A SENSOR SYSTEM FOR GAIT ANALYSIS

CONCURRENT VALIDITY OF AN AFFORDABLE WEARABLE SENSOR 3D MOTION CAPTURE SYSTEM FOR GAIT ANALYSIS

Authors:

Heather Weber, College of Nursing and Health Sciences, Flinders University

https://orcid.org/0000-0003-4945-8445

Maayken van den Berg, College of Nursing and Health Sciences, Flinders University

https://orcid.org/0000-0002-5878-7649

Michael P. Russo, College of Science and Engineering, Flinders University

https://orcid.org/0000-0002-4784-0539

David Hobbs, College of Science and Engineering, Flinders University

https://orcid.org/0000-0003-1164-3899

Mark Taylor, College of Science and Engineering, Flinders University

https://orcid.org/0000-0001-7842-6472

Christopher Barr, College of Nursing and Health Sciences, Flinders University

https://orcid.org/0000-0002-6266-661

Keywords: Gait; motion capture; wearable sensor.

Declaration of Competing Interest: The authors declare that they have no known conflicts of interest that could have influenced the work contained in this paper. Additionally, the authors declare that they have no known competing financial interests.

Corresponding Author: Heather Weber heather.weber@flinders.edu.au

ABSTRACT

Objective: Wearable sensor systems can offer in situ human motion capture to provide contextual data in a variety of settings. This study investigates the concurrent validity of an affordable, commercial wearable sensor system for gait analysis when used off-the-shelf. Methods: In 15 healthy adults the Notch sensor system was used simultaneously with the Vicon optical camera system, the current gold standard, to capture motion data during six gait cycles. From a total of 82 gait cycles kinematics were calculated using each systems' proprietary software. Pearson's correlation and intraclass correlation coefficients (ICC) were used to compare key sagittal lower limb angles produced by the two systems. Results: Maximum hip flexion demonstrated moderate correlation, however, in all other angles the correlations were poor. Conclusion: These results suggest that the Notch system used in this study is not viable for accurate quantitative gait analysis.

1. Introduction

Motion capture refers to the objective recording, measurement and analysis of human movement and is widely used in various fields including ergonomics, rehabilitation and sport to provide detailed information on joint kinematics and kinetics. This assessment of complex biomechanics can be used to optimise movement patterns for improved performance (Ford et al., 2005), detect and diagnose physical abnormalities (Ferrarin et al., 2015) or evaluate the effect of different variables such as footwear (Tian et al., 2018). Motion capture has particular application in gait analysis as observational gait analysis has been shown to lack reliability (Kawamura et al., 2007; Williams et al., 2009).

The current 'gold standard' of motion capture, three dimensional (3D) optical systems such as the Vicon Motion Capture System, requires expensive and laboratory based optical 3D cameras and markers and yields highly accurate results (Dorociak & Cuddeford, 1995; Windolf et al., 2008). However, a laboratory setting may not be representative of the environment in which the human movement would normally occur, which may in turn influence the performance of the movement captured (Foucher et al., 2010), and the motion capture is limited to the area of camera view and by marker occlusion.

As an alternative to 3D optical systems for kinematic motion capture, video recording in 2D is relatively inexpensive and portable, allowing in situ measurement. However accurate data capture is limited to the video field of view, the movement plane perpendicular to the camera, and can be affected by parallax errors (Paul et al., 2016; Reinking et al., 2018; Schurr et al., 2017). In addition, manual data processing post-capture can be time and labour intensive. Markerless 3D video systems, such as the Microsoft Kinect, are another relatively low cost motion capture option, using an optical camera combined with depth sensing technology, but when used as a single camera as designed, they currently lack accuracy for research and clinical purposes (Muller et al., 2017; Pfister et al., 2014), and are also limited by field of view of the camera.

Wearable sensor systems provide in situ options to measure joint kinematics and can capture data in a range of contextual environments (O'Reilly et al., 2018). The data obtained from each sensor is sent to a computer via wired or wireless means to calculate the relevant motion capture variables and can be processed via associated software or custom written algorithms. Validity of these systems has been shown to vary depending on the complexity and speed of the movement, the plane being studied and the type of sensor used (Poitras et al., 2019).

Notch is a recently developed wearable sensor system, which uses up to 18 accelerometer and magnetometer-based sensors to provide a portable and user-friendly 3D motion capture in any environment. Once calibrated, the sensors can be operated via a mobile app employed on a smartphone or tablet, with real time processing and avatar visualisation of the motion (wearnotch.com). Whilst this system has been used in observational workplace research (Lenzi et al., 2019a, 2019b), and has been proposed to be used with Kinect cameras for upper limb workplace observation (Tarabini et al., 2018), the accuracy of the Notch system has not been independently evaluated. The aim of this study was to evaluate the concurrent validity of the Notch system against the Vicon system during gait in healthy adults.

2. Methods

2.1 Study design

This study utilised a cross-sectional observational design to evaluate the concurrent validity of lower limb kinematics reported by the Notch system against the gold standard Vicon system.

2.2 Setting and participants

Each participant attended a single session at a rehabilitation and motion analysis laboratory. Participants were eligible if they were over the age of 18 with no self-reported mobility impairment. Ethical approval was obtained from the Southern Behavioural Research Ethics Committee prior to the study commencing and all participants provided written informed consent.

2.3 Study procedures

A Vicon Bonita B10 ten camera system (Vicon Motion Systems, Oxford, UK) and a 13 sensor Notch system with firmware version 105 (Notch Interfaces Inc, New York, US) were individually calibrated in the motion analysis laboratory immediately prior to testing. The Vicon reflective markers were applied to the skin or tight-fitting clothing using double sided adhesive tape in a modified Helen Hayes full body marker set arrangement (Davis et al., 1991) with medial knee markers to further define the knee axis with a virtual Knee Alignment Device (Leboeuf et al., 2019) (Fig 1).

The 13 Notch sensors were placed in a full body configuration. Upper and lower arm and leg midsegment sensors were attached directly to the skin using doubled sided tape, while head and torso sensors were attached to soft elastic straps wrapped around the segments (Fig 1).

Figure 1. Participant with white triangular Notch sensors and round reflective Vicon optical markers in situ.

Markers and sensors were placed by an experienced research physiotherapist and further calibration procedures performed according to manufacturer instructions for both systems.

Participants performed a sit-stand-sit movement to allow synchronisation of the two systems before walking at a self-selected speed through the capture area until up to six clean walking trials were captured, three for each leg.

2.4 Data processing and analysis

Data was processed with each systems' proprietary software including Vicon "Plug-in Gait full body AI" model (Vicon Motion Systems, Oxford, UK) and the standard Notch skeleton android application (Version 1.9.33). Sagittal plane hip, knee, and ankle joint angles were exported from each system for analysis using Excel. These were selected from the available data as walking is cyclical and predictable in nature, with low variation between cycles and easily comparable to previously published motion analysis data (Picerno et al., 2008).

Each data set was normalised to 100% of the gait cycle (GC). A single GC was defined as from the time when the heel makes initial contact with the ground to the time when the same heel next contacts the ground. Maximal sagittal (flexion/extension) angles of the hip, knee, and ankle during clinically relevant phases of the GC (McLoughlin et al., 2016) were extracted and analysed; hip flexion (0-20% GC), hip extension (40-60% GC), knee extension (0-10%GC), knee flexion (60-80% GC), ankle dorsiflexion (0-10% GC and 40-60% GC) and ankle plantarflexion (50-70% GC) (see Fig 2). Sagittal plane angles were chosen as the plane with highest reliability (McGinley et al., 2009).

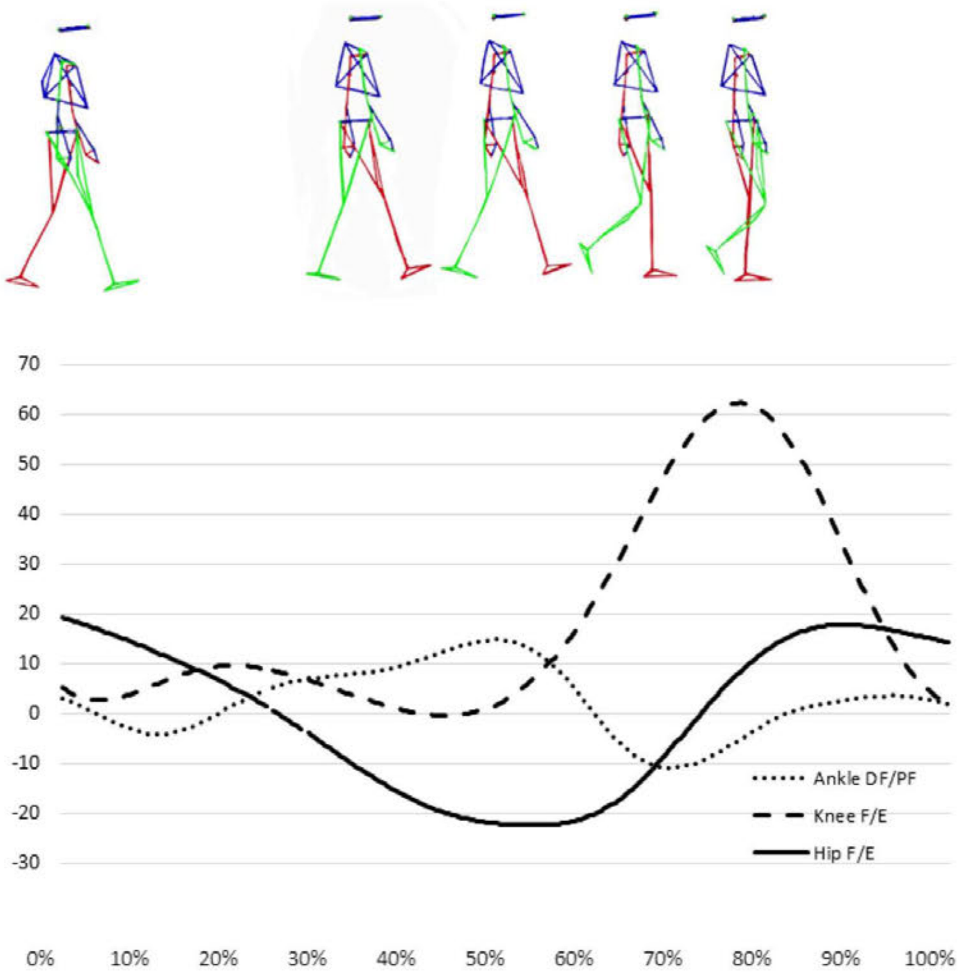

Figure 2. Sagittal plane hip, knee and ankle angles normalised to 100% of the gait cycle Abbreviations: DF/PF = plantarflexion/dorsiflexion; F/E = flexion/extension

2.4.1 Statistical methods

Statistical analysis was conducted using SPSS v25 (IBM, Chicago, US). Descriptive statistics were calculated for participant demographics.

Data points were visually inspected and outliers were excluded from analysis by removing values more than 1.5 interquartile rankings (IQRs) below the first quartile or above the third quartile (Tukey, 1970). Data identified as potentially anatomically incorrect but within 1.5

IQRs of the inter quartile range were included in the analysis in order to evaluate the true accuracy of the device. Data was then assessed to confirm normal distribution before descriptive statistics and the coefficient of variance (CV) were calculated on each kinematic variable.

To compare the Notch system against the Vicon system the Pearson's Correlation Coefficient [r] was calculated for each kinematic variable. Similarly, Intraclass Correlation Coefficient (ICC) estimates were calculated with a single rating, 2-way mixed-effects model for both absolute-agreement and consistency. For Pearson's correlations alpha was set to 0.05, and ICC was considered excellent for values greater than 0.90, good for 0.75–0.90, moderate for 0.5-0.75 or poor for 0.50 or lower (Koo & Li, 2016).

3. Results

3.1 Participants

Fifteen individuals (9 female), mean age 32.8 (SD 10.4), mean BMI 25.2 kg/m^2 (SD 4.26) with no self-reported mobility impairments were recruited into the study. From each participant three gait cycles from each leg were recorded, resulting in a total of 90 gait cycles. Due to incomplete Notch data recording, eight gait cycles from three participants were excluded leaving 82 gait cycles for correlation analysis.

3.2 Kinematics

The results for each kinematic variable are summarised in Table 1. A total of 574 data points, (seven kinematic variables in 82 gait cycles) were analysed for each motion capture system. Thirty-five statistical outliers were removed, 22 from the Notch data and 13 from the Vicon data.

Table 1 Summary of kinematic variables for both systems

	Notch Sensor Motion Capture			Vicon Optical Motion Capture		
	n	Mean (SD)	CV	n	Mean (SD)	CV
Maximum hip flexion (0-20%GC)	77	27.7 (7.5)	26.9	90	30.2 (7.9)	26.0
Maximum hip extension (40-60%GC)	81	-13.4 (6.5)	-48.1	90	-14.2 (6.8)	-48.0
Maximum knee extension (0-10%GC)	80	11.1 (7.2)	64.9	85	7.3 (3.9)	53.8
Maximum knee flexion (60-80% GC)	81	66.2 (9.4)	14.2	86	59.0 (5.3)	9.0
Maximum ankle dorsiflexion* (0-10% GC)	77	1.9 (7.6)	395.1	90	-1.1 (2.9)	-261.8
Maximum ankle dorsiflexion* (40-60% GC)	75	-11.4 (8.0)	-70.6	89	-14.3 (2.7)	-18.7
Maximum ankle plantarflexion* (50-70% GC)	81	11.0 (17.1)	155.2	88	13.1 (5.8)	43.9

Abbreviations: CV= coefficient of variation; GC = gait cycle.

* At the ankle a negative value indicates dorsiflexion and a positive value indicates plantarflexion.

3.3 Correlation between the Notch system and Vicon system

Correlation between the Notch and Vicon systems (Table 2) was significant and moderately correlated (r=0.549) for maximum hip flexion (0-20% GC), whereas maximum hip extension (40-60% GC), knee flexion (60-80% GC), ankle dorsiflexion (0-10% GC) and ankle dorsiflexion (40-60% GC) were all significant but weakly correlated (r<0.05). Both absolute and consistency ICC were moderate (ICC 0.5-0.75) for maximum hip flexion (0-20% GC) and poor (ICC<0.50) for hip extension (40-60% GC). No other significant relationships were observed.

Table 2. Correlation between the Notch system and Vicon system

	r	ICC absolute (95% CI)	ICC consistency (95% CI)
Maximum hip flexion (0-20% GC)	0.549**	0.539 (0.361-0.680)**	0.549 (0.371-0.687)**
Maximum hip extension (40-60% GC)	0.490**	0.489 (0.305-0.638)**	0.489 (0.304-0.638)**
Maximum knee extension (0-10%GC)	0.096	0.064 (-0.117-0.254)	0.078 (-0.149-0.297)
Maximum knee flexion (60-80% GC)	0.336**	0.179 (-0.050-0.395)	0.281 (0.062-0.474)
Maximum ankle dorsiflexion (0-10% GC)	0.422**	0.257 (0.047-0.448)	0.285 (0.066-0.477)
Maximum ankle dorsiflexion (40-60% GC)	0.275*	0.137 (-0.069-0.339)	0.151 (-0.077-0.364)

Maximum ankle plantarflexion (50-70% GC)	0.081	0.047 (-0.173-0.264)	0.047 (-0.174-0.265)

Abbreviations: GC = gait cycle; ICC = Intraclass Correlation Coefficient; r = Pearson's Correlation Coefficient.

*Correlation is significant at the 0.05 level (2-tailed) ** Correlation is significant at the 0.01 level (2-tailed).

4. Discussion

This study investigated the concurrent validity of a low-cost wearable motion capture system by simultaneously recording gait parameters with the Notch and Vicon systems. Peak sagittal plane lower limb joint angles were compared during seven key phases of the gait cycle. Overall, the correlation between the measured joint angles was poor. The results suggest that at present the validity of the Notch system does not provide a viable option for accurate quantitative motion capture of gait in healthy adults.

The correlation between the hip, knee and ankle angles reported by Notch and Vicon systems was poor. Our results are in contrast to similar studies that reported moderate to excellent validity of different wearable sensor systems, such as Xsens (Al-Amri et al., 2018; Cloete & Scheffer, 2008; Ferrari et al., 2010; Palermo et al., 2014; Seel et al., 2014), Physilog (Rouhani et al., 2012) and Rehagait (Nuesch et al., 2017) in sagittal plane lower limb kinematics during gait. The variance in reported accuracy of different wearable sensors for motion analysis may be attributable to variations in both hardware designs and software processing utilised, as well as the methodology employed in each study.

The biomechanical model used to calculate the kinematics of body movement can influence the accuracy of the measured joint angles (Ferrari et al., 2010; Robert-Lachaine et al., 2017). The Vicon system was used as the gold standard, however, although validated, the Vicon Plug in Gait model has some limitations (Schwartz & Dixon, 2018). The biomechanical model used by the Notch system is proprietary to the company making it difficult to compare the output of both systems without first extracting the raw data. Differences in measurements provided by the two systems in our study could be due to the software filtering and algorithms used to construct the joint angles. The present study utilised only the proprietary application provided by Notch to process the raw data. Motion capture validity results reported in the literature often utilise custom processing scripts written for the purpose of each project, rather than the commercial software supplied by the manufacturers (Petraglia et al., 2019). Previous studies have shown that optimising the filtering parameters can reduce joint angle errors (Saito & Watanabe, 2011), correct for soft tissue artefacts (Iosa et al., 2016) and increase accuracy (Takeda et al., 2009). Applying a custom processing script to the raw data obtained from the Notch sensors may have improved the correlations between the two systems, however using the proprietary app is reflective of how a typical user would utilise this system. Soft tissue artefacts are a source of motion capture inaccuracy in sensor systems (Lebel et al., 2017; Seel et al., 2014), and optical systems (Fiorentino et al., 2017). As the sensors from the two systems were not placed on identical anatomical locations, differences in skin motion artefacts at different locations may have also influenced the results (Seel et al., 2014).

Statistical methods identified outliers greater than 1.5 IQR that were then removed from our data prior to analysis, however this did not remove all physically impossible results. Accuracy would improve with a handpicked selection of best trials, or whole cohort assessment by a clinician, however this study aimed to test the pragmatic accuracy of the system and therefore did not improve the results by exclusion of poor-quality trial data.

There a few study limitations that should be addressed. Further trials with more participants or more gait cycles per participant may have provided different results, however six gait cycles per participant reflects pragmatic clinical usage. Further system limitations also need to be considered. Metal interference from ferromagnetic materials, which influence the magnetometer within the Notch sensor, is known to limit accuracy of sensor based motion capture systems, especially when placed within one metre (de Vries et al., 2009; Picerno, 2017). The data in this study was collected within a gait laboratory which likely resulted in electromagnetic interference. The accuracy of the Notch system may be improved in areas of less interference, but such interference is unavoidable in most clinical, research and community settings. Magnetic interference in motion laboratories is greatest 5cm above the floor (de Vries et al., 2009), which may explain the poor ankle joint correlations between the two systems. Magnetometer drift may also influence results (Lebel et al., 2015). Notch calibration procedures were followed, and recordings limited to fifteen seconds each to minimise this, however, the difference in accuracy between the first and last trials was not assessed. Notch sensors are calibrated by securing the sensors in their provided docking station and performing a series of rotations. This process could be improved, consequently improving sensor accuracy, by using a low friction rotation rig to standardise movement, with care taken to keep rotations in the desired plane. Ensuring stationary subject positioning during participant calibration by using a rigid jig may also increase sensor accuracy (Kim & Lee, 2017), and combining Notch data with data collected from multiple Microsoft Kinect cameras has also been proposed to overcome the limitations of each system (Tarabini et al., 2018). Finally, it is possible that another set of Notch sensors may provide different results as there remains potential for individual sensors to perform differently, even within the same brand and type (Picerno et al., 2011).

This assessment of the Notch was conducted on an early hardware and software release and further updates and improvements may lead to more accurate reporting of joint angles. If accuracy can be improved, the Notch system may have applications in workplace ergonomics for work health and safety, in design and ergonomics, in health for use in telerehabilitation (Buonocunto et al., 2018), or for immediate feedback for retraining motor control patterns (Shull et al., 2014). Overall, while there are many applications for an accurate and affordable portable sensor-based motion capture system, our results indicate that the accuracy of the Notch system used in this study is not within acceptable limits for use in research or clinical settings.

Acknowledgements

Heather Weber is supported by an Australian Government Research Training Program Scholarship.

Authors' Contribution

All authors contributed to the study design and writing of the manuscript. HW, MvdB, MR and CB contributed to data collection and analysis.

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Appendix F: Notch Validity Study Ethics Approval

From: Human Research Ethics
To: Heather Weber; Maayken van den Berg; Chris Barr; David Hobbs; Mark Taylor
Subject: 8143 SBREC Final approval notice (24 August 2018)
Date: Friday, 24 August 2018 4:33:32 PM

Dear Heather,

The Chair of the Social and Behavioural Research Ethics Committee (SBREC) at Flinders University considered your response to conditional approval out of session and your project has now been granted final ethics approval. This means that you now have approval to commence your research. Your ethics final approval notice can be found below.

FINAL APPROVAL NOTICE

Project No.:	**8143**
Project Title:	Accuracy assessment of two low-cost movement analysis methods
Principal Researcher:	Ms Heather Weber
Email:	Heather.weber@flinders.edu.au
Approval Date:	24 August 2018
Ethics Approval Expiry Date:	**1 April 2020**

The above proposed project has been **approved** on the basis of the information contained in the application, its attachments and the information subsequently provided.

RESPONSIBILITIES OF RESEARCHERS AND SUPERVISORS

1. **Participant Documentation**
   Please note that it is the responsibility of researchers and supervisors, in the case of student projects, to ensure that:

   - all participant documents are checked for spelling, grammatical, numbering and formatting errors. The Committee does not accept any responsibility for the above mentioned errors.
   - the Flinders University logo is included on all participant documentation (e.g., letters of Introduction, information Sheets, consent forms, debriefing information and questionnaires – with the exception of purchased research tools) and the current Flinders University letterhead is included in the header of all letters of introduction. The Flinders University international logo/letterhead should be used and documentation should contain international dialling codes for all telephone and fax numbers listed for all research to be conducted overseas.
   - the SBREC contact details, listed below, are included in the footer of all letters of introduction and information sheets.

   This research project has been approved by the Flinders University Social and Behavioural Research Ethics Committee (Project Number 'INSERT PROJECT No. here following approval'). For more information regarding ethical approval of the project the Executive Officer of the Committee can be contacted by telephone on 8201 3116, by fax on 8201 2035 or by email human.researchethics@flinders.edu.au.

2. **Annual Progress / Final Reports**

   In order to comply with the monitoring requirements of the *National Statement on Ethical Conduct in Human Research (March 2007)* an annual progress report must be submitted each year on the **24 August** (approval anniversary date) for the duration of the ethics approval using the report template available from the Managing Your Ethics Approval SBREC web page. *Please retain this notice for reference when completing annual progress or final reports.*

   If the project is completed *before* ethics approval has expired please ensure a final report is submitted immediately. If ethics approval for your project expires please submit either (1) a final report; or (2) an extension of time request and an annual report.

   Student Projects

   The SBREC recommends that current ethics approval is maintained until a student's thesis has been submitted, reviewed and approved. This is to protect the student in the event that reviewers recommend some changes that may include the collection of additional participant data.

   Your first report is due on **24 August 2019** or on completion of the project, whichever is the earliest.

3. **Modifications to Project**

   Modifications to the project must not proceed until approval has been obtained from the Ethics Committee. Such proposed changes / modifications include:

   - change of project title;
   - change to research team (e.g., additions, removals, principal researcher or supervisor change);
   - changes to research objectives;
   - changes to research protocol;
   - changes to participant recruitment methods;
   - changes / additions to source(s) of participants;
   - changes of procedures used to seek informed consent;
   - changes to reimbursements provided to participants;
   - changes / additions to information and/or documentation to be provided to potential participants;
   - changes to research tools (e.g., questionnaire, interview questions, focus group questions);
   - extensions of time.

   To notify the Committee of any proposed modifications to the project please complete and submit the *Modification Request Form* which is available from the Managing Your Ethics Approval SBREC web page. Download the form from the website every time a new modification request is submitted to ensure that the most recent form is used. Please note that extension of time requests should be submitted prior to the Ethics Approval Expiry Date listed on this notice.

   Change of Contact Details

   Please ensure that you notify the Committee if either your mailing or email address changes to ensure that correspondence relating to this project can be sent to you. A modification request is not required to change your contact details.

4. **Adverse Events and/or Complaints**

   Researchers should advise the Executive Officer of the Ethics Committee on 08 8201-3116 or 8201-7938 human.researchethics@flinders.edu.au immediately if:

- any complaints regarding the research are received;
- a serious or unexpected adverse event occurs that effects participants;
- an unforeseen event occurs that may affect the ethical acceptability of the project.

Kind regards
Wendy Green

On behalf of Andrea Mather

Ms Andrea Mather (formerly Fiegert) **and Ms Rae Tyler**
Ethics Officers and Executive Officers, Social and Behavioural Research Ethics Committee

Ms Andrea Mather | Monday - Friday	T: +61 8201-3116 | E: human.researchethics@flinders.edu.au
Ms Rae Tyler | Monday, Wednesday and Friday mornings	T: +61 8201-7938 | E: human.researchethics@flinders.edu.au
A/Prof David Hunter | SBREC Chairperson	T: +61 7221-8477 | E: david.hunter@flinders.edu.au
Dr Deb Agnew | SBREC Deputy Chairperson	T: +61 8201-3456 E: deb.agnew@flinders.edu.au
SBREC Website	Social and Behavioural Research Ethics Committee (SBREC)

Research Development and Support | Union Building Basement
Flinders University
Sturt Road, Bedford Park | South Australia | 5042
GPO Box 2100 | Adelaide SA 5001

Appendix G: Notch Validity Study Participant Information Sheet & Consent Form

Ms Heather Weber
College of Nursing and Health Sciences

Flinders University at Tonsley
1284 South Road Tonsley 5042

GPO Box 2100
Adelaide SA 5001

Tel: +61 7221 8345
heather.weber@flinders.edu.au

INFORMATION SHEET
For Participants

Accuracy assessment of two low-cost movement analysis methods

Researcher
Ms Heather Weber
College of Nursing and Health Sciences
Flinders University
Tel: 7221 8345

Supervisors

Dr Maayken van den Berg	College of Nursing and Health Sciences	Flinders University	7221 8437
Assoc Prof Chris Barr	College of Nursing and Health Sciences	Flinders University	7221 8298
Mr David Hobbs	College of Science and Engineering	Flinders University	7221 3167
Prof Mark Taylor	College of Science and Engineering	Flinders University	8201 5732

Description of the study
This project will investigate the accuracy and validity of two different ways of recording and analysing human movement. This project is supported by Flinders University, College of Nursing and Health Sciences.

Purpose of the study
This project aims to find out if a new portable motion capture system is accurate at recording and analysing human movement in healthy adults. The results of this study will inform the design of future research.

What will I be asked to do?
If you are an adult and consider yourself to be without any movement impairments then you are invited to attend a single one-on-one visit in the gait laboratory at Tonsley with a researcher. It is expected the visit will take about 30 minutes and participation is entirely voluntary. At this visit we will record some simple personal information (age, gender, height, weight and leg length) and then place some movement sensors on your body with soft elastic straps and double sided adhesive tape. Once these are fitted you will be asked to rise from a chair, walk three metres, turn around and return to sit in the chair again. We will also ask you to stand on flat platform that records your balance with your eyes open and shut for 30 seconds. We would like you to do both tests three times, and

you may rest as much as you need in between. Your movement will be video recorded for so it can be analysed.

What benefit will I gain from being involved in this study?
You may not directly benefit from being involved in this study. However, the results of this study will help inform future research in health and human movement.

Will I be identifiable by being involved in this study?
All participants will be allocated a unique identifier to be used with their data to keep it anonymous. However, the nature of the video recording means you may be identifiable to the researchers when analysing your movement. All information and results obtained in this study will be stored in a secure way in a password protected computer, with access restricted to relevant researchers. Any data published from this study will not identify individuals.

Are there any risks or discomforts if I am involved?
The researcher anticipates negligible risk or discomfort from your involvement in this study. You are asked to wear your own fitted clothing to the research visit. The elasticated straps and adhesive to hold the sensors and markers in place may present minor discomfort to some people, however the straps are completely adjustable and will be modified to fit you. Similarly the adhesive used to attach the markers is designed for human skin and removable. If you have any concerns regarding anticipated or actual risks or discomforts from participating in this research, please raise them with the researcher.

How do I agree to participate?
Participation is voluntary. You may answer 'no comment' or refuse to answer any questions, and you are free to withdraw from the session at any time without effect or consequences. A consent form accompanies this information sheet. If you agree to participate please read and sign the form and return to the research team.

Recognition of contribution / time / travel costs
You will not receive any payment for participating in this study.

How will I receive feedback?
If you wish to know your weight, height and leg length we can provide this to you at the time of the session but you will not receive any personal feedback on your movement.

Thank you for taking the time to read this information sheet, and we hope that you will accept our invitation to be involved.

This research project has been approved by the Flinders University Social and Behavioural Research Ethics Committee (Project number: 8143).
For more information regarding ethical approval of the project only, the Executive Officer of the Committee can be contacted by telephone on (08) 8201 3116, by fax on (08) 8201 2035, or by email to human.researchethics@flinders.edu.au

Flinders
UNIVERSITY

CONSENT FORM FOR PARTICIPATION IN RESEARCH
(by experiment)

Accuracy assessment of two low-cost movement analysis methods.

I ………………………………………………………………………………………………

being over the age of 18 years hereby consent to participate as requested in the Information Sheet for the research project "Accuracy assessment of two low-cost movement analysis methods".

1. I have read the information provided.
2. Details of procedures and any risks have been explained to my satisfaction.
3. I agree to video recording of my information and participation.
4. I am aware that I should retain a copy of the Information Sheet and Consent Form for future reference.
5. I understand that:

- I may not directly benefit from taking part in this research.
- Participation is entirely voluntary and I am free to withdraw from the project at any time; and am free to decline to answer particular questions.
- While the information gained in this study will be published as explained and my participation will not be anonymous; I will not be identified and any information I provide will remain confidential.
- If I am a student: Whether I participate or not, or withdraw after participating, will have no effect on my progress in my course of study, or results gained.
- If I am a staff member: Whether or I participate or not, or withdraw after participating, will have no effect on my current employment
- I may ask that the video recording be stopped at any time, and that I may withdraw at any time from the session or the research without disadvantage.

Participant's signature……………………………………Date…………………...

I certify that I have explained the study to the volunteer and consider that she/he understands what is involved and freely consents to participation.

Researcher's name…………………………………………………………..............

Researcher's signature…………………………………..Date…………………….

Appendix H: Observational study PISCF physiotherapist

Flinders UNIVERSITY
College of Nursing & Health Sciences

Government of South Australia
SA Health

Participant Information Sheet/Consent Form
Physiotherapist

Interventional Study - *Adult providing own consent*

Title	A comparison of physiotherapy practice with and without active video and computer-based rehabilitation technology
Chief Investigator	Dr Maayken van den Berg
Investigators	Ms Heather Weber Assoc Prof Chris Barr Site specific person (Nicole Prideaux/ Marissa Sorich)
Location	Modbury Hospital/Hampstead Rehabilitation Centre, SA Health

Part 1 What does my participation involve?

1 Introduction

You are invited to take part in this research project. This is because you are a physiotherapist conducting rehabilitation at SA Health. The research project is investigating similarities and differences between physiotherapy rehabilitation conducted with and without active video and computer-based technology.

This Participant Information Sheet/Consent Form tells you about the research project. It explains what is involved. Knowing what is involved will help you decide if you want to take part in the research.

Please read this information carefully. Ask questions about anything that you don't understand or want to know more about. Before deciding whether or not to take part, you might want to talk about it with a relative or friend.

Participation in this research is voluntary. If you don't wish to take part, you don't have to. Your relationship with your employer will not change whether or not you take part.

If you decide you want to take part in the research project, you will be asked to sign the consent section. By signing it you are telling us that you:
• Understand what you have read
• Consent to take part in the research project
• Consent to the use of your personal information as described.

You will be given a copy of this Participant Information and Consent Form to keep.

2 What is the purpose of this research?

This research is to observe physiotherapy rehabilitation conducted with and without active video and computer-based (AVC) technology. Technology for rehabilitation is already in use in many centres and involves using devices that capture patient movement such as standing platforms and motion capture cameras to interact with a computer-based environment. Examples of this technology you may know include Wii Fit and Xbox Kinect gaming systems.

We plan to observe what changes, if any occur in the way physiotherapy is practiced when using AVC technology. The results of this study will allow us to understand how physiotherapy using AVC technology is being conducted and is the first step in determining optimal physiotherapy practices with technology therapies.

The results of this research will be used by the study researcher Heather Weber to obtain a Doctor of Philosophy degree. This research is being conducted through Flinders University.

3 What does participation in this research involve?

Taking part in this study will require you to complete a questionnaire, attend an orientation session, use AVC technology during 10 physiotherapy rehabilitation sessions and attend an interview.

4 What do I have to do?

If you agree to participate in this study you will be asked to sign the consent form and complete a short initial screening questionnaire to ensure you do not have any eye conditions that would preclude you from participating.

We will ask you to attend an induction workshop at a convenient time at your workplace to orientate you to the AVC rehabilitation technologies being used in this research. During this 30-minute orientation session you will be able to try the equipment and ask questions to ensure you are comfortable with its use, and will be asked to complete a questionnaire detailing your age, gender, clinical and technology experience

You will be asked then to identify up to 10 of your rehabilitation patients who may be eligible for the study and ask them for permission for a researcher to approach them to discuss their involvement. Patients who agree will be individually and independently approached for consent by the researchers.

During up to 10 of your usual physiotherapy rehabilitation sessions with consented patients, you will be asked to use one of the AVC technologies (Wii Fit, Xbox Kinect, Humac Balance Platform and Dr Kinetic Intelligent Rehabilitation Solutions) for half of one of their usual physiotherapy activities (sit to stand, stepping, standing or dynamic balance practice) and perform the remaining half as usual. It is a cross over study so both physiotherapy conditions will be completed but the order will be randomised, so there is equal chance which physiotherapy condition you will perform first in each session. The equipment will be set up by the researchers and ready for you to use. There are no restrictions on your professional practice. You are encouraged to monitor your patient throughout and provide any assistance or rests as you usually would.

The physiotherapy activity will be observed by a researcher both with and without the AVC technology and recorded with a video camera. We will also ask you to wear glasses which record what you look at.

This research project has been designed to make sure the researchers interpret the results in a fair and appropriate way and avoids study researchers or participants jumping to conclusions.

There are no additional costs associated with participating in this research project, nor will you be paid. All equipment required as part of the research project will be provided \will be set up for you prior to rehabilitation sessions by the researchers.

At the conclusion of the study we will invite you to participate in an interview of up to one hour to ask your perceptions about technology use in rehabilitation physiotherapy. This interview will be audio recorded and transcribed. You will have an opportunity to review the transcription prior to data being extracted.

There are no additional costs associated with participating in this research project, nor will you be paid.

5 Other relevant information about the research project

This study will be conducted at two SA Health sites and is expected to involve up to 20 physiotherapists and up to 200 patients. Researchers are from Flinders University.

6 Do I have to take part in this research project?

Participation in any research project is voluntary. If you do not wish to take part, you do not have to. If you decide to take part and later change your mind, you are free to withdraw from the project at any stage.

If you do decide to take part, you will be given this Participant Information and Consent Form to sign and you will be given a copy to keep.

Your decision whether to take part or not to take part, or to take part and then withdraw, will not affect your relationship with SA Health.

7 What are the alternatives to participation?

You do not have to take part in this research project to work at this hospital. If you choose not to participate your employment will not be affected.

8 What are the possible benefits of taking part?

We cannot guarantee or promise that you will receive any benefits from this research; however, possible benefits may include increased knowledge of the use of active video and computer based technology in rehabilitation. This study aims to further knowledge in this field and may improve future physiotherapy rehabilitation practice using technology.

9 What are the possible risks and disadvantages of taking part?

Participating in this research may take additional time to attend the orientation session and the interview.

10 What if I withdraw from this research project?

You are free to withdraw from the project at any stage. If you do withdraw your consent during the research project, the researchers will not collect additional personal information from you, although personal information already collected will be retained to ensure that the results of the research project can be measured properly and to comply with law. If you decide to withdraw please notify the researchers.

11 What happens when the research project ends?

At the conclusion of this research project, once the data has been analysed, you will be offered the opportunity to be advised of the results.

Part 2 How is the research project being conducted?

12 What will happen to information about me?

By signing the consent form you consent to relevant research staff collecting and using personal information about you for the research project. Information obtained in connection with this research project that can identify you will remain confidential unless disclosure is required by law. Information will kept in locked cabinets or digitally in password protected secure files at Flinders University accessible only by the researchers. Your questionnaire and observations from the rehabilitation session will be coded with a unique identifier so your name is not attached to it and the digital files from the video camera and glasses will be viewed only by the researchers for the purpose of extracting data. Your information will only be used for the purpose of this research project and it will only be disclosed with your permission, except as required by law. All information from this project will be retained by Flinders University for 15 years when it will be securely destroyed.

It is anticipated that the results of this research project will be published and/or presented in a variety of forums. In any publication and/or presentation, information will be provided in such a way that you cannot be identified, except with your permission.

13 Complaints and compensation

If you have any concerns or complaints you should speak to the principal investigator. If you wish to withdraw from the study your relationship with the researchers, SA Health or Flinders University will not be affected. By participating in this study you do not give up your legal rights.

14 Who is organising and funding the research?

This research project is being conducted through Flinders University.
No member of the research team will receive a personal financial benefit from your involvement in this research project (other than their ordinary wages).

15 Who has reviewed the research project?

All research in Australia involving humans is reviewed by an independent group of people called a Human Research Ethics Committee (HREC). The ethical aspects of this research project have been approved by the Southern Adelaide Clinical Human Research Ethics Committee (SAC HREC).

This project will be carried out according to the *National Statement on Ethical Conduct in Human Research (2007)*. This statement has been developed to protect the interests of people who agree to participate in human research studies.

16 Further information and who to contact

The person you may need to contact will depend on the nature of your query.

If you want any further information concerning this project or if you have any problems which may be related to your involvement in the project, you can contact the principal researcher on 7221 8437 or any of the following people:

Clinical contact person

Name	Site specific person (Nicole Prideaux/ Marissa Sorich) to be added
Position	*[Position]*
Telephone	*[Phone number]*
Email	*[Email address]*

If you have any complaints about any aspect of the project, the way it is being conducted or any questions about being a research participant in general, then you may contact:

Reviewing HREC approving this research and HREC Executive Officer details

Reviewing HREC name	*Southern Adelaide Clinical HREC*
HREC Executive Officer	*Executive Officer*
Telephone	*8204 6453*
Email	*Health.SALHNOfficeforResearch@sa.gov.au*

Local HREC Office contact (Single Site -Research Governance Officer)

Name	*Site specific details to be added*
Position	*[Position]*
Telephone	*[Phone number]*
Email	*[Email address]*

Consent Form - *Adult providing own consent*

Title	A comparison of physiotherapy practice with and without active video and computer-based rehabilitation technology
Chief Investigator	Dr Maayken van den Berg
Investigators	Ms Heather Weber Assoc Prof Chris Barr Site specific person (Nicole Prideaux/ Marissa Sorich)
Location	Modbury Hospital/Hampstead Rehabilitation Centre, SA Health

Declaration by Participant

I have read the Participant Information Sheet or someone has read it to me in a language that I understand.

I understand the purposes, procedures and risks of the research described in the project.

I have had an opportunity to ask questions and I am satisfied with the answers I have received.

I freely agree to participate in this research project as described and understand that I am free to withdraw at any time during the study without affecting my future employment.

I understand that I will be given a signed copy of this document to keep.

Name of Participant (please print) ______________________________

Signature ______________________ Date ______________________

Declaration by Senior Researcher†

I have given a verbal explanation of the research project, its procedures and risks and I believe that the participant has understood that explanation.

Name of Study Doctor/
Senior Researcher† (please print) ______________________________

Signature ______________________ Date ______________________

† A senior member of the research team must provide the explanation of, and information concerning, the research project.

Note: All parties signing the consent section must date their own signature.

Appendix I: Observational study PISCF patient

Participant Information Sheet/Consent Form
Patient

Interventional Study - *Adult providing own consent*

Title	A comparison of physiotherapy practice with and without active video and computer-based rehabilitation technology
Chief Investigator	Dr Maayken van den Berg
Investigators	Ms Heather Weber Assoc Prof Chris Barr Site specific person (Nicole Prideaux/ Marissa Sorich)
Location	Modbury Hospital/Hampstead Rehabilitation Centre, SA Health

Part 1 What does my participation involve?

1 Introduction

You are invited to take part in this research project. This is because you are undertaking rehabilitation at SA Health and your physiotherapist is a participant in this project. The research project is investigating similarities and differences between physiotherapy rehabilitation conducted with and without technology.

This Participant Information Sheet/Consent Form tells you about the research project. It explains the treatments involved. Knowing what is involved will help you decide if you want to take part in the research.

Please read this information carefully. Ask questions about anything that you don't understand or want to know more about. Before deciding whether or not to take part, you might want to talk about it with a relative, friend or your local doctor.

Participation in this research is voluntary. If you don't wish to take part, you don't have to. You will receive the best possible care whether or not you take part.

If you decide you want to take part in the research project, you will be asked to sign the consent section. By signing it you are telling us that you:
- Understand what you have read
- Consent to take part in the research project
- Consent to have the treatments that are described
- Consent to the use of your personal and health information as described.

You will be given a copy of this Participant Information and Consent Form to keep.

2 What is the purpose of this research?

This research is to observe any differences between physiotherapy rehabilitation conducted with and without active video and computer-based (AVC) technology. Technology for rehabilitation is already in use in many centres and involves using devices that capture patient movement such as standing platforms and motion capture cameras to interact with a computer-based environment. Examples of this technology you may know include Wii Fit and Xbox Kinect gaming systems.

We plan to observe what changes, if any occur in the way physiotherapy is practiced when using AVC technology. The results of this study will allow us to understand how physiotherapy using AVC technology is being conducted and is the first step in determining optimal physiotherapy practices with technology therapies.

The results of this research will be used by the study researcher Heather Weber to obtain a Doctor of Philosophy degree. This research is being conducted through Flinders University.

3 What does participation in this research involve?

You will be asked to complete a questionnaire and use AVC technology during your physiotherapy rehabilitation session on up to two occasions. Each session should add no more than 5 minutes to your rehabilitation session.

4 What do I have to do?

If you agree to participate in this study you will be asked to sign the consent form and complete a questionnaire detailing your age, gender, diagnosis, stage of rehabilitation, rehabilitation goals and technology experience. During up to two of your usual rehabilitation sessions, your physiotherapist will use an AVC technology with you for half of one of your usual activities (sit to stand, stepping, standing balance or dynamic balance practice) and the remaining half of this activity will be conducted without the technology.
You will complete both conditions in turn but the order of activity conditions will be randomised, so there is equal chance which you will perform first. Your physiotherapist will remain with you throughout the session as usual and will provide you with any rests or assistance as required. You will not be asked to do any more or any less than your usual therapy.
A researcher will observe the activity with and without the AVC technology. Your physiotherapist will also be wearing glasses which record what your physiotherapist is looking at during the activity and a video camera will record the session.
This research project has been designed to make sure the researchers interpret the results in a fair and appropriate way and avoids study researchers or participants jumping to conclusions. There are no additional costs associated with participating in this research project, nor will you be paid.

5 Other relevant information about the research project

This study will be conducted at two SA Health sites in Adelaide and is expected to involve up to 20 physiotherapists and up to 200 patients.

6 Do I have to take part in this research project?

Participation in any research project is voluntary. If you do not wish to take part, you do not have to. If you decide to take part and later change your mind, you are free to withdraw from the project at any stage.

If you do decide to take part, you will be given this Participant Information and Consent Form to sign and you will be given a copy to keep.

Your decision whether to take part or not to take part, or to take part and then withdraw, will not affect your routine treatment, your relationship with those treating you or your relationship with SA Health.

7 What are the alternatives to participation?

You do not have to take part in this research project to receive treatment at this hospital. If you choose not to participate your rehabilitation will not be affected.

8 What are the possible benefits of taking part?

This study aims to further knowledge in this field and may improve future physiotherapy rehabilitation using technology, however, it may not directly benefit you.

9 What are the possible risks and disadvantages of taking part?

Participating in this research is not anticipated to involve any additional risks or disadvantages as the physiotherapy movements will be the same as your usual rehabilitation.

10 What if I withdraw from this research project?

You are free to withdraw from the project at any stage. If you do withdraw your consent during the research project, the researchers will not collect additional personal information from you, although personal information already collected will be retained to ensure that the results of the research project can be measured properly and to comply with law. If you decide to withdraw please notify the researchers.

11 What happens when the research project ends?

This research project involves only a small part of up to two of your rehabilitation sessions and your standard rehabilitation will continue as planned.

Part 2 How is the research project being conducted?

12 What will happen to information about me?

By signing the consent form you consent to relevant research staff collecting and using personal information about you for the research project. Any information obtained in connection with this research project that can identify you will remain confidential and will be kept in locked cabinets or password protected secure files at Flinders University accessible only by the researchers. Your questionnaire and observations from your therapy session will be coded with a unique identifier so your name is not attached to it and the digital files from the video camera and eye tracking glasses will be viewed only by the researchers for the purpose of extracting data. Your information will only be used for the purpose of this research project and it will only be disclosed with your permission, except as required by law. All information from this project will be retained by Flinders University for 15 years when it will be securely destroyed.

It is anticipated that the results of this research project will be published and/or presented in a variety of forums. In any publication and/or presentation, information will be provided in such a way that you cannot be identified, except with your permission.

13 Complaints and compensation

If you suffer any injuries or complications as a result of this research project, you should contact the study team as soon as possible and you will be assisted with arranging appropriate medical treatment. If you are eligible for Medicare, you can receive any medical treatment required to treat the injury or complication, free of charge, as a public patient in any Australian public hospital.

14 Who is organising and funding the research?

This research project is being conducted through Flinders University.
No member of the research team will receive a personal financial benefit from your involvement in this research project (other than their ordinary wages).

15 Who has reviewed the research project?

All research in Australia involving humans is reviewed by an independent group of people called a Human Research Ethics Committee (HREC). The ethical aspects of this research project have been approved by the Southern Adelaide Clinical Human Research Ethics Committee (SAC HREC).

This project will be carried out according to the *National Statement on Ethical Conduct in Human Research (2007)*. This statement has been developed to protect the interests of people who agree to participate in human research studies.

16 Further information and who to contact

The person you may need to contact will depend on the nature of your query.

If you want any further information concerning this project or if you have any medical problems which may be related to your involvement in the project (for example, any side effects), you can contact the principal researcher on 7221 8437 or any of the following people:

Clinical contact person

Name	Site specific person (Nicole Prideaux/ Marissa Sorich) to be added
Position	*[Position]*
Telephone	*[Phone number]*
Email	*[Email address]*

If you have any complaints about any aspect of the project, the way it is being conducted or any questions about being a research participant in general, then you may contact:

Reviewing HREC approving this research and HREC Executive Officer details

Reviewing HREC name	*Southern Adelaide Clinical HREC*
HREC Executive Officer	*Executive Officer*
Telephone	*8204 6453*
Email	*Health.SALHNOfficeforResearch@sa.gov.au*

Local HREC Office contact (Single Site -Research Governance Officer)

Name	*Site specific details to be added*
Position	*[Position]*
Telephone	*[Phone number]*
Email	*[Email address]*

Consent Form - *Adult providing own consent*

Title	A comparison of physiotherapy practice with and without active video and computer-based rehabilitation technology
Chief Investigator	Dr Maayken van den Berg
Investigators	Ms Heather Weber Assoc Prof Chris Barr Site specific person (Nicole Prideaux/ Marissa Sorich)
Location	Modbury Hospital/Hampstead Rehabilitation Centre, SA Health

Declaration by Participant

I have read the Participant Information Sheet or someone has read it to me in a language that I understand.

I understand the purposes, procedures and risks of the research described in the project.

I give permission for my doctors or other health professionals, to release information to Flinders University concerning my disease and treatment for the purposes of this project. I understand that such information will remain confidential.

I have had an opportunity to ask questions and I am satisfied with the answers I have received.

I freely agree to participate in this research project as described and understand that I am free to withdraw at any time during the study without affecting my future health care.

I understand that I will be given a signed copy of this document to keep.

Name of Participant (please print) ______________________________

Signature ______________________ Date ______________________

Declaration by Senior Researcher†

I have given a verbal explanation of the research project, its procedures and risks and I believe that the participant has understood that explanation.

Name of Senior Researcher† (please print) ______________________________

Signature ______________________ Date ______________________

† A senior member of the research team must provide the explanation of, and information concerning, the research project.

Note: All parties signing the consent section must date their own signature.

Appendix J: Observational Study Ethics Approval

Office for Research

Flinders Medical Centre
Ward 6C, Room 6A219
Flinders Drive, Bedford Park SA 5042
Tel: (08) 8204 6453
E: Health.SALHNOfficeforResearch@sa.gov.au

Government of South Australia
SA Health
Southern Adelaide Local Health Network

Final Approval for Ethics Application

26 June 2019

Dr Maayken van den Berg
College of Nursing and Health Sciences
Flinders University

Dear Dr van den Berg,

OFR Number: 100.19
HREC reference number: HREC/19/SAC/109
Project title: A comparison of Physiotherapy practice with and without active video and computer-based rehabilitation technology
Chief Investigator: Dr Maayken van den Berg

Ethics Approval Period: 26 June 2019 – 26 June 2022

The Southern Adelaide Clinical Human Research Ethics Committee (SAC HREC) (EC00188) have reviewed and provided approval for this application which meets the requirements of the *National Statement on Ethical Conduct in Human Research (2007, updated 2018).*

You are reminded that this letter constitutes **Ethics** approval only. **Ethics approval is one aspect of the research governance process**.

You must not commence this research project at any SA Health sites listed in the application until a Site Specific Assessment (SSA), or Access Request for data or tissue form, has been approved by the Chief Executive or delegate of each site.

Public health sites approved under this application:

- Modbury Hospital
- Hampstead Rehabilitation Centre

The below documents have been reviewed and approved:

Document	Version	Date
Human research ethics application	AU/1/AB8A312	25 June 2019
Project description	4	11 April 2019
Master patient participant information sheet and consent form	-	13 May 2019
Master physiotherapist participant information sheet and consent form	-	13 May 2019
Interview guide	4	11 April 2019
Patient participant demographic form	-	10 May 2019
Physiotherapist participant demographic form	-	10 May 2019

Page **1** of **2**

TERMS AND CONDITIONS OF ETHICS AND GOVERNANCE APPROVAL

The Principal Investigator must ensure this research complies with the National Statement on Ethical Conduct in Human Research (2018) & the Australian Code for the Responsible Conduct of Research (2007 updated 2018) by immediately reporting to the Office for Research (OFR) anything that may change the ethics or scientific integrity of the project. Final approval is granted subject to the researcher agreeing to meet the following terms and conditions:

1. Confidentiality of research participants MUST be maintained at all times.
2. If the research involves the recruitment of participants, a signed copy of the 'Consent Form' must be given to the participant. Any changes to the Participant Information Sheet/Consent Form must be approved by the lead HREC prior to being used.
3. No promotion of a study can commence until final ethics and SALHN executive approval has been obtained. All advertisements/flyers need to be approved by the committee and media contact should be coordinated through the FMC media unit.
4. Non-SA Health researchers viewing confidential SALHN data are required to complete and sign a SALHN Confidentiality Disclosure Deed
5. All approved requests for access to medical records at any SALHN site must be accompanied by this approval letter.
6. If your study involves a tertiary institution, contact the University to ensure compliance with University requirements prior to commencement of this study. This includes any insurance and indemnification.
7. The PI must adhere to Monitoring and Reporting requirements for both ethics and governance which are available on the SALHN Research Website.
8. The PI must immediately report to SAC HREC anything that may change the ethics or scientific integrity of the project
9. An annual report must be submitted to the SAC HREC and SALHN governance on each anniversary of the date of final approval. Please visit the Office for Research website for the current template.
10. Non-SA Health researchers coming onsite at SALHN must provide evidence of a recent (<3 years) screening check. It is the responsibility of the Principal Investigator to ensure any non-SA Health personnel who conducts or monitors research meets SA Health screening requirements as per the SA Health Criminal & Relevant History Screening Policy Directive before they access any SA Health site. The cost of any such screening is the responsibility of the individual accessing the site or their employer.
11. Any reports or publications derived from the research should be submitted to the Committee at the completion of the project.
12. Once the research project has concluded, any new product/procedure/intervention cannot be conducted in the SALHN as standard practice without the approval of the SALHN New Medical Products and Standardisation Committee or the SALHN New Health Technology and Clinical Practice Innovation Committee (as applicable). Please refer to the relevant committee link on the SALHN intranet for further information.
13. SALHN site-monitoring of authorised studies - this approval/authorisation is subject to participation in this monitoring process. You will be notified in advance if your site has been selected for an inspection.

Please visit the SALHN Research website regularly and comply with all submission requirements as they may change from time to time.

For any queries about this matter, please contact The Office for Research on (08) 8204 6453 or via email to Health.SALHNOfficeforResearch@sa.gov.au

Signature removed for privacy reasons

Chair
Southern Adelaide Clinical Human Research Ethics Committee

Appendix K: Observational study site-specific approvals

23 July 2019

Government of South Australia
SA Health

Central Adelaide Local Health Network
Research Office
Level 3, Roma Mitchell House
North Terrace, Adelaide SA
Australia 5000

T : 08 7117 2209
T : 08 8222 6841
E : Health.CALHNResearchGovernance@sa.gov.au

Marissa Sorich
Allied Health - Physiotherapy
Hampstead Rehabilitation Centre

Dear Ms Sorich

Project title: A comparison of physiotherapy practice with and without active video and computer-based rehabilitation technology.

HREC Ref: HREC/19/SAC/109
SSA Ref: SSA/19/CALHN/289
MyIP Ref: 11548

RE: Governance authorisation
Thank you for submitting an application for authorisation of this project. I am pleased to inform you that authorisation has been granted for this study to commence at Hampstead Rehabilitation Centre, SA.

Authorisation is valid from **23 July 2019 to 23 July 2020**. Proposed extensions beyond this term must be submitted to the CALHN Research Office.

The following conditions apply to the authorisation of this research project. These are additional to those conditions imposed by the Human Research Ethics Committee (HREC) that granted ethical approval to this project:

1. Authorisation is limited to the site/s identified in this letter only.
2. Project authorisation is granted for the term specified above, or until the project is complete (whichever date is earlier).
3. The study must be conducted in accordance with the conditions of ethical approval provided by the lead HREC, SA Health policies, and in conjunction with the standards outlined in the *National Statement on Ethical Conduct in Human Research* (2007) and the *Australian Code for the Responsible Conduct of Research (2007)*.
4. Proposed amendments to the research protocol or conduct of the research which may affect both the ongoing ethical acceptability of the project and the site acceptability of the project are to be submitted to the CALHN Research Office after a HREC decision is made.
5. Proposed amendments to the research protocol or conduct of the research which only affects the ongoing site acceptability of the project, are to be submitted via email to the CALHN Research Office;
6. For all clinical trials, the study must be registered in a publicly accessible trials registry prior to enrolment of the first participant.
7. A copy of this letter should also be maintained on file by the Coordinating Principal Investigator as evidence of project authorisation.
8. Notification of completion of the study at this site is to be provided to the CALHN Research Office.

All future correspondence regarding this study must include the MyIP reference number in the subject header.

We wish you every success in your research project.

Signature removed
for privacy reasons

Manager, CALHN Research Office
Ph: 7117 2209
Email: Health.CALHNResearchGovernance@sa.gov.au

11548 sorich calhn - lnr ssa form - governance approval letter.doc 1 | Page

Government of South Australia
SA Health

Northern Adelaide Local Health Network

Research Governance Office
Level 2, Clinical Trials Unit
Lyell McEwin Hospital
Haydown Road
ELIZABETH VALE SA 5112
Tel: 08 8182 9346
Email: healthnalhnrgo@sa.gov.au

26 August 2019

Ms Nicole Prideaux
Manager Physiotherapy
Modbury Hospital
Smart Road
MODBURY SA 5092

Dear Ms Prideaux

HREC reference number: HREC/19/SAC/109
SSA reference number: 19-091-Sorich
Project title: A comparison of physiotherapy practice with and without active video and computer-based rehabilitation technology

I am pleased to advise that the above project is approved to be conducted at the Modbury Hospital site.

This approval is subject to compliance with the conditions set out below in addition to the conditions specified by the reviewing HREC.

1. Record keeping is maintained in accordance with GCP, NHMRC, State and National guidelines.
2. Notify the NALHN Research Governance Office of:

- Any HREC approved amendments to the project
- The annual progress of the project (annual report)
- Extensions to the ethical approval of the project
- Serious or unexpected adverse effects for NALHN participants
- Site based protocol deviations
- Any changes to the indemnity, insurance arrangements or CTRA for the project
- Your inability to continue as Principal Investigator or any other change in research personnel involved in this project
- Failure to commence the study within 12 months of site approval / or if a decision is taken to end the study at this site
- Any other unforeseen events
- Any other matters which may impact the conduct of the project in NALHN
- A comprehensive final report at study completion including any published material
- Site audits and final audit report

3. Maintain confidentiality of NALHN participants at all times, as required by law.
4. Dispose of research materials in accordance with the requirements outlined in the NHMRC Australian Code for the Responsible Conduct of Research.
5. Principal Investigators should check their state legislation requirements regarding research involving exposure of research participants to ionising radiation before commencement of this study.
6. For all clinical trials, ensure the study is registered in a publicly accessible trials registry prior to enrolment of the first participant

If University personnel are involved in this project, the Principal Investigator should notify the University before commencing their research to ensure compliance with University requirements including any insurance and indemnification requirements.

SSA reference number: 19-091-Sorich
Project title: A comparison of physiotherapy practice with and without active video and computer-based rehabilitation technology

The NALHN Research Governance Office may conduct an audit of the project at any time.

Please note: templates for the post approval submission of documents to the RGO can be accessed from: https://www.sahealth.sa.gov.au/nalhnresearch

Should you have any queries about the consideration of your Site Specific Assessment form, please contact me on 08 8182 9346 or healthnalhnrgo@sa.gov.au

The SSA reference number should be quoted in any correspondence about this matter.

Yours sincerely

Signature removed for privacy reasons

Research Governance Officer
Northern Adelaide Local Health Network (LMH/MH/PHC)

Approved documents:

In addition to the HREC approved documents, the following site specific documents are authorised for use at the Modbury Hospital:

Document	Version	Date
Modbury Hospital PIC Participants	1	13 May 2019
Modbury Hospital PIC Physio	1	13 May 2019

Key Dates:

Document	Due date
Annual Report	26/06/2020
Insurance certificate expiry	31/10/2019

SSA reference number: 19-091-Sorich
Project title: A comparison of physiotherapy practice with and without active video and computer-based rehabilitation technology

Appendix L: Observational study patient demographic questionnaire

PATIENT QUESTIONNAIRE AVC STUDY

Patient ID:C			**Date**:	___/___/_____
Age:	________ years Prefer not to say		**Gender:**	M F X Prefer not to say
Rehab Service:	□ Inpatient □ DRS □ Outpatient □ Other: _______________			
Time since admission to rehab: ________ days / weeks				
Diagnosis: (Reason for rehab)				
Category:	□ Neurological □ Orthopaedic □ Other: _______________			
Mobility limitation:	□ Sit to stand □ Stepping □ Standing Balance □ Dynamic Balance Details:			
Current goals of rehab:				
Any technology used in your rehabilitation to date?	□ No □ Yes Details (what, when, how often):			
Any previous experience with video or computer games?	□ No □ Yes Details (what, when, how often):			

Appendix M: Observational study physiotherapist demographic questionnaire

<table>
<tr><td colspan="2">Physiotherapist ID: P</td><td></td><td></td><td>Date:</td><td>___/___/_____</td></tr>
<tr><td colspan="6">Do you have any of the following eye conditions: use of glasses with more than one power, history of eye surgery, diagnosed eye movement or alignment abnormalities?
□ Yes Thank you for your time, you are unfortunately ineligible to participate in this study.
□ No Please continue.</td></tr>
<tr><td>Age:</td><td colspan="3">______ years Prefer not to say</td><td>Gender:</td><td>M F X Prefer not to say</td></tr>
<tr><td>Rehab Service</td><td colspan="5">□ Inpatient □ DRS □ Outpatient □ Other: ______________</td></tr>
<tr><td colspan="6">Total years of clinical experience: _______years

Clinical areas worked and for how long: e.g. Brain Injury Rehab, 4 years

1. Area: ____________________________________ Years: _______

2. Area: ____________________________________ Years: _______

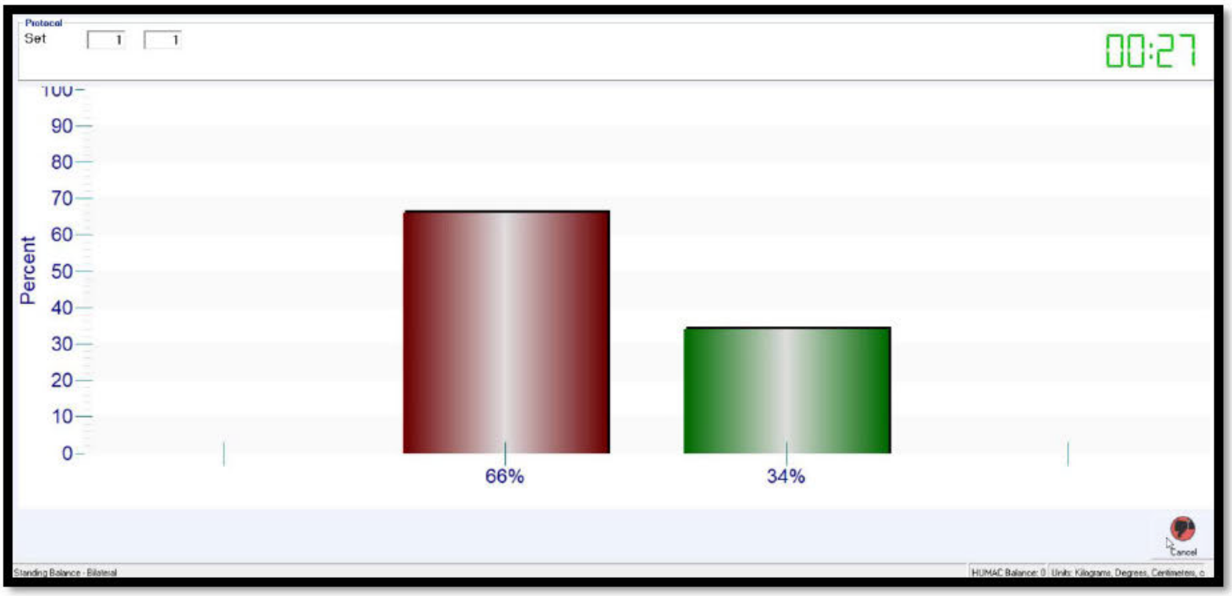
3. Area: ____________________________________ Years: _______

4. Area: ____________________________________ Years: _______</td></tr>
<tr><td>Any previous experience with videogame or computer-based technologies in rehabilitation?</td><td colspan="5">□ No □ Yes Details (what, when, how often, conditions):</td></tr>
<tr><td>Any previous experience with video or computer game technologies in general?</td><td colspan="5">□ No □ Yes Details (what, when, how often):</td></tr>
</table>

Appendix N: AVC exercises and games used in the observational study

Humac Balance Board

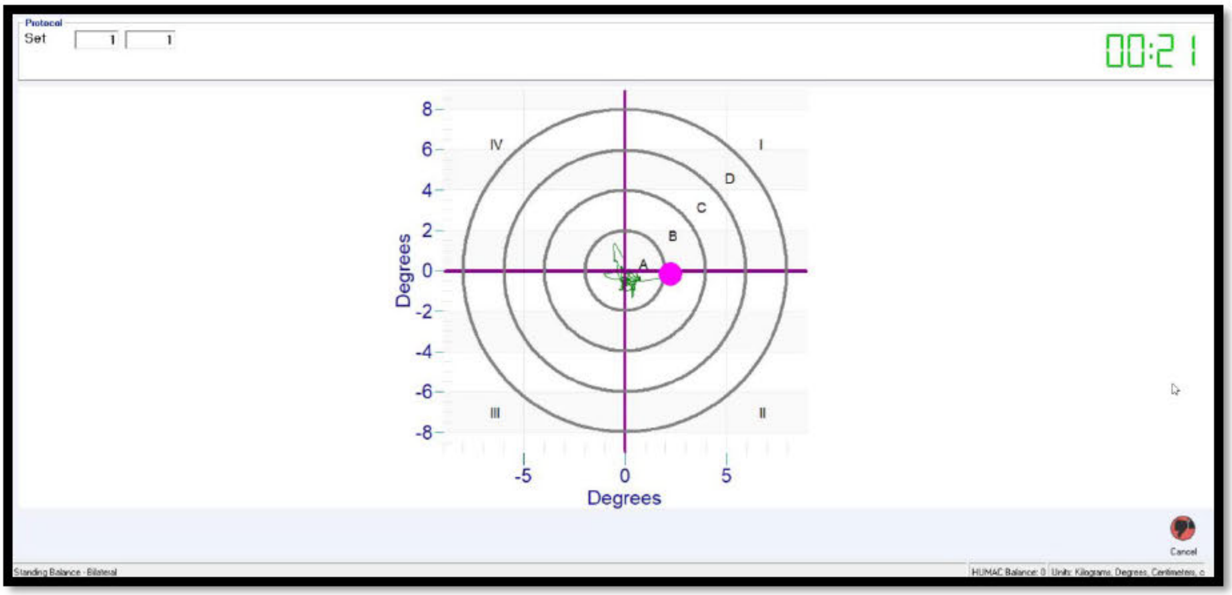
Weight Bearing



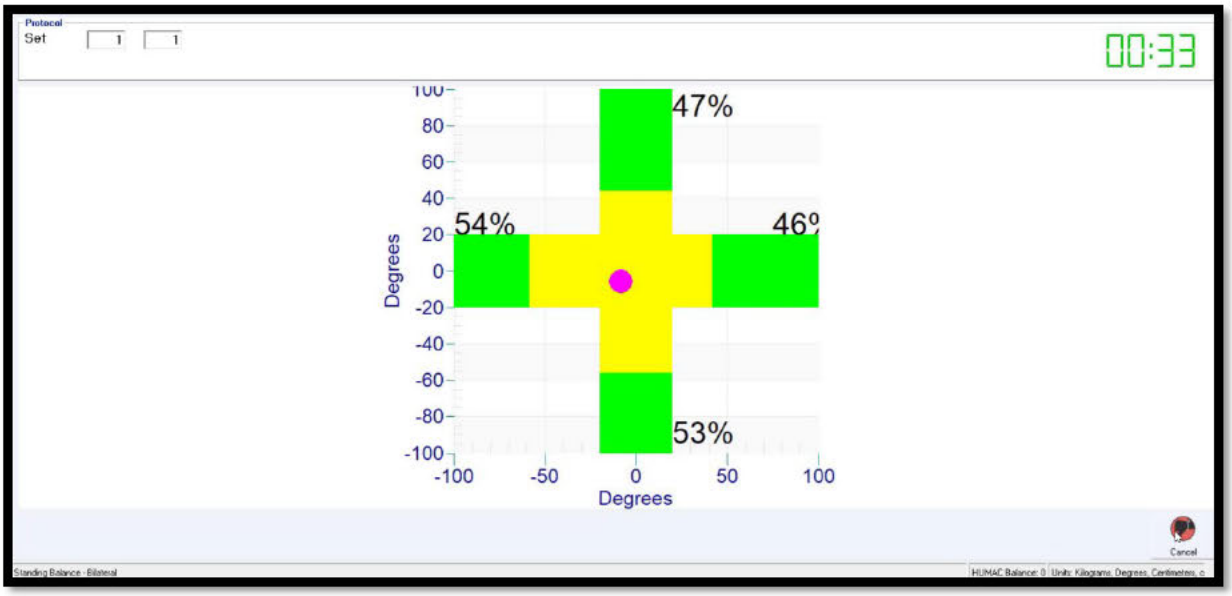
Humac weight bearing screen display

In this exercise real time feedback is continuously provided to indicate the proportion of weight on each half of the board via large bars and the percentage of weight may be displayed in numerals underneath. Typically this is used to indicate weight bearing through each leg, and it is up to the physiotherapist to instruct the patient on how to use this feedback. In this study it was used to practice even (50/50) weight bearing in static standing and during movements such as squats and sit to stand. It was also used to encourage increased weight bearing through the affected leg. The screen also displays a timer presenting time spent in the exercise.

Centre of Pressure and Weight Bearing XY



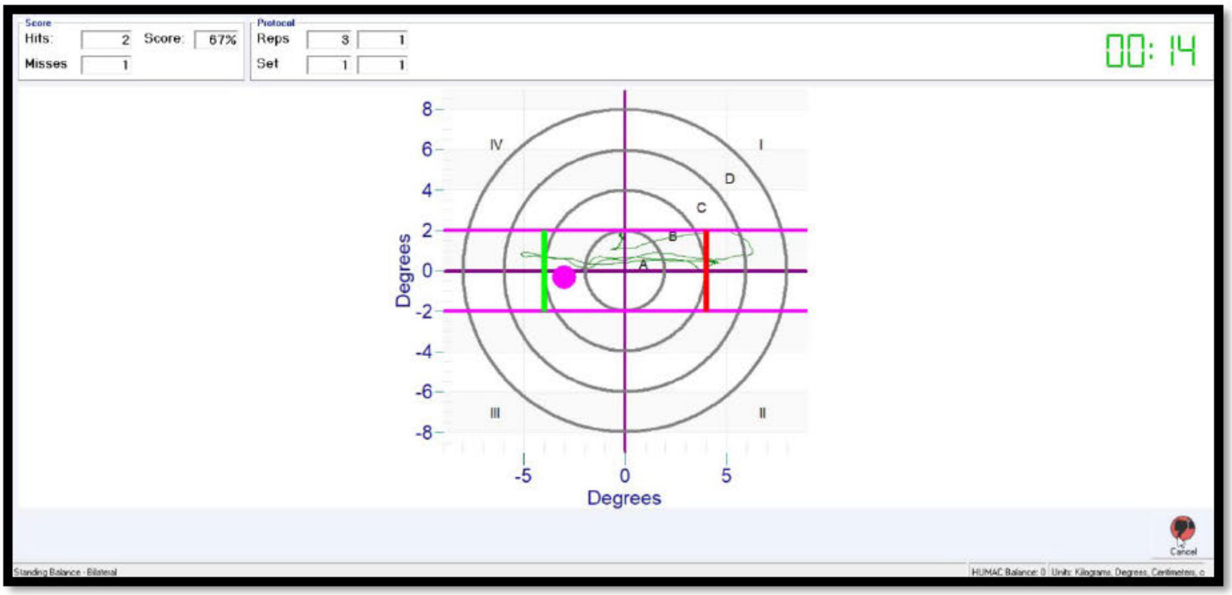
Humac centre of pressure screen display



Humac weight bearing XY screen display

Both of these exercises display a pink dot to indicate the centre of pressure (COP). Weight Bearing XY has the addition of a green set of bars and yellow indicators around the COP dot to further illustrate the weight shift left to right and anterior to posterior. The time spent in this exercise is also present on the screen. As with Weight Bearing, the physiotherapist needs to direct the patient as to the desired location of COP and exercises can involve static standing or weight shift activities.

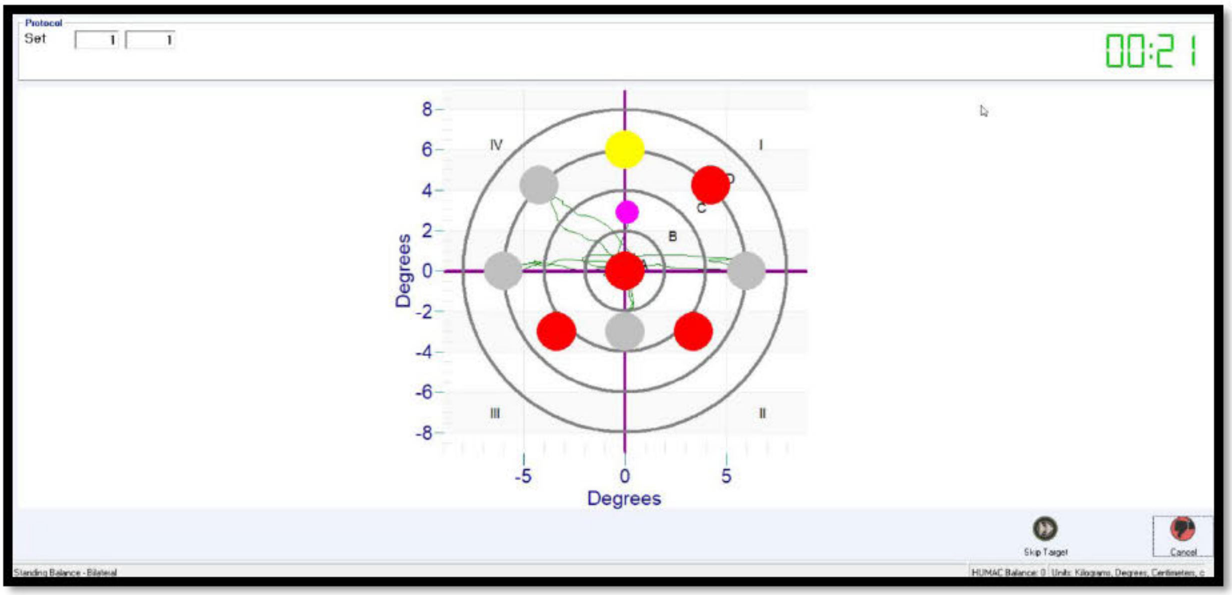
Weight Shift



Humac weight shift screen display

Prior to this exercise, parameters are set to determine the location and length of two target "gates" placed opposite each other within two purple boundary bars. During the exercise, the pink COP dot is displayed and the patient moves their COP to pass across the green gate. This gate changes to red and the other gate becomes green and is the new target. The successful repetitions are counted and a score of hits and misses displayed on the screen. A timer continuously counts the time in the exercise. Parameters of the gates can be changed during the exercise if desired (e.g., shifting a gate further out), making it longer or rotating the pair to different angles (e.g., 45° to horizontal). This exercise is used to encourage controlled weight shift in standing, often preparatory for gait. Similar exercises in usual rehabilitation include standing and transferring a small beanbag or other item from one side to the other.

Limits of Stability



Humac limits of stability screen display

In limits of stability, eight target red circles are displayed around the centre. When the exercise commences, an outer circle flashes yellow to indicate it is the current target and the patient is required to shift their pink COP dot to rest over the flashing yellow circle until it changes colour to grey. The centre circle then flashes yellow and the patient must move their COP centrally over this circle before another outer circle becomes the target. The distance of the circles from the centre and the length of time needed to remain stationary over each target is customisable and targets can be skipped if necessary. The screen display also incorporates a count up timer. This exercise is used to practice controlled, multidirectional weight shift. In usual care a similar exercise would involve reaching to touch a target held by the therapist in varied places around the patient.

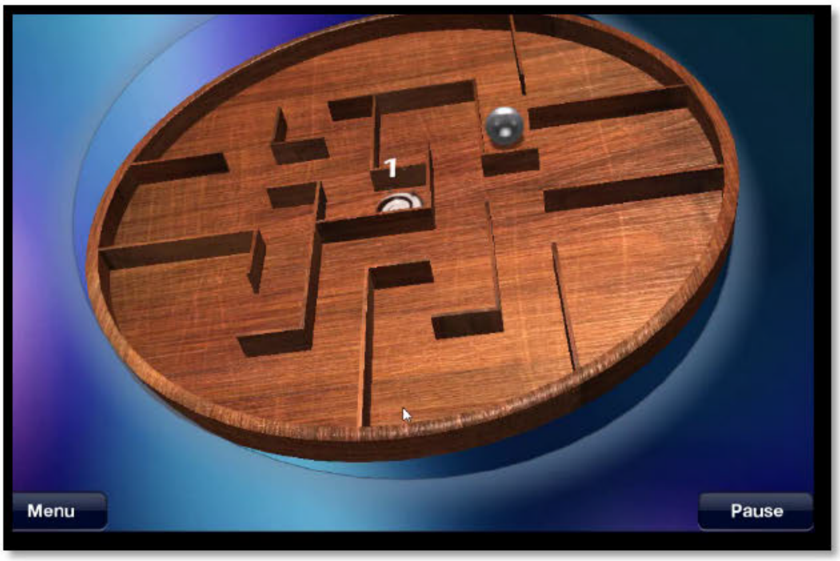
Snowboard and Ski

Humac snowboard screen display

Humac ski screen display

Snowboard and Ski are two similar games, each displaying a downhill skiing course where the movement of the skier is controlled by the patient weight shift. The course is fenced, so the player cannot fall off the course. There are 12 different levels, with higher level courses also containing additional target gates within the course to aim for. The display continuously shows time spent and current level, and the sensitivity of the board in each direction (left, right, anterior, posterior) is tailored to the patient prior to use. In Ski the board is positioned with the long edge parallel to the screen so the emphasis is on shifting pressure in the coronal plane to steer down the course, while in Snowboard the board is rotated 90° with the short edge parallel to the screen. These exercises allow practice of controlled, multidirectional weight transfer. Similar exercises in usual care include standing and hitting a balloon with a therapist.

Balance

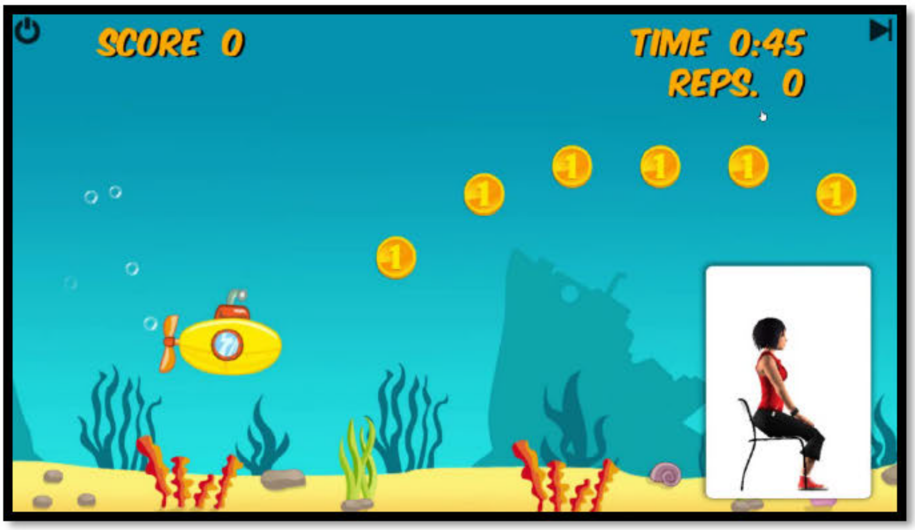


Humac balance screen display

The Balance game consists of a ball in a maze on a circular board. The weight shift of the patient influences the angle of the board, directing the ball through the maze towards a swirling target. A barrier around the edge of the board prevents the ball from falling off so the game does not end until the target is reached or a decision is made to exit the game. The screen also displays the level of the maze and the time spent in the exercise. There are 15 different levels, each with a different maze, and the sensitivity of the board is tailored to the patient prior to use. Motor skills practiced in this exercise relate to fine-tuned, co-ordinated weight shift.

Intelligent Rehabilitation Solutions

Submarine



IRS submarine screen display

Submarine is a game to provide sit to stand practice. A submarine continuously moves across an underwater environment on the screen. Initially a second window is also shown with a person demonstrating the movements to perform. As the patient rises and lowers the submarine also moves up and down, collecting coins and avoiding mines. The screen displays the time, score and repetitions during the game play. In usual rehabilitation sit to stand is a commonly practiced task.

Hip flexion, hip extension, knee lift and knee flexion.

IRS hip flexion screen display

A number of common lower limb exercises (hip flexion, hip extension, knee lift and knee flexion), all performed in standing, use the same game action where each successful movement helps erect a building. An avatar on screen performs the chosen exercise and the shadow represents the patient movement. When the patient moves so the shadow matches the avatar, a part of the building is constructed. Exercises can be tailored so the patient is instructed to do only one leg or alternate legs, and movement range can be set for half range or full range of movement. Score, level, time and repetitions are constantly displayed.

Lunge and squat

IRS lunge screen display

IRS squat screen display

The lunge and squat exercises each have the same associated game. An avatar stands on a raft in a river along which are spinning gems at intervals. The avatar performs the exercise, prompting the patient, represented on screen by a shadow, to do the same. When the patient movement matches the avatar the raft is propelled forwards. Moving the raft through a gem collects points. The lunge exercise can be prescribed for one leg or both legs, and both lunges and squats can be modified for half range or full range of movement. Score, time and level are continuously displayed during the game.

Sidestepping

IRS controlled sidestepping screen display

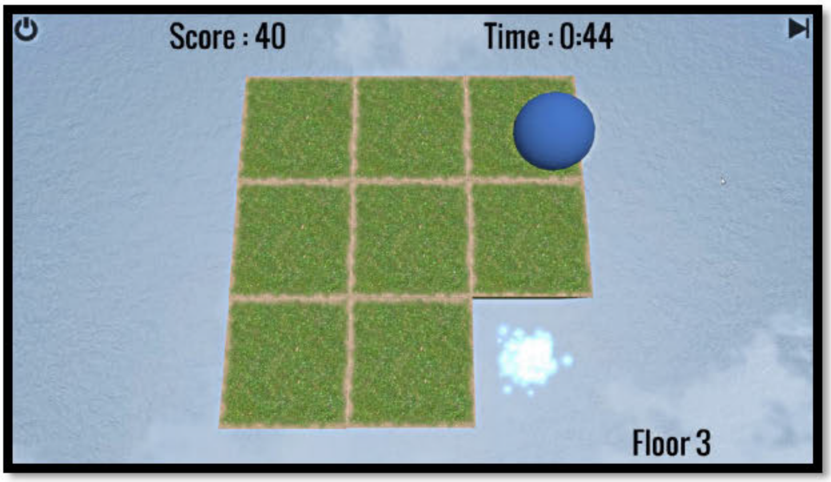
During controlled sidestepping the patient is represented by a boat under a waterfall. Gems fall down the waterfall on the left and right, encouraging the patient to step sideways to bring the boat under each falling gem to catch it. Sidestepping always alternates from left to right, and increasing the difficulty level increases the speed of the falling gems. As in usual rehabilitation, this exercise can be performed within parallel bars for additional support if required.

IRS dynamic sidestepping screen display

In dynamic sidestepping the patient is represented by a car on a three-lane road. The patient car moves continuously forward and can change lanes if the patient steps sideways. Stationary cars and coins encourage movement between the three lanes. The difficulty level is associated with the speed of the car. Similar exercises in usual care include catching a ball or balloon thrown by the therapist to encourage the patient to step sideways.

For both games the score, time and level are displayed during the game.

Dynamic Stepping



IRS dynamic stepping screen display

In dynamic stepping the patient is presented with a grid, the size of which is determined by the physiotherapist depending on the room size available. The location of the patient is represented by a blue ball, and a flashing firework indicates where the gap is that the patient needs to move to. When the movement of the patient causes the ball to reach the gap, the ball falls through the level and a new grid is shown. The physiotherapist can set the options to encourage walking in a variety of different patterns, such as from only one line (e.g. only forwards and backwards) to random walking in any direction. The screen displays the level, score and time. Gait is a commonly practiced activity in rehabilitation, and in usual rehabilitation multidirectional gait can be practiced between cones laid out in a zig zag pattern, in an activity with a ball or balloon such as tennis, or with the therapist calling out directions.

Xbox One Kinect

Tennis

Xbox Kinect tennis screen display

In the Xbox Kinect tennis game the player can play tennis against another game player or a computer-generated opponent. For this study, the patient played tennis against a competitor provided by the game. While pretending to hold a racquet, the patient moves their arm and body to cause their avatar to hit the tennis ball. The number or direction of steps, speed of the ball and position of the arm required are not controlled by the therapist. The anticipated location of the approaching tennis ball is indicated by a gold circle. Score is presented on the screen continuously, with further feedback such as “perfect hit” or “out” provided intermittently. In rehabilitation, Xbox Kinect tennis can be used in static standing to practice reaching and weight shift or can be combined with stepping to create a multidirectional stepping exercise.

Bowling

Xbox Kinect bowling screen display

In ten pin bowling game the player can compete with another game player or a computer-generated opponent. In this study the patient bowled against a competitor provided by the game. Patient movement is represented by the onscreen avatar. Reaching out to the side with the preferred arm and closing the hand picks up the virtual bowling ball which the patient can then bowl with a usual bowling action. The score is continuously presented on screen, with additional motivational feedback displayed after each bowl. In mobility rehabilitation, virtual bowling provides an opportunity to practice standing balance and single forward stepping and can be similarly employed in usual rehabilitation with a lightweight ball.

Wii Fit

Table Tilt

Wii Fit table tilt screen display

Table tilt has a series of levels, each with a unique game board controlled by the patients' COP. Upon the board rest a number of balls, with higher levels having more balls. The goal of the game is to guide the ball(s) into the hole(s) by shifting body weight laterally, anteriorly, and posteriorly. When the final ball falls into the hole it completes the level and the next board appears while time is added to the countdown timer. Whilst game boards have a small ridge around the edge it is still possible for the balls to roll off, causing the board to spin around and a replacement ball to drop onto the board. The screen displays the level and time remaining. This game provides an opportunity to practice controlled multidirectional weight shift.

Soccer heading

Wii Fit soccer heading game

In soccer heading the patient is represented by an avatar soccer player on the screen. Balls and other objects are kicked towards the avatar player, centrally or to left or right. Remaining central or leaning left or right moves the avatar accordingly, allowing the avatar to "head" the ball and score points, or lose points by heading other approaching objects such as shoes. The score and time is displayed on the screen. This allows for practice of lateral weight shift in standing.

Appendix O: Observational study: AVC technologies used and mobility limitations observed

Technologies and mobility limitations for each session

	Wii **n (%)**	**Xbox** **n (%)**	**Humac** **n (%)**	**IRS** **n (%)**	**TOTAL** **n (%)**
Sit to stand **n (%)**			14 (14.7)		**14 (14.7)**
Standing balance **n (%)**	3 (3)		33 (34.7)	1 (1.1)	**37 (38.9)**
Stepping **n (%)**		2 (2.1)		11 (11.6)	**13 (13.7)**
Dynamic balance **n (%)**		4 (4.2)		27 (28.4)	**31 (32.6)**
TOTAL n (%)	**3 (3.2)**	**6 (6.3)**	**47 (49.5)**	**39 (41.1)**	

Appendix P: World Physiotherapy Congress 2021 Platform Presentation

Title: Physiotherapists' visual attention during technology assisted rehabilitation: an exploratory observational study

Authors: Weber, H., Barr, C.J., van den Berg, M.E.L.

Background: Active videogame and computer-based (AVC) technologies are increasingly used, in addition to usual care, to increase patient engagement in repetitive, high intensity rehabilitation programs. Little is known about how the use of AVC technologies affects the way clinical practice is delivered, including if and how it impacts therapists' focus of attention.

Purpose: To assess physiotherapists' focus of visual attention during a rehabilitation session with and without the use of AVC technologies.

Methods: In this observational study physiotherapist and patient dyads were recruited from two inpatient rehabilitation wards. Traditional physiotherapy exercises, addressing patients' difficulties with either sit to stand, stepping, standing balance or dynamic balance, were matched with AVC assisted exercises, using the Humac Balance System (CSMi Solutions) or Intelligent Rehabilitation Solutions (Doctor Kinetic). Next, exercises in both conditions were conducted and recorded in random order whilst the physiotherapist wore eye tracking glasses (Tobii Pro Glasses 2). Eye gaze data was processed with the Tobii I-VT (Attention) filter, which identifies when the fovea of the eye is stabilised on an area of interest. Fixations identified by the software were manually coded for area of interest, i.e. patient (patient face, patient body), equipment (AVC technology screen, hardware, other equipment) or other (physiotherapist own body, researcher, or elsewhere in the room).

Results: Data from 30 rehabilitation sessions, with 11 physiotherapists and 27 patients, was analysed. Wilcoxon Signed Rank Tests revealed that for all areas of interest (patient, equipment and other) the percentage of fixations, as well as percentage of time, was significantly different between traditional exercise and AVC assisted exercise conditions ($p<0.05$). During traditional physiotherapy the physiotherapist's primary focus of visual attention was the patient (median (IQR) was 76(55-88)% of total fixations and 79(57-94)% of total fixation time). Conversely, during AVC assisted physiotherapy the equipment used was the physiotherapist's primary focus of visual attention, demonstrated with a median (IQR) of 53(41-72)% of total fixations, and 77(58-86)% of total fixation time directed to the screen, hardware, or other equipment.

Conclusion: Study results suggest that the use of AVC-based technology in rehabilitation impacts the conduct of clinical practice and that technology use leads to therapist focus shifting from the patient to the technology equipment.

Implications: Further research is needed to determine how the change of physiotherapists' focus of visual attention influences the interaction between patient and therapist, and how this impacts on patients' exercise performance.

Keywords: therapist visual attention, active videogame and computer-based technologies

Funding acknowledgements: Heather Weber is supported by an Australian Government Research Training Program Scholarship.

Appendix Q: APA Thrive 2021 Conference Presentation

Title: Physiotherapists' focus of visual attention during mobility rehabilitation with and without active videogame and computer-based (AVC) technologies.

Aim: To investigate the similarities and differences in physiotherapist visual attention during mobility rehabilitation with and without AVC technologies.

Design: Prospective observational study.

Method: Participants were physiotherapist and patient dyads undertaking mobility rehabilitation at one of two major hospitals. Dyads performed (in randomised order) a usual physiotherapy rehabilitation exercise and matched AVC exercise (from Humac Balance System or Intelligent Rehabilitation Solutions). Physiotherapist visual attention was recorded by Tobii Pro Glasses2 and fixations during the active exercises categorised for area of interest: patient, equipment or other.

Results: Data from 30 rehabilitation sessions (11 physiotherapists and 27 patients) were analysed. Proportion of total fixation time was significantly less on the patient in AVC rehabilitation: median(IQR); usual:79(57-94)%; AVC:18(8-39)%, p<0.01), while average duration of each fixation on the patient remained similar (usual:341(259-492)ms; AVC:296(243-524)ms, p>0.05). Physiotherapist proportion of number of fixations on equipment was significantly more in AVC rehabilitation (usual:6(0-25)%; AVC:77(58-86)%, p<0.01), with significantly longer average fixation durations (usual:314(258-418)ms; AVC:876(617-1244)ms, p<0.01).

Conclusion: Physiotherapist visual attention shifts from patient in usual rehabilitation to equipment in AVC rehabilitation. It is unknown if this shift is intentional (e.g. for information-gathering) or unintentional (i.e. due to distraction). Further research is needed to determine how physiotherapist visual attention influences physiotherapy practice and the subsequent effect on patient outcomes.

Key Practice Points:

- AVC technologies impact the focus of physiotherapist visual attention during rehabilitation
- Further research is required to explore the reasons for the differences in physiotherapist visual attention in rehabilitation with and without AVC technologies, and to determine the influence of physiotherapist visual attention on patient outcomes

Appendix R: APA Thrive 2021 Conference Presentation

Title: Physiotherapist-provided verbal instruction and feedback during mobility rehabilitation with and without active videogame and computer-based (AVC) technologies.

Aim: To investigate the similarities and differences in physiotherapist verbal instruction and feedback during mobility rehabilitation with and without AVC technologies.

Design: Prospective observational study.

Method: Physiotherapist and patient dyads engaged in mobility rehabilitation were recruited from two major hospitals. Dyads performed a usual rehabilitation exercise and matched AVC exercise (from Humac Balance System or Intelligent Rehabilitation Solutions) in randomised order. Physiotherapist verbal instruction and feedback provided during the (videotaped) exercises were coded for content and focus of attention. Frequencies were standardised to 5 minute periods.

Results: Thirty rehabilitation sessions, with 11 physiotherapists and 27 patients, were analysed. Verbal instruction and feedback was provided frequently in both conditions: median(IQR); usual:76.9(62.4-98.8); AVC:67.5(37.8-79.3) per 5 minute period.

Content: Task instruction was used less (usual:31.8(12.4-42.8); AVC:17.5(7.9-33.9), $p>0.05$), and movement performance instruction significantly less in AVC rehabilitation (usual:14.0(6.9-22.7); AVC:7.7(3.4-16.15), $p<0.05$). Motivational statements were provided with similar frequency: usual:21.7(11.9-33.1); AVC:20.9(13.6-34.9). Feedback was provided less often than instructions and motivational statements in both conditions.

Focus of attention: Significantly more internally focussed statements were provided in usual rehabilitation (usual:20.0(6.6-35.6); AVC:11.8(3.4-16.6), $p<0.05$).

Conclusion: Overall, there were only small differences in physiotherapist instruction and feedback in rehabilitation with and without AVC technologies, despite this also being provided by AVC technologies.

Key Practice Points:

- The use of AVC technologies in rehabilitation may not decrease overall physiotherapist verbal instruction and feedback, but may reduce the need for some instruction.
- Further research is required to determine how instruction and feedback can be optimised in AVC rehabilitation for maximum patient benefit.

Appendix S: Observational study instruction and feedback data extraction sheet

Category	Session interval	Modality: Haptic	Modality: Visual	Modality: Auditory			Cueing/instruction			Type: feedback			Motivation	Commentary	Checking in	Focus of attention				Framing		
Examples	each 15 second epoch	*tapping, guiding movement, providing support*	*hand gestures, pointing, modelling*	*saying words*	*can be interpreted as words mmhm*	*clapping etc*	*left foot yellow*	*move your weight forward to stand up*	*next time make it a bigger step*	*you're leaning too far*	*your step was long enough that time*	*you knocked them all down, counting reps up*	*great job*	*feeling ok?*	*weather etc*	*attention to movt - squeeze you bottom*	*attention to environment - touch my hand*	*do the same again*	*no movement focus*	*Lift the knee a bit higher next time*	*you didn't lift you knee high enough*	*so you're the blue ball*
Physiotherapist instruction or feedback	only active time	no further coding required		therapist talking	therapist non verbal	therapist non vocal	task instruction	performance instruction	prescriptive feedback	KP	KR movt/ skill	KR game/score	motivational non specific	Checking in	Unrelated	Internal	external	Neutral/ mixed	N/A	Positive	Negative	Neutral

Appendix T: Correlations between visual attention metrics and quantity of instruction and feedback

Spearman's rho correlation between visual attention metrics and quantity of instruction and feedback in rehabilitation without AVC technologies

	Task instruction	Movement instruction	Knowledge of performance	Knowledge of results (movement)	Knowledge of results (task/game)	Prescriptive feedback	Motivational comments	Checking in	Unrelated statements
Proportion of the total number of fixations on patient face	0.303	-0.083	0.133	0.254	-0.083	0.180	0.089	0.545**	-0.108
Proportion of the total number of fixations on patient body	-0.298	0.475**	0.257	0.067	0.410*	-0.077	-0.152	0.188	0.096
Proportion of total fixation time on patient face	0.301	-0.173	0.019	0.256	-0.029	0.124	0.020	0.574**	-0.217
Proportion of total fixation time on patient body	-0.295	0.406*	0.255	0.029	0.362*	0.072	-0.213	0.127	0.078
Average duration of each fixation on patient body	0.201	-0.348	0.381*	-0.014	0.035	0.278	-0.216	0.225	-0.053
Average number of uninterrupted fixations on patient body	-0.404*	0.580**	0.221	0.103	0.317	0.038	-0.189	0.221	0.118

Proportion of the total number of fixations on equipment	0.157	-0.208	-0.273	-0.146	-0.323	-0.223	0.209	-0.410*	0.022
Proportion of total fixation time on equipment	0.145	-0.169	-0.229	-0.146	-0.346	-0.256	0.240	-0.408*	0.044
Average duration of each fixation on equipment	0.233	-0.491*	0.152	-0.115	-0.229	0.191	-0.081	-0.073	0.341
Average number of uninterrupted fixations on equipment	-0.445*	0.374	0.272	-0.057	-0.159	0.123	0.029	-0.284	0.566**

All values are presented as ρ.

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).

Spearman's rho correlation between visual attention measures and quantity of instruction and feedback in rehabilitation with AVC technologies

	Task instruction	**Movement instruction**	**Knowledge of performance**	**Knowledge of results (movement)**	**Knowledge of results (task/game)**	**Prescriptive feedback**	**Motivational comments**	**Checking in**	**Unrelated statements**
Proportion of the total number of fixations on patient face	0.321	-0.010	0.160	0.330	-0.173	-0.126	0.100	0.332	0.036
Proportion of the total number of fixations on patient body	-0.266	0.101	0.446*	0.191	0.040	0.207	-0.318	0.274	-0.439*

Proportion of total fixation time on patient face	0.284	-0.067	0.183	0.331	-0.147	-0.229	0.096	0.396*	-0.102
Proportion of total fixation time on patient body	-0.282	0.080	0.369*	0.260	0.018	0.292	-0.308	0.119	-0.478**
Average duration of each fixation on patient body	-0.417*	-0.155	0.105	-0.249	0.486**	0.275	-0.408*	-0.347	-0.341
Average number of uninterrupted fixations on patient body	-0.037	0.226	0.306	0.366	-0.132	0.051	-0.116	0.362	-0.316
Proportion of the total number of fixations on screen	0.267	0.224	-0.290	-0.322	0.068	-0.014	0.324	-0.152	0.383*
Proportion of total fixation time on screen	0.263	0.184	-0.266	-0.338	-0.027	-0.132	0.333	-0.046	0.368*
Average duration of each fixation on screen	-0.096	0.115	0.087	-0.485**	0.301	0.004	-0.086	-0.153	-0.010
Average number of uninterrupted fixations on screen	0.401*	0.388*	-0.067	-0.023	-0.189	-0.053	0.283	0.274	0.364*

All values are presented as ρ.

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).