Virtual reality design for stroke rehabilitation

AUTHOR(S)

Darryl Charles, Dominic Holmes, Therese Charles, Suzanne McDonough

CITATION

Charles, Darryl; Holmes, Dominic; Charles, Therese; McDonough, Suzanne (2022): Virtual reality design for stroke rehabilitation. Royal College of Surgeons in Ireland. Journal contribution. https://hdl.handle.net/10779/rcsi.13377224.v1

HANDLE

10779/rcsi.13377224.v1

Interactive Virtual Reality Stroke Rehabilitation System Design

Darryl Charles[1], Dominic Holmes[1], Therese Charles[2], and Suzanne McDonough[3]

[1] School of Computing, Engineering, and Intelligent Systems, Ulster University, N.I.
[2] The Office of PVC (Education), Ulster University, N.I.
[3] School of Physiotherapy, Royal College of Surgeons in Ireland, Dublin, Ireland

{dk.charles, d.holmes, mt.charles, s.mcdonough}@ulster.ac.uk

Abstract

Stroke is a leading cause of disability, and with the stroke survivor population rising in most countries it is increasingly difficult to provide optimal treatment to patients once they return home. Assistive technology solutions can potentially contribute to meeting demand, and also be cost effective. In this chapter, we consider the design and development of engaging serious virtual reality (VR) games for upper arm stroke rehabilitation. Fundamental design principles are summarised and related to our experience of creating game-based VR rehabilitation. The application of ideas from psychology, particularly behavioural change and flow theory are discussed, as well as related learning and gamification principles. We address how to manage differences between people through design, user profiling, and intelligent dynamic system behaviour, and we also explore how to account for variation in stroke survivor capability and personality. The idea of a hero's journey as a metaphor for stroke recovery is introduced and we discuss how this metaphor may guide system design, its relationship to game design principles, and how patient narratives and embedded stories might support engagement with treatment. An overview of our previous work is summarised and we discuss how our experience and increased knowledge and capability has informed improved approaches to development processes. Finally, our approach is illustrated with reference to a recent EU project.

Key Words: stroke rehabilitation, upper limb, virtual reality, gamification, design

Effects of Stroke and Treatment

Stroke survivors have varying degrees of physical impairment following a stroke; it is vital that a person with an onset stroke, who is medically stable, receives frequent, short daily mobilisation during their time in hospital. Early mobilisation aims to minimise the risk of the complications of immobility and improve functional recovery quicker. Typical mobilisation will begin 24 to 48 hours of an onset stroke (Intercollegiate Stroke Working Party, 2012). Early rehabilitation of physical impairments is vital in the first months after stroke to increase the chances of a rapid recovery. Physiotherapists focus on restoring a person's functional movement, by helping the person learn to use their paretic limbs again through exercise, manipulation, massage and electrical treatments. These treatments help regain muscle control and strength in the paretic limbs as much as possible. Occupational therapists focus on evaluating, managing and improving functional abilities that the person often uses during their daily life. They do this by assessing their strengths and weaknesses during activities of daily living (ADL), for example, dressing, making dinner, or brushing their teeth.

After an initial assessment of the stroke survivor's movement skills, physiotherapist and occupational therapists design a rehabilitation plan tailored to the individual. Part of this program is setting rehabilitation goals to monitor the person's progress towards recovery. Practical goal setting should include family and carers wherever possible; goals should be meaningful, challenging and have personal value to the person. Goals should be assigned a timeframe, depending on the person's condition, these goals can be short-term, long-term or both. As rehabilitation continues, therapists may change or adapt a person's current goals depending on their continued assessment of the person's condition (Hurn, Kneebone, & Cropley, 2006; Intercollegiate Stroke Working Party, 2012). Meeting these goals usually require intensified rehabilitation; guidelines suggest that the person should ideally receive a minimum of 45 minutes of rehabilitation (optimally 5 hours per day) for a minimum of five days per week for people that with an ability to do so. Repetitive exercise facilitates the re-wiring of the brain, creating new neurological pathways in parts of the brain that are not damaged is known as neuroplasticity. This refers to a brain's capacity to reorganise neural processing to improve various types of physical function, including arm motion (McBean & Wijck, 2013). Upper limb impairment is a common effect after a stroke, with over three-quarters of people experiencing some level of arm impairment. Common symptoms associated with upper limb impairment include paresis, loss of fractionated movement, abnormal muscle tone and spasticity. These symptoms can severely affect the patient's ability to perform ADLs, so intense and frequent upper limb rehabilitation must be performed to improve arm function and reduce the effect of these symptoms.

The focus of rehabilitation of the paretic upper limbs is on relearning specific motor skills to support fuller engagement with ADLs and to reduce the reliance on others for help and gives the person increased independence. After upper limb assessment and rehabilitation goals have been set for the upper limbs, depending on the assessment results, a physiotherapist and occupational therapist will devise personalised training exercises. If a therapist identifies movement limitations, they will usually offer repetitive task training. Usually, the training involves reaching, grasping, manipulation, releasing and daily task-specific activities such as lifting a cup. *Reaching* – to lengthen the arm out toward a specific location to touch or grasp something; locations can be in varies distances and heights to target specific arm movements. *Grasping and manipulation* – the aim of touching and holding on to an object using fingers and wrist. Object size and shape can vary to improve grasp strength, precision and size. Typically, when grasping is performed, a person is usually asked to move the grasped object to a different location and release it. The paretic upper limb can be exercised separately, although most ADLs require both limbs to move in unison, either in symmetrical or bimanual actions such as pouring water into a glass from a jug. Many ADLs require reaching motion towards objects before they can be grasped, or manipulated, PTs and OTs will generally start with reaching to grasping exercises or tasks for the person to perform their ADLs (Stroke Association, 2009).

Potential Benefits of Virtual Reality for Rehabilitation

Conventional upper limb stroke rehabilitation exercises have been effective in maintaining and improving functional upper limb mobility and

ADLs. However, one limitation of conventional rehabilitation is that stroke survivors tend to find the exercises monotonous and tiring. Motivation to perform the exercises may be reduced, causing a lack of engagement in their rehabilitation program. Therefore, the person often becomes complacent with respect to the frequency and intensity of their rehabilitation exercises, or they stop altogether. This lethargy can have an impact on their functional recovery resulting in no improvements or in some cases, deterioration in their upper limb mobility. Much research has been undertaken over the last two decades, investigating how Virtual Reality (VR) and games can increase people's engagement and motivation to maintain their stroke rehabilitation (Levin, Weiss, & Keshner, 2015; McNulty et al., 2015; Webster & Celik, 2014). It provides users with the opportunity to practice intensive repetition of meaningful task-related activities necessary for effective rehabilitation (Crosbie, Lennon, Basford, & McDonough, 2007). A recent Cochrane review found evidence that VR and games might be beneficial in improving upper limb function and ADLs as an adjunct to usual care or when compared with the same dose of conventional therapy (K. Laver et al., 2017). There is an increasing number of studies mainly focused on using commercially available hardware devices to support upper limb rehabilitation (K. E. Laver, George, Thomas, Deutsch, & Crotty, 2015). VR systems are effective in supporting feedback, have the capability adapt to individual needs, can deliver high intensity and meaningful repetitive exercises to encourage motor control and motor learning. Recent advancements in commercially available VR and games hardware has provided opportunities for less expensive and more useable rehabilitation technology solutions. These technologies have the potential to improve the accuracy of performance monitoring and reporting. A user interface (UI) is one of the most important aspects of any VR or gaming experience. Modes of interaction can vary from a mouse to natural body motion tracking via the Kinect or speech-based interfaces using devices such as Amazon's Alexia. A VR system with a poorly designed UI can lessen usability. An important factor of usability from a rehabilitation perspective is that a system can adapt to a range of individual motor skills over time (J. W. Burke et al., 2009a). Adaptation is essential as a user may become frustrated if the tasks are too challenging, or become bored if tasks are too easy.

Game Design Fundamentals

The games industry is now quite mature, and game design theory and practice are well established and understood by professionals. This section covers the basic game design ideas, and in the next section, we consider some of the main differences in designing for VR.

Games and Play

Fun, enjoyment, pleasure, joy, relaxation, and escapism are some of the positive feelings that we would wish a player to experience playing a game. Schell "states that fun is pleasure with surprises" (Schell, 2008), which is strongly related to Koster's idea that fun "is the feedback the brain gives us when we are absorbing patterns for learning purposes" (Koster, 2004). A game is designed to attain these goals and typically comprises six 'c's: conflict, choice, change, chance, connections, and control. By definition, a game is interactive and should have some form of *conflict* – challenges to overcome – with meaningful *choices* that *change* the perceptible game world's state. A game should also have a degree of uncertainty that reflects *chance* or serendipity in the real world (Costikyan, 2013). Games are more social than casual observers tend to understand, and social *connections* are crucial in modern game design to maintain traction with players. Games are interactive, and so the design of a player's *control* within the game world is crucial to their enjoyment and immersion. The player is responsible for success or failure through the choices and actions that they take to affect the environment. The following definitions of a game provide good coverage of a range of key ideas for game design: "*A game is a problem-solving activity, approached with a playful attitude*" (Schell, 2008), and noting win-lose states a game may be thought of as "*a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome*" (Salen & Zimmerman, 2003), and as a game is typically unproductive then the "*playing of a game is the voluntary attempt to overcome unnecessary obstacles*" (Suits, 1990). These definitions collectively hold several of the essential ideas that provide a foundation for effective game design. A player learns the rules of the game through integrated gameplay teaching in games and autonomous player learning. In this way, through practice and discovery, a player increases skill towards mastery. Frequent just-in-time feedback is crucial, as well as summative guidance on outcomes. Lack of real-world consequence is a common component of many game definitions. However, a serious game blurs the boundary of this design principle, which has a specific objective to improve some aspect of a person's real-world knowledge or skill. For example, physical games offer exercise tasks that can have real-world benefits.

Play typically differs from gameplay in that it generally has subjective outcomes and no fixed rules; consider how young children play. The design of playful interactive experiences (i.e. no rule-based challenge) must not be overlooked for rehabilitation systems as it provides freedom for people to express themselves at their own pace. In some cases, this approach may be more suitable than a game. For example, a creative process involving free painting or exploring an environment offers a person more autonomy. Autonomy is one of the core factors that can enhance someone's intrinsic motivation to play. However, it must be noted that a disabled person may require or desire less autonomy, e.g. due to reduced concentration or cognitive ability, but might require a much more directed approach.

Man, Play and Games (Caillois, 2001) groups games into four categories: *Agôn*, *Alea*, *Ilinx* and *Mimicry*. Where Agôn represents games that are based around competition, such as chess or racing games, and players try to gain an advantage over each other. Alea oriented gameplay emphasises chance more than competition. On the other hand, Ilinx comprises games based on the pursuit of 'giddiness' such as spinning on a merry-go-round or jumping. Mimicry type gameplay encompasses role-playing games, in which the players immerse themselves in an invented world. Within each category, games are ordered by placing them on a scale between *paidia* and *Ludus*. With Ludus the quality of the play experience is governed by rules, while with paidia games are characterised by inventiveness and play (Bateman & Boon, 2006). We consider these variations of play preferences when we discuss personality later.

Game Design Principles and Patterns

Schell sets out the importance of listening in game design; listening to team, audience, game, financial stakeholders, and yourself (Schell, 2008). Later we discuss the importance of this attitude to person-centred design and related challenges. However, the central matter of game design is to create an aesthetic experience for players that instils some form of emotional response (Schell, 2008). The nature of this experience may be different for people with disability within a serious game. We consider this in more detail at the end of this section.

A common model often used in game design thinking is the MDA (Mechanics, Dynamics, Aesthetics) framework (Hunicke, Leblanc, & Zubek, 2004) or more recently Schell's similar Elemental Tedrad: Mechanics, Aesthetics, Story, Technology (Schell, 2008). The MDA framework is helpful in that it represents the dynamic play process or cyclical structure in which a player resides. Mechanics are central to what defines a game. They are the rules, purpose and scope of gameplay. They intentionally restrict the player to enhance the gameplay experience and set out progressively more complex challenges to overcome. Games are inherently learning and teaching machines; where one purpose of a game is to help a player learn how to play and increase their ability within the game.

Dynamics define the nature of player interaction within a game, which give rise to a change of game state both in terms of the underlying data and the game's interface to the player. Aesthetics has a clear relationship to player experience and emotional or intellectual response to sensory feedback from games (graphics, audio, and haptics). Schell adds Technology to his version of the framework, as modern game design is highly influenced (perhaps always has been) by the platform on which is it played: what kind of display is used? What sort of control is required?

Games can have a linear or non-linear progression design. Story and quest-based games tend to be more non-linear, whereas action-adventure games tend to be more linear. Progression is often structured using convexity design where the options are limited at the beginning of a game (or level). As the player learns the necessary skills and becomes increasingly comfortable with the game mechanics, then more possibilities are offered. Player choice increases toward the mid-point of a game level/game and then decrease towards the climax of the game/level. In this way, the player's learning and progression are managed, and each level has a difficulty/intensity curve that resembles the dramatic structure of a movie or play – this is especially true in story-rich games. Choices should have meaning or consequences and not be completely random. The pace of gameplay should also be controlled to offer the player time-limited slices of controlled intensity, followed by periods of rest, reflection, preparation and planning. Learning to play effectively is essential to success in any game.

“Gameplay is a crucial element in any skill-and-action game … [and] everyone agrees that good gameplay is essential to the success of a game and that gameplay has something to do with the quality of the player’s interaction with the game. … I suggest that this elusive trait is derived from the combination of pace and cognitive effort required by the game” (Crawford, 1984). This definition, by one of the forefathers of modern digital game design, helps expose core issues in designing for people with disability; that of how to manage gameplay pace and cognitive difficulty. For example, a stroke survivor may have cognitive issues as well as physical impairments that result in reduced *physical strength, speed of movement,* or *reflexes*. Several of the common design factors that we have encountered in our research as requiring modification due to disability include *game session length, interaction timing, accuracy, repetition, challenge, problem solving and cognitive ability, autonomy, reward, cheating, identity, user personality and preference, control design,* and other *VR specific issues*. Serious game design also often needs to take external factors into consideration such as: *cost-effectiveness*, *transferability to meaningful activities of daily life*, *alignment with existing clinical structures and rehabilitation outcomes*. Provision for a range of *psychological profiles*, *play preferences*, *capabilities*, and a *balance between recovery and entertainment benefits*. As disability can vary considerably between people, it’s important to be able to profile users in terms of a range of factors including movement capability, movement articulation, strength, cognitive ability, play preference and others. Profiles can be used to tailor interactions and games to individuals. As ability can change over time, ideally with a trend upwards, then it is also preferable to have dynamic difficulty adjustment and other progressive modifications to the interactive experience based on improved behaviour and task achievement.

Learning and Engagement

Learning is central to progression is a game and is also crucial to patients performing tasks appropriately and improving. Learning outcomes. The inherent rule-bound structure of a computer game has a goal of immersing a player within a temporary world, in increasing skills and knowledge serves to help overcome challenges and achieve specific goals. This is essentially a learning process (Gee, 2003, 2005; Koster, 2004; Oblinger, 2008; Prensky, 2001), and so it seems conceivable that techniques from game design might be used to improve engagement in non-game contexts, such as physiotherapy or occupational therapy. Games are intended to provide an experience that intrinsically motivates players to progress in the absence of extrinsic rewards (Malone, Lepper, Snow, & Farr, 1987). This can mean that players spend hours mastering a game that is often difficult, complex and long (Gee, 2003; Oblinger, Oblinger, & Lippincott, 2005; Prensky, 2006). The motivational qualities of games have led some to argue that games have the potential to motivate, engage and ultimately enhance the way in which people learn (Shaffer, 2005; Squire & Jenkins, 2004).

There are many engagement characteristics in common between game playing and learning for a real-world purpose. These may be condensed into several common factors: *fun*, *structure*, *challenge*, *feedback*, *relationships*, *identity* (McGinnis, Bustard, Black, & Charles, 2008), *narrative* and *uncertainty*. *Fun*: Engagement is more natural if the experience is enjoyable. Fun can be 'hard' in that it relates to overcoming increasingly difficult challenges, but it can also be 'soft' and be more about feelings such as joy, pleasure, or surprise. *Relationships*: Engagement is reinforced by the social support and cooperation of others going through the same experience. Social features help enhance relatedness and make status more visible and meaningful. *Identity*: Engagement can be encouraged if everyone has a visible role in the learning environment. Identity can relate to escapism, fantasy, presence, role play (expressiveness), recognition by others. *Challenge*: Engagement can build on the human desire to learn and improve and is arguably central to the pursuit of optimal life experience. Challenge factors include competency, competition, and problem-solving. *Structure*: Engagement is more likely if objectives and constraints are clear and acceptable. Structural factors include choice, control, goals, and rules. *Feedback*: Engagement is reinforced by making achievements explicit and timely. Reward is a part of this, which may have endogenous value or real-world. *Narrative*: The communication of progress as a story, mainly when related to meaningful goals, can be impowering. *Uncertainty*: Engagement may be increased with an appropriate level of risk, having an opportunity for exploration and discovery, or when the extent of success is unknown. The key difference between serious games and entertainment-focused games is the lack of consequence in entertainment games. Both positive and negative feedback is essential; arguably people can learn more from failure than success!

Learning and Engagement based Game Design Framework

Fig. 1 illustrates how the four common elements of a game design framework relate to game components, typically resident in the game mechanics, and engagement factors which are most evident in the player's aesthetic experience. All processes and elements of design should be user-centred, except for designer creativity. A designer should be afforded some autonomy to innovate within the scope of the project; otherwise, gameplay can be stale and uninteresting. The diagram is purposely in 3D to reinforce the fact that design also depends considerably on the hardware and software upon which it with operate. For example, current mobile VR has battery and performance limits over PC "wired" VR. Input controller can also vary widely between platforms. Structure is the next layer of our design foundation; designing structure for learning, play, and progression. Providing meaningful, understandable structure about how to progress, and frequent feedback on progress is vital to engagement and the learning process. The design focus should be on building a useable user interface (UI), an enjoyable user experience (UX), supportive learning design and providing informative feedback. Understanding game mechanics and learning gameplay are at the core of all games, and player fun is a common objective. Fun is intangible to define, but we may say it depends on learning and experience. It also depends on the interplay between our three disks (Fig. 1): the design of gameplay rules (*Mechanics*), game choices and interactions (*Dynamics*), and a player's sensory and emotional experience (*Aesthetics*).

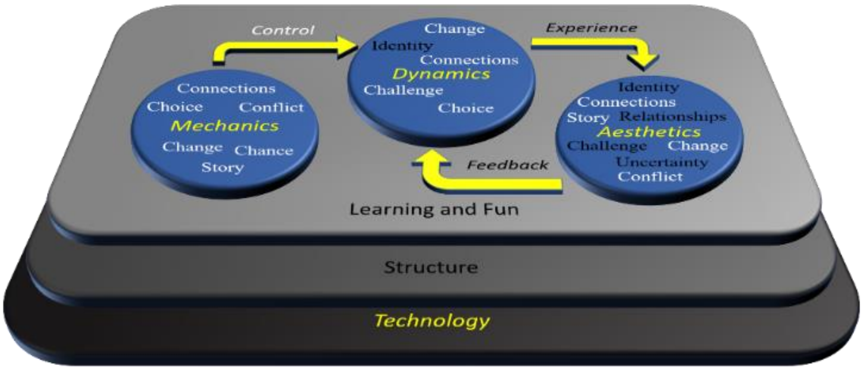


Fig. 1 Showing the relationship between common aspects of game design framework (yellow/italics), essential functional game components (white), and experiential characteristics related to engagement, gameplay progression and fun (black).

In a game, a player has the autonomy to control the state of their environment (within bounds) and to co-author their own experience (story). Immediate feedback informs the consequences of actions, mediates their choices, and stimulates learning. This experience-driven control loop is central to the definition of gameplay. The designer should also consider that there is a range of learning preferences, including visual, aural, verbal, physical, logical, social, solitary learning. There are also different learning styles; for example, Kolb (1983, p. 26) states that "*learning is the process whereby knowledge is created through the transformation of experience*". He argues that successful learning requires a cycle of concrete experience (*feeling*), abstract conceptualisation (*thinking*), reflective observation (*watching/listening*) and active experimentation (*doing*). Kolb describes the union of feeling and watching as a *diverging* learning style. Accounting for this type of player in a game we might consider them preferring an aesthetic experience. Learners with a preference for *thinking* $\cup$ *doing* are known as *converging* types, and we might consider this group as being more engaged by game mechanics. *Doing* $\cup$ *feeling* people are known as *accommodating* types and they may be more attracted to game dynamics (the interactive experience) within a game. *Watching* $\cup$ *thinking* people are considered as *assimilating* types because they are more cautious than other types. These people may be more suited to less dynamic games, and perhaps are akin to people who enjoy watching other people play.

Flow

Csíkszentmihályi's Flow theory (Csikszentmihalyi, 1991) is concerned with how to achieve optimal life experience and enjoyment in all of life's activities. An understanding of the psychology of Flow can help us understand how to design games that support a player to attain mastery. However, it is less clear how well people with disability can aspire to optimal experience within their rehabilitation.

The idea of Flow is intuitively comprehensible since the related phrase "in the flow" is in everyday use. Csíkszentmihályi's underlying idea is that enjoyment may be attained through the deliberate process of becoming increasingly proficient in any task, even if this is a repetitive and potentially dull task at work or in the home. An autotelic person is best at this; since once they chose a goal to achieve, or a skill to master, they commit to it and are focused its attainment. An autotelic person may apply a flow principle naturally to all parts of their life, and not get distracted by tasks that they have not prioritised. Autotelic people have a unique sense of curiosity and purpose that helps provide them with the structure and drive to be successful in much of what they set out to achieve. Learning about how an autotelic person manages their daily life can provide an insight into one way a person can adapt their mindset to enhance their enjoyment of life and general contentment. This knowledge can also inform task design within a system.

Flow is related to learning theories and attitudes to tackling challenges by placing emphasis on task achievement and overcoming challenges. If the challenge is too high, a person may become anxious and discouraged, but if it is well within their capabilities, they may lose interest. Csíkszentmihályi describes the path between these two extremes as the *flow channel*. As a person becomes more competent at a task, then the challenge difficulty should increase. This adjustment to suit a person's skill provides him/her with a 'pleasant degree of frustration'. The game is neither too hard that it becomes exasperating or too easy to become tedious. diSessa (2000) argues that pleasant frustration is an optimal state for learning. Koster (2004) applies similar ideas to game design when he more abstractly refers to the experience and challenges within a game as unfamiliar patterns to be consumed; once the pattern within the game becomes too familiar, then a player may become bored, whereas if the pattern appears too chaotic then the player may also become unengaged. Csíkszentmihályi uses the phrase *psychic entropy* to explain how people see there is “more to do than one can actually accomplish and feeling able to accomplish more than what conditions allow”. High psychic entropy is a state of disorder within the conscious mind, which may lead to unhappiness. High entropy equates to high levels of uncertainty in information-theoretic terms. It is, therefore, possible to draw a link between psychic entropy and experiential entropy within a game. According to Koster a significant reason that we enjoy games is that we are reducing disorder in the patterns presented by a game. Learning to overcome increasingly difficult challenges is part of this. A person’s *psychic entropy* and their perception of *gameplay entropy* are thus closely linked. A stroke patient’s psychic entropy level is potentially quite high due to mental and cognitive issues. Therefore, initial game complexity should probably be lower for a stroke patient than for non-disabled people and increase more gradually.

Virtual Reality Design and Development

The term virtual reality (VR) is generally credited to Jaron Lanier who used it to describe the experience afforded by goggles, gloves and other technologies in 1989. However, Charles Wheatstone’s Stereoscope might be the first physical device that bore some resemblance to modern VR.

We may consider VR as a 3D virtual space that a person enters via a VR headset or by another name, a head-mounted display (HMD). A person is immersed in the aesthetic experience of a 3D artificial world (reality-like or fantasy-based), and the HMD and affords them control of a camera to unrestricted 360° world view. As these worlds are dynamic, a person can interact with virtual objects and move around the world using handheld controllers, image processed hand gestures, or VR treadmills. World physics, lighting and shadows, and weather are simulated, and Artificial intelligence may be used to create dynamic or ambient intelligent behaviour for non-player character (NPC) creatures, people, or objects. A virtual world is additionally defined as persistent and shared with other real people (Bartle, 2003). A virtual world also provides a person with a virtual representation of themselves and they can interact within the world in real-time. Feelings of embodiment and agency that a person experiences within a virtual world can be very empowering. Dale’s cone of experience (Dale, 1963) illustrates how direct, purposeful experiences are the most concrete, and the most likely to have a lasting impact on learning (relating to Kolb’s *accommodating* or *converging* learner type).

The VR Experience

VR provides a particularly direct experience for the user compared to other digital media, with only a thin layer between the user senses and the representation of reality via an HMD as an artificial intermediary (Jerald, 2015, Chapter 1). Within VR, a person can have a very visceral experience due to *immersion* and heightened *presence*. The more a person is immersed, the more they feel present in the moment within the artificial medium. VR can immerse a person within a virtual context, so they are less aware of the real-world context; they become absorbed within the virtual space via their senses. Immersion is “the objective degree to which a VR system and application projects stimuli onto the sensory receptors of users in a way that is extensive, matching, surrounding, vivid, interactive, and plot informing” (Slater & Wilbur, 1997). That is, there is a wide range of user sensory modalities, with good matching correspondence between observed and expected sensory response (e.g. low motion lag), wide field of view, believable aesthetics, logically interactive. Where there is a story, it seems embedded within the virtual environment. Presence is related to immersion, but a person may become immersed without experiencing heightened presence. Presence is about the “psychological state or subjective perception in which even though part or all of an individual’s current experience is generated by and/or filtered through human-made technology, part or all of the individual’s perception fails to accurately acknowledge the role of the technology in the experience” (https://ispr.info/about-presence-2/about-presence). Presence is more readily attained within an immersive VR world than a casual mobile game experience on a small 2D screen due to the varying type of viewports. Similarly, some people are more likely to experience presence than others, depending on their personality, prior experiences, and personal preferences. *Agency* is a pivotal contributor to feelings of presence, where high agency reflects a person’s capability to affect change through interactions within the virtual space. The illusion of *self-embodiment* within VR can also heighten a person’s experience of presence. If a person has an avatar in VR that matches their actual real-world physical movement, via inverse kinematics, this can have a significant impact on agency and presence. Real-world physical haptic feedback experienced when a person’s avatar interacts with a virtual object can further enhance the illusion of ‘being there’ – see the rubber hand illusion (Botvinick & Cohen, 1998).

VR Design Factors

There are some potential issues or risks that often have to be considered in non-VR software that is more pertinent in VR. For example, as the VR representation of the real-world approaches the fidelity of real-life, the more disturbing it can be to a person's perception of what they see. The region of realism that significantly reduces an observer's comfort level is called the uncanny valley. It is often better to design for believability than realism as this reduces the issue of the uncanny valley, and people are generally comfortable to accept an unreal context if the content is consistent and meaningful within the context. Motion sickness can occur if there is too much lag in processing the visual response to user input interactions, e.g. moving their head to alter the viewport into the virtual scene or grasping an object with their virtual hand by moving their actual hand. The correspondence between virtual and real motion/interactions needs to be high due to the human body's reafference process within the nervous system (Jerald, 2015). The lag between a user moving their head and observing it should be better than 15ms (equates to mobile VR), with closer to 7ms being ideal (current high-end wired VR) (Kjetil Raaen, 2015).

"Learned helplessness" can be an issue in using VR with some demographics, who may have a previously adopted the attitude that they are not competent with technology. There is also a risk that if the VR experience is not accessible and successful from the beginning that a person would feel that they are not able to use the technology at all. Induction, orientation and training are crucial for new users; as is the adoption of appropriate user-centred design, and suitable development and testing processes. Proprioception is the sense of one's body moving and its position in space. This sense could be required to induce feelings of self-embodiment within an avatar in virtual space. Modern VR interactive systems with full-body inverse kinematic systems can play a part in higher levels of user agency. Exercise, particularly balance tasks, can help improve proprioception. Proprioception effects may be necessary for recovery using virtual physical therapy systems (Giroux et al., 2018) and so needs to be considered carefully in design. It may be even more critical to virtual mirror therapy since this treatment relies heavily on the illusion that an impaired arm is moving more freely.

Depth perception is important in VR, especially for reach and touch/grasp tasks on upper arm stroke rehabilitation. Depth perception is more naturally experienced within VR than on a 2D display (Sakata, Grove, Hill, Watson, & Stevenson, 2017), but still more challenging than in the real environment due to the multitude of cues that assist depth assessment within the real world. Various cues are helpful to improve depth perception including object occlusion, perspective projection, relative scaling of objects by depth in a scene, surface texturing, lighting and shadow effects, motion parallax, and colour shading. Perceptual capacity and load are important factors in designing VR for stroke survivors due to attention problems, brightness aversion, lower cognition, and other sensory issues.

VR Health Effects

There are a few health effects that are potentially more prominent in VR than in using 2D displays. The most well-known is VR sickness, which is predominantly due to the motion of VR objects relative to the player view or motion of the camera view into VR. This feeling ill due to poor correspondence between movement in VR and a person's conscious or subconscious expectation of that movement might be called simulator sickness. Factors that can affect this condition are poor render framerate, input lag, poor VR camera design, display flicker, fatigue, length of a play session, and prior health conditions. An example of poor camera design in VR is the game Lucky's Tale. In this game, the player observes and controls the actions of the player character (Lucky) from a view that is above and behind Lucky The player view is the camera view into in the VR world, and so when the player character moves the camera follows – thus so does the player view. The player is moving through the world as they would in many modern 3D games, but the view is entirely different in VR because the player inhabits the world and thus experiences a greater sense of agency. In Lucky's Tale, the problem is less about the motion of player view in following Lucky, though this can be disorienting to some people, instead it is about how the camera comes to a stop gradually when the Lucky halts. The camera motion is decelerated until the camera position comes to rest behind Lucky. So, when Lucky stops suddenly, the player view continues to move (decelerating) until it is closer to Lucky. The purpose of this dampened camera motion is to reduce a state hysteresis problem concerning vacillation of movement directions and between animation states. However, the disassociation between Lucky's movement and that of the camera can cause motion sickness. The award-winning VR game Moss deals with this issue for a similar type of game by fixing the camera view to the side of the character and using a mainly static camera position within each game zone. A wide field of view can increase the chances of motion sickness due to people being more sensitive to vection in the periphery of their vision. This visual effect appears to be more of an issue when a user moves their camera view through a VR environment. The VR version of the commercial game Skyrim attempts to address this problem by narrowing the player field of view as they move forward (essentially applying a dark vignette at the edges of the view).

Other issues may include eye strain, physical fatigue (due to standing or holding/moving controllers away from the body), or discomfort due to the HMD (weight, warmth, fit). Care must be taken with HMD hygiene, particularly in cleaning and replacing the soft padded inserts at the back of the HMD. As with all entertainment media, the designer must account for game effects that might trigger epilepsy in their design and use appropriate warnings.

VR Development Principles

In addition to the established system and game design principles, there are many VR design-specific aspects to consider. However, in general, the overriding goal is the same, to create an engaging and enjoyable user experience. Additionally, the main serious game objective is to be effective; in the case of upper arm stroke rehabilitation, the ultimate goal is to contribute to improved arm and hand function, so that a person can function better in activities of daily life.

Optimising experience within VR may be achieved in a range of ways. For example, increase immersion to help enhance presence, while using techniques to minimise loss of presence. Minimise the risk of the “uncanny valley”, by focusing more on believability and suspension of disbelief than on realism. Prioritise fidelity type: representational, interaction or experiential. In many gameplay scenarios, the quality of interaction is more important to immersion and presence than representation fidelity. Design a range of consistent, associative sensory cues and use appropriate feedback for guidance. Use colour theory for environmental and semiotic design (bearing in mind disability). Use binaural cues for enhanced perception of sound location, and salience (shiny, colourful, audible) or out of place objects to help capture a user’s attention. Create intuitive interfaces that are suited to VR, e.g. curved information UI displays and logical input control. Collect data to validate what users have their attention on to improve UI implementation. Increase user performance by simplifying a scene, increase a game's difficulty by adding distractors. Use Flow theory to optimise challenge. Make use of computer-controlled characters to support the player. Encourage reflection after tasks and ensure that users end their experience on a high, so they are more likely to return.

Health-related issues carry more concern in VR due to the immersive nature of the HMD, particularly with the possibility of motion sickness. For stroke users and other people with disability, the HMD needs to be chosen carefully based on its expected use, e.g. watching movie content or playing a 3D interactive game. Choose the HMD with the best display frame rate, latency and controller tracking resolution. It should be light and balanced on the head, easy to put on, be comfortable and cool to wear and be wireless if possible. Users should begin with short sessions then gradually increase exposure over time. Design short, chained experiences, with interactive arm movement sessions adapted to each user, providing adequate rest time between each game or exercise set. Input modes may be varied, e.g. between head gaze selection, button presses and input controller movement. Encourage slow head movements and maintain appropriate latency level and stability through intensive testing and adaptive game framerate management. Minimise forward and rotational accelerations/decelerations and use a fixed camera position in 3D space if possible, e.g. a seated position for the user. Leading indicators can help with motion sickness and camera orientation, i.e. showing the path that must be taken. Minimise visual stimulation close to the eyes and use darker scenes to minimise flicker while avoiding flashing lights. Manage low latency issues by fading the screen when this occurs and manage any loss of controller tracking.

A designer should focus on user experience and believability rather than photorealism in content and level creation. Use real-world similes or metaphors to help users relate virtual achievements to real-world benefit. Make a story clear, relatable and focus on emotional impact. Focus on the purpose for people to be in VR and eliminate redundant content. Use affordances and indicators as cues and guidance for interactions.

Story and Personal Narratives

A story can be a controversial component of a game design framework. Not all games have stories, and indeed, game stories should not be used excessively in non-interactive ways such as with cut-scenes. We have a focus on future narratives that can be powerful and empowering, encouraging a person to imagine possible future scenarios (beyond the short term) while consciously minimising negative thoughts about the past and present. People can be encouraged to construct a mental image of a reinvented future-self in new roles or participating in their most enjoyable experiences in new ways. In its purest form, this is about setting goals and visualising achieving them.

When someone survives a stroke, they often undergo significant physical and psychological change. A catastrophe has rocked the known world and forced personal transformation. In a sense, the stroke survivor receives a call to adventure; to take on the new challenge that is rehabilitation. They are asked to take a leap of faith into the unknown, for their own sake as well as family and friends. Rehabilitation is a voluntary journey, and the choice may be psychologically tough due to unknown challenges and uncertain outcomes. They may be fearful, depressed, or have the instinct to admit defeat. However, to acquiesce to their current plight is not an option and so they begin their quest to improve their condition. However, as support wanes and their progress continues to be difficult, many can become despondent and unenthusiastic to persevere. This sequence has a parallel to the classic Hero's Journey narrative, which can be used to influence system design.

The Hero

We may utilise the metaphor of a stroke survivor as a Hero who is called to undertake a journey of recovery through rehabilitation. There are limits to this metaphor, but the imagery may be useful in guiding design. Campbell (Luomala & Campbell, 1950) contends that the structure of the familiar Monomyth tale strongly relates to the human experience over the millennia. Moreover, there is an evident relationship to narrative-based game design. A narrative design structure created on the principle of the Monomyth may help develop a resonance for the user between therapy-inspired virtual tasks and their real-world objectives.

Our hero is the central person in the narrative; however, each stroke survivor has an individual personality, needs, capabilities and desires, and so they will each develop their own unique personal story arc. One way to

consider story generation is that it is created based on the actions that users take, an action's outcome and its implications. Each person has a unique experience that may be relayed to their friends and family, but it can also be recorded by the system and replayed to them. In-game design, this is called a player story. The system can also include a designer created story, with a story development that has a familiar narrative structure using a traditional drama curve, and has a convexity design for game progression as discussed earlier.
Let us consider *Free Will vs Determinism*. In designing games, particularly serious games, we need to understand the conflict about who is the author/director of the action and storyline. There may be a mismatch between designer intention and player choice. In rehabilitation games, a designer's challenge is to accommodate tailored rehabilitation alongside a user's freedom to choose activities. Games are inherently interactive, and so a player takes actions and makes choices to affect outcomes. Therefore, authorship of the experience is more complicated than for other forms of interactive media. For serious game stories, there is a clear need for the designer to craft an interactive story with a positive narrative to encourage progress, but this needs to be blended with individual stories that are created through player interaction and choices. The narrative should thus be developed using an intelligent interactive story system. As with action-based game design, a balance needs to be struck between a player's assurance and comfort of known play patterns against the excitement of new opportunities. For disabled peopåle, it is less risky to be more deterministic in design but to offer limited opportunities for free choice. An illusion of freedom is quite common in game design and interactive storytelling. For example, by using the convexity design pattern, players have choices in the middle of a game or level, but they always end up at the same exit point or story climax (though this may be tailored based on choices made). Exaggerated performance is also a helpful design pattern for disabled users with its positive psychological approach to engagement, it can increase subsequent performance, and it relates well to the Hero metaphor.

The Hero's Journey

Our hero (the stroke survivor), like many protagonists in stories, is an unexpected participant in the development of a dynamic narrative; choices made affect the outcome of their story. They have an altered perception of reality as they now must contend with multiple new realities. The old world that they have known from birth has changed, which we may think of as the hero's village, and a new unexplored world beckons across the boundary limits of the village. As a hero leaves their village (their prior reality), they experience a degree of trepidation. There may also be a fear of failure. Thus, the notion of a hero leaving their village to seek adventure is a simile for a stroke survivor's physical and mental adjustment to their disability, their rehabilitation, and altered means of interaction with the real world. The structure of a hero's journey and its narrative can be used to express the story of a person's journey towards their objectives. Below, we consider the phases of a traditional hero's journey.

The Departure: In a traditional hero's journey, the protagonist's perception of the world and their place in it is disturbed by a dramatic event. Their faith is tested, and status compromised. They are challenged to go on a quest to remedy the situation, for their sake as well as others. The hero is usually reluctant and initially refuses the call but eventually is persuaded that this is the only course of action. The awakening to a new state of being may be thought to be like a person waking after a stroke, faced with a changed world state, and difficult mental and physical challenges ahead of them. The hero decides to leave the comfort of their "village", fearful of failure, but taking one uncertain step at a time to cross the "first threshold". Breaking through this barrier is internally transformative. At this point, our hero typically meets a supernatural aid, perhaps a godlike spiritual character, who appears at just the right time to provide advice, equipment, nourishment, and to mentor them on their journey. We can think of this entity as the VR system (with clinical support as part of this). This guide appears at just the right time and provides the means to move forward with the quest.

The Challenge: As our hero progresses, they have trials (exercises) as they encounter enemies (effects of a stroke), but they also meet allies (friends, carers, other stroke survivors) who join the hero's party and onward quest. Ultimately, the hero approaches the "inmost cave" which locates the core objective of their quest and their most significant challenge; and it may seem insurmountable. This is also a metaphor for a person's inward demons and internal emotional and mental struggle and is the main ordeal and crisis point for the hero. Overcoming this challenge provides the "ultimate boon" and a magnificent reward for saving the world! The stroke survivor has met their goal(s) and can now return to a better life.

The Return: The hero may at first refuse to return to their previous life and may need “rescue from without” from their guide. The key for returning to the “real world” requires a crossing of the “return threshold” transformed but retaining the knowledge and skill attained on their quest. The stroke survivor should return from VR to the real world with knowledge and skills to be happy and successful in performing activities of everyday life. They progress with their rehabilitation and continue to improve, and so become “master of two worlds” which is like a “resurrection” or rebirth. The boon or elixir gained on the quest empowers the hero with the “freedom to live” a less fearful life. It is the reintegration into society and work.

Psychology and Game Design

Psychological theories have a large part to play in game design, gamification and serious game design. Continuing from the previous section and considering how to reward a player adequately; cognitive evaluation theory and reinforcement schedules are particularly relevant to game design.

Personality

Personality type can influence the types of games we like to play and the playing style that we adopt. Personality comprises characteristic patterns of thoughts, feelings, and behaviours that make a person unique. The research of prominent psychologists (Allport, 1937; Briggs, 1976; Cattell & Drevdahl, 1955; Eysenck & Eysenck, 1965; Jung, 1923) has proved influential in understanding personality and its relationship with player types. Jung’s work is considered one of the foundations for theories of player types. Jung proposed four functions through which we experience the world: sensing, intuition, feeling and thinking (Jung, 1923). These functions are paired into opposites and then applied an attitude to describe the underlying direction of person’s interests and energy flow, either inward to subjective (introversion) or outward to the environment (extraversion). Myers-Briggs extended Jung’s work into a more practical methodology producing a 16-element model, known as the Myers-Briggs Type Indicator (MBTI) (Briggs, 1976). The MBTI applies an extra dimension, Judging-Perceiving, and uses this additional dimension as a type indicator and as a means of determining functional dominance directed via introversion or extraversion. More recently (Keirsey & Bates, 1984) built upon the MBTI model and identified four basic patterns or temperaments, Artisan, Guardian, Rational, and Idealist, divided along two axes based on Communication and Action. Keirsey asserts that people communicate concretely or abstractly, with those communicating in a concrete fashion focusing more on reality, compared to those who communicate abstractly and tend to focus on ideas and theories and the possibilities that exist in the world. Research suggests that there is a connection between personality types and player motivation (Bartle, 1996; Caillois, 2001; Lazzaro, 2004), and several player typologies and have been proposed that combine various aspects of the most well-known theories (Ferro, Walz, & Greuter, 2013; Stewart, 2011). Stewart proposes links Bartle's player personality types to Keirsey's temperaments as well as identifying the Myers-Briggs types that would be associated with the correlated pairings. For example, Bartle's Killer and Keirsey's Achiever types are linked by their acting and sensing behaviours, implying that players who act within a game world do so based on senses within their environment.

Motivation and Persuasion

As the reader may have gathered by our initial discussion, player motivation is one prerequisite to understanding how to design a fun experience. This understanding is even more pertinent in a serious game, such as in the VR games that we build for stroke rehabilitation. While designing systems for extrinsic motivation can provide immediate and accessible fun, designing with intrinsic motivation in mind is more important. Extrinsic motivational systems encourage people to initiate play sessions and scaffold basic learning processes. Whereas intrinsic motivational schemes help guide more sophisticated skill development and increased levels of enjoyment. Four common factors tied to enhanced self-determinism and intrinsic motivation are (Deci, L & Ryan, M, 2010), *Relatedness* (social factors): Relationships and building friendships can become motivating. Group dynamics can stimulate interest in learning and improve retention with an activity, such as physical rehabilitation. *Autonomy* (freedom and choice): As well as feeling part of a team or group, people may also be highly motivated by the freedom to express themselves and to make their own choices. Striking a balance between structural guidance for a player and offering a degree of freedom for each to explore and develop in their own way is a fundamental skill of a designer. This understanding is especially useful in serious game design due to the importance of developing a patient's capability for performing activities in the real world. *Mastery* (learning/attainment): The quest for mastery of an activity, skill or understanding is central to much of human enjoyment. Enjoyment is central to Csíkszentmihályi's Flow theory (Csikszentmihalyi, 1991), which has been applied to game design numerous times. *Purpose* (meaning and knowing why): Having an understanding of why something has to be done, why no one else can do it, and what it will achieve is crucial. When a person's goals align with broader objectives, they can become highly motivated. A lack of understanding about the purpose of their task is demotivating. Games are commercial digital games are particularly good at explaining the purpose of an activity. With regards to physical therapy such as in stroke rehabilitation, linkage of the specifics of VR/game tasks to functional improvement is especially important in developing intrinsic motivation.

Perhaps the less positive side of psychology is the use of influence, coercion and persuasion in marketing or selling products and other situations that involve changing someone from one mind-set to another. Cialdini summarises six facets of persuasion: *Reciprocity*: If someone gives you some of their time, a loan of equipment, or a present, then you are more likely to reciprocate. *Commitment and consistency*: Once a person has committed to do something, they are more likely to remain committed due to an inbuilt desire for consistency. *Social Proof*: We are more likely to do something if we see others doing it. *Liking*: We are more likely to be influenced by people that we like. In this way, peer support may improve engagement (and use of positive feedback). *Authority*: Similarly, we often feel obliged to respond to authority figures or people in uniform. Clinical staff can have a significant impact on adherence to a programme. Connected health audio/visual connections can help improve someone's feeling of isolation and provide access to support. *Scarcity*: Items and activities are often more attractive when they seem to have restricted access. Scarcity can be manufactured to make an activity seem more popular than it otherwise would be, e.g. an online multi-user social club with limited occupancy.

It is our experience that influencing techniques are not used very often to enhance engagement with serious games. However, they offer some attractive possibilities, particularly as a novel gamification approach to improve retention. In the next section, we discuss behaviour change, which has a relationship with persuasion and coercion.

Gamification and Reward Structures

Digital games have always rewarded players for attainment and overcoming challenges. A modern game now typically offers a wider variety of play experiences and challenges within the same game, and different forms of rewards to suit diverse play preferences. We may also think of a modern game as having a layer of gamification on top of the main game design. Gamification is a new label for the use of game design principles or patterns to enhance human engagement with a process. It is typically applied to a non-game process such as learning, exercise, or rehabilitation, but can also be recursively applied to games. Gamification, in its most basic form, comprises a reward system based on points (P), badges (B), and leader boards (L). These are often centred on extrinsic motivation, but just as with Microsoft's Xbox gamer points and achievements system, the attainment of these can be fun, particularly from a social perspective in sharing attainments with friends. PBL can mark progress so that it is visible outside the game through player profiles and leader boards. The gamification system can help a player identify aspects of gameplay challenge that can enhance or prove their skill, and so be more intrinsically motivating. This technique can be used to motivate a person to become more expert, providing features and feedback that are most engaging to the user. When well designed, gamification can enhance retention levels and improve progression. For it to be successful in health technologies, gamification design should be tightly coupled with clinical processes and personal goals. It is evident that while effective gamification design owes much to game design, it also strongly relates to core ideas within psychology. Bartle makes a pertinent point concerning gamification, that good game designers reward players for doing what they already enjoy and want to achieve (http://mud.co.uk/richard/Shoreditch.pdf). This objective should be the same in serious game design. This later consideration relates to what Schell (Schell, 2008) calls the endogenous value of a game reward. That is, the designer should focus on understanding and implementing a reward system based on what is valuable to a player within the context of the game.

A designer should consider how reward can be made more valuable to the player. The following are some of the variations of reward structures. *Tangible/intangible*: trophies or status symbols can be fun but more tangible rewards such as player upgrades (health, wealth, items, item power) can have more endogenous value. Tangible rewards can help a player achieve their objectives more effectively/efficiently, and so their receipt may be more intrinsically motivating. *Expected/unexpected*: while surprise rewards are very engaging, it is also essential to include structured expected rewards that provide clear objectives to which a player can progress. Unexpected rewards can add variation to the gameplay and increases player anticipation. *Contingency*: Where task non-contingence is a reward not connected to any player attainment, but more of a surprise reward. For example, a random reward box appearing in front of the player. *Engagement contingent* is a reward to maintain game traction and player retention. For example, spin a reward wheel once a day, or exponentially increasing game cash rewards based on consecutive days/weeks of play. *Completion contingent,* for example, rewards for completing levels, quests or defeating enemies are essential. *Performance contingent* is the quality or quantity of rewards related to the performance of a task. For example, finishing a level and collecting all items would reward additional game cash, achievements, and other unique items of endogenous value.

Reward schedules should also be considered and include different combinations of schedules to enhanced gameplay variety. *Fixed interval*: Providing reward or reinforcement at fixed time intervals, e.g. 1, 2, 3, 4, or 5 minutes. This schedule might be appropriate for infinite scrolling type games – in which the main objective is to continue playing for as long (or travel as far) as possible. It is also appropriate for physical tasks. *Variable interval* (non-patterned can be more motivating): This could be task non-contingent or based on a random or unpredictable fixed temporal pattern. *Fixed ratio*: Reward is delivered after an expected set of task completions. Like fixed interval, this forms the basis for much of the rules embedded in the game mechanics. *Variable ratio*: Reward is delivered after an unpredictable number of actions or task completions. This schedule is best used in combination with others to avoid player frustration, but when used can help engage due to heightened expectancy. *Exaggerated feedback*: It has been shown that if a 10% higher reward is provided than deserved, a person can improve their performance by that amount on the next attempt (Wulf, Chiviacowsky, & Lewthwaite, 2012).

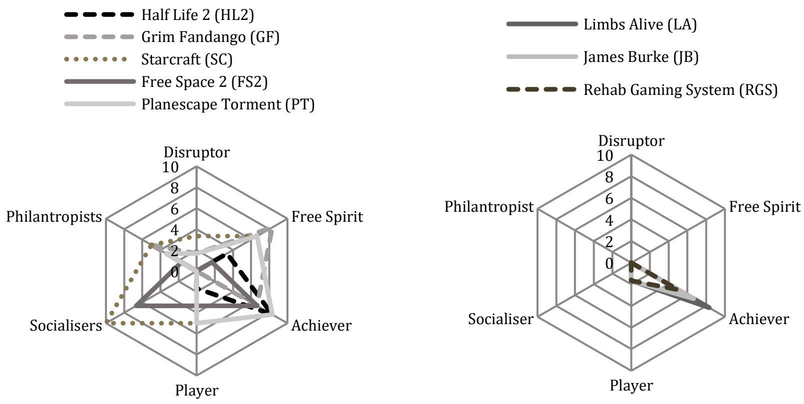
Behaviour Change

Behaviour change is also a key consideration in the design of rehabilitation systems. The ABC of Behaviour Change Theories book (Michie, West, Campbell, Brown, & Gainforth, 2014) outlines 83 fundamental theories, which influenced the design of the behaviour change wheel (BCW) (Michie, Atkins, & West, 2014). The approach with the BCW may be summarised as: 1) Define the behavioural problem, to target/specify the target behaviour, then identify what needs to change; 2) Identify interventions options; 3) Identify appropriate behavioural change techniques (BCTs) and delivery strategy.
Central to the BCW approach is the COM-B model: that a person's capability, motivation, and opportunity may potentially present barriers to behaviour change. Thus, the design focus for an effective solution should minimise the impact of these factors as they might have a negative impact on system traction and user retention. Action triggers are also important (Fogg, 2009), especially to help inspire the use of new technology. A sudden crisis or improved understanding can trigger someone into action that can lead to changed behaviour. Chapter 3 of (Michie, van Stralen, & West, 2011) provides and comprehensive list of 93 potential BCTs and groups them by taxonomy, theoretical domain framework (TDF), and intervention techniques. BCTs are incorporated into our Rehabilitation Game Model (below) for guiding serious game design.

Gamification Typologies

Several authors have addressed the problem that as people have different personalities, so they may be motivated by different gamification schemes. Bartle's (1996) taxonomy of player types was one of the first developed and has been particularly influential. (Marczewski, 2013) influenced by Bartle and other psychological/motivational models, has produced a practical typology for classifying players by gamification type:

1. *Disruptor*: motivated by *change*, they enjoy exploiting flaws in-game mechanics or modding software or hardware.
2. *Free Spirit*: motivated by *autonomy,* they enjoy exploring, being creative, and not being bound by rules.
3. *Achiever*: motivated by *mastery,* they focus on self-improvement and enjoy being challenged in order to better themselves.



4. *Player*: motivated by *rewards,* they do what is necessary to win or be better than others.
5. *Socializer*: motivated by *relatedness,* they enjoy social connections with others.
6. *Philanthropist*: motivated by a *purpose,* they prefer to understand the reason for their undertaking challenges and are also more altruistic.

Fig. 2 Gamification type evaluation of commercial (left) and rehabilitation games (right).

We have explored the application of this gamification approach within education (Herbert, Charles, Moore, & Charles, 2014) and stroke rehabilitation (Boureaud et al., 2016). As part of our investigation, we performed an exploratory analysis of several well-known commercial and rehabilitation games to consider how well they are designed for this variation in motivation preference. Five popular commercial games from core genres were evaluated along with three relevant rehabilitation games by our research team (D. Holmes, 2014). Commercial games typically exhibited more variety in accounting for player type, though as expected all games demonstrated the importance of the achiever player type (Fig. 3 left). Evaluated rehabilitation games contained well-designed and entertaining gameplay. However, they appeared to have a narrower design focus on achievement orientated rewards than commercially designed games (Fig. 3 right). This may be expected due to the strong linkage between goal-orientated structures in rehabilitation programs, and generally less experienced design teams. However, arguably, variation in motivation and play preference should be accounted for to be more inclusive of different players.

The rehabilitation Gaming Model (RGM) is a tool (see Fig. 3) which we developed a tool for the design and evaluation of games or gamified solutions for rehabilitation. Our first practical implementation (D. Holmes, 2014) contains three core aspects: a gamification typology (Marczewski, 2013), a game design pattern ontology y (Marczewski, 2013), a game design pattern ontology) (Bjork & Holopainen, 2004), and a behaviour change framework) (Bjork & Holopainen, 2004). The gamification typology built into the first version of the RGM is Marczewski's Hexad model of motivation for different personality types. Bjork's game design pattern ontology was incorporated due to its comprehensive ontology of 295 game design patterns. The RGM also utilises a Behaviour Change Wheel framework, created from 19 other established behaviour change frameworks, utilising 93 behavioural change techniques (Appendix B).

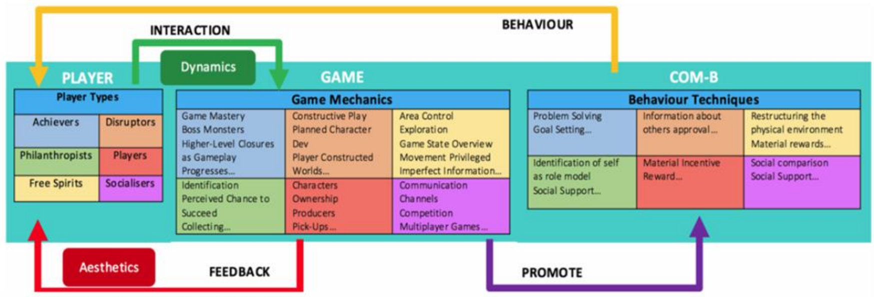


Fig. 3 The Rehabilitation Game Model.

The RGM can be used to identify gamification elements and game design patterns that map to BCTs, and vice versa. It also helps the designer to account for different personalities, play preferences and gamification types. Table 1 shows the mapping for an Achiever personality (other types in Appendix A, BCT groups in Appendix B). BCTs that may be embedded into a gamification scheme for an Achiever type are quite comprehensive; not surprising bearing in mind achievement is a challenge and task-oriented and games may be thought of and teaching and learning machines (Gee, 2005; Koster, 2004). Also, bear in mind that we are identifying BCTs that help positively modify a person behaviour to physical rehabilitation and use of technology that supports this. There needs to be a real-world message of progress associated with virtual success. This mapping is critical. Let's consider an example – a clone of Angry Birds in which the player must activate a catapult with their hands to launch a missile at a stacked set of blocks to topple and destroy them. A camera tracks their real hands, and they see a virtual copy of their hands moving within VR. Reaching and touching a launch button beside the catapult results in a missile being fired, and also enables them to get some beneficial exercise. A serious game may be designed to provide progressive difficulty with in-game challenges. So, for example, in this case, the missile may become smaller, and the stacked blocks placed further away (and later with obstacles obstructed the player missile), and the missile type can change to reflect the increase in cognitive and tactile skill. As a player progresses, their arm strength and stamina may improve, and they also may be able to perform increasingly tricky hand gestures. Table 1 provides may ways to engage the player, but they require specific information to help them relate their achievements to the real world and motivate them to return to the system. Leader boards, message boards, and chat areas allow players to connect social, which for many is enough motivation, but having the progress on display offers them the opportunity to feel proud and for others to praise them. Any interaction with the system and the rehab games should be considered a success and positive messages (and rewards/awards) be given based on the player's consistency, effort and progress. It should be clear to participants that there is a link between their progress in the game and their potential improved capability in activities of daily living. Tasks and difficulty curves should be adapted to each person, and reward systems (gamification) may also be adapted to their preference. Even within the Achiever gamification type, there is variation between people, for example, some people may be obsessive about collections while others may prefer to beat other players (akin to Bartle's Killer type).

Table 1 Achiever Gamification Type. Mapping relevant BCTs to gamification element.

Gamification Element	Game Design Patterns	BCT Opportunities (Appendix B) that can alter rehab behaviour through the VR system and games.
Challenges	Alignment, Deadly Traps, Enemies, Evade, Guard, Limited Resources, Manoeuvring, Obstacles, Puzzle Solving, Race, Time Limits.	1.1, 1.3-1.9, 2.2-2.7, 3.1-3.3, 4.4, 6.2-6.3, 7.1-7.4, 8.1, 8.3, 8.7, 9.1, 9.3, 10.1-10.11, 12.2, 12.6, 13.1-13.4, 14.1-14.10, 15.1-15.4.
Certificates	Competence Areas, Game Mastery, Producers.	1.3, 1.5, 1.7, 6.2, 6.3, 7.2, 10.8, 10.10, 13.1, 13.2, 14.1-14.10, 15.3, 16.1, 16.2.
Quests	Collection, Committed Goals, Continuous Goals, Ephemeral Goals, Goal Points, Hierarchy of Goals, King of the Hill, Mutual Goals, Near Miss Indicators,	1.1-1.9, 2.2-2.7, 3.1-3.3, 4.4, 6.2-6.3, 7.1-7.4, 8.1, 8.3, 8.7, 9.1, 9.3, 10.1-10.11, 13.1-13.4, 14.1-14.10, 15.1-15.4.

	Optional Goals, Predefined Goals, Selectable Sets of Goals, Supporting. Goals, Unknown Goals.	
Learning/New Skills	Character Development, Experimenting, Gain Competence, Gain Information, Handicaps, Memorizing, New Abilities, Perceived Chance to Succeed, Power-Ups, Privileged Abilities, Reconnaissance, Role Reversal, Skills, Symmetry.	1.1-1.9, 2.2-2.7, 7.1-7.4, 8.1, 8.3, 8.6, 8.7, 10.1-10.11, 12.1, 12.2, 12.5, 12.6, 13.5, 14.1-14.10, 15.3.
Boss Battles	Boss Monsters, Bragging Rights, Higher-Level Closures as Gameplay Progresses.	1.7, 2.7, 3.2, 6.2, 8.1, 8.7, 10.5, 10.6, 10.7, 13.2, 13.4, 13.5, 14.1-14.10, 15.1-15.4, 16.2, 16.3.
Levels/ Progression	Diminishing Returns, Improved Abilities, Levels, Obstacles, Resources, Score, Skills, Smooth Learning Curves.	1.1-1.9, 2.2-2.7, 7.1-7.4, 8.1, 8.3, 8.6, 8.7, 10.1-10.11, 12.1, 12.2, 12.5, 12.6, 13.5, 14.1-14.10.

Appendix A shows 5 other gamification types, with player and socialiser type being the most common player types. In an unreported recent experiment with 68 healthy users (predominantly 18-20-year-old, mixed-sex students) of a virtual learning world we found that there were few pure gamification types, but rather we identified 19 typical gamification profiles that were combinations of the core gamification archetypes.

Design and Development Processes

The creation of serious VR game for stroke rehabilitation is by its very nature a collaborative affair. It is to be expected that the design process should be user-centred, ideally with the target group playing an integral part in the design and development. Co-design practice should be used with contributions from practising clinicians, stroke survivors, carers, designers, developers, academics, and other stakeholders. One of the primary challenges in creating an effective and high quality product is in the project management for such a diverse group, and communication issues due to variation in digital and traditional literacy, differences in terminology between disciplines, experienced in the use of technology or playing games, or lack of understanding of clinical processes by technical staff. Our participatory framework is shown in Fig. 4, and mapping of the behavioural wheel components COM-B (Michie et al., 2011) to PACT is shown in Table 2. An implementation of PACT is illustrated in (Charles & McDonough, 2015), which demonstrates how to integrate the essential PACT elements into a design and development process. We discuss this later in an extension to PACT to encouraging behaviour change (PACT-B) with respect to regularly engaging with rehabilitation exercise.

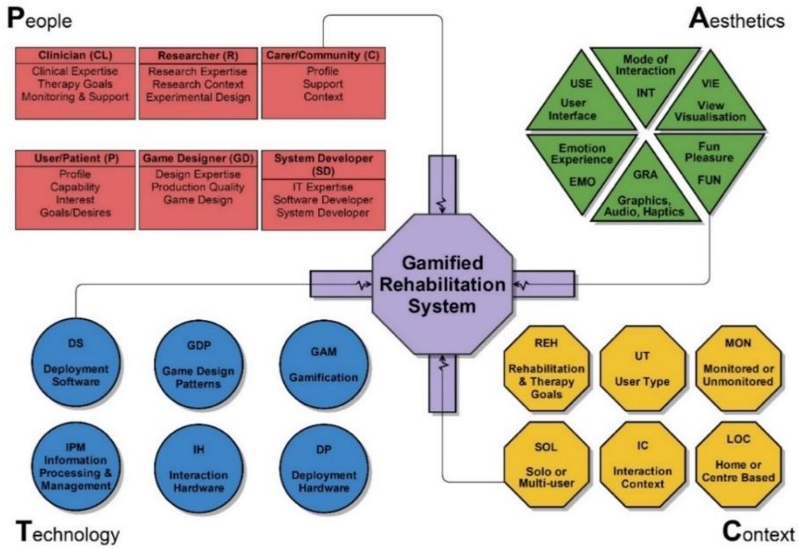


Fig. 4 Four PACT components for a participatory design framework (Charles & McDonough, 2015).

Communication and understanding can be improved through a willingness of all parties to invest time in understanding terminology and practices in other disciplines and through the use of non-technical language if possible. Regular meetings are essential for this. Both the design and development processes can be lean, iterative and evolutionary using the well-established Agile software development methodology. In essence, this can be achieved through a series of design and testing workshops with representatives of all stakeholders being presented at these workshops. It is vital to give experienced VR game designers and developers time and space to be creative with the scope of the project. Though, it is equally important that their design ideas are tested on paper and through iterative early prototyping. It has been shown that if a game is tested at the Vertical Slice that is more likely to succeed, where the Vertical Slice (McAllister & White, 2015) is the point where the core features of a game can be thoroughly tested (i.e. early in the development phase). Practical project management tools should be adopted, and the team trained in its use, e.g. Asana, and modes of communication established along with appropriate document and software storage strategies (e.g. Office 365 Skype, OneDrive, Outlook, Calendar). Project management can be more challenging in an inter-disciplinary team due to project tasks, clinical and technical, not always having well-aligned priorities.

Table 2 PACT-B: COM-B mappings to PACT.

PACT Attribute	Capability	Opportunity	Motivation
People	*	*	*
Aesthetics			*
Context		*	
Technology	*	*	*

Previous Experiments

Our research group has been investigating games, virtual and assistive technologies to enhance stroke rehabilitation since 2004. Here we summarise several of the experiments undertaken, provide an overview of the changing nature of technologies, and discuss what we have learned about developing software systems and games over this period (Appendix C).

Much of the focus of our research has been on making rehabilitation more accessible and motivating to perform at home, with appropriate quality, regularity, and intensity. We look to create systems that optimise engagement using by using game design patterns, psychological principles, gamification techniques, and accessible inspiring new technologies in our design. We continue to be watchful about the possibility of using commercial off the shelf (COTS) games, and we initially tested a wide range of games and games hardware with the support of health professionals to assess their applicability to stroke rehabilitation (e.g. PS2 Eye-Toy, Wii games, dance mats). Feedback from testers was that while these games were fun, the exercises did not coincide with the required rehab exercises enough, some games may have been unsuitable for some people (e.g. type and length of exercise, an opportunity for breaks, visual issues). Feedback from this evaluation confirmed Rand’s findings (Rand, Kizony, & Weiss, 2004) – although there was a great deal of potential in these off-the-shelf games for stroke rehabilitation, the pacing of the games was too fast for all but the ablest of stroke users. New VR games may provide excellent opportunities for general exercise, but a lot of

curating of suitable games and optimising their parameters would be required. So, we have instead concentrated on making bespoke games through co-designing with patients, clinicians and technical experts.
Our first experiments with VR, games and stroke physical therapy was with Ascension's Flock of Birds system. VR HMDs at that time were bulky and imbalanced on the head. They had lower resolution, higher latency tracking and lower render frame rate. The gloves that a user wore for hand and finger tracking were effective for that time period but were challenging for a disabled person to put on, and they had clumsy wires connected from them to the computer. The magnetic tracking system used magnetic so powerful that they could interfere with a pacemaker and other electronic devices.
We made several casual games including a Whack-a-Mole style game and a game involving catch apples/oranges in a basket falling from a tree. In the first game, the person could hold a small physical hammer, and the second they could hold a basket. As they were wearing trackable gloves, there was no issue with occlusion that might occur with camera tracking. This mix of the virtual with the real physical world, moving an actual basket and seeing a virtual basket move, was a potent mix for physiotherapy due to the increase in immersion, presence, and proprioception. Holding an actual object had obvious physiotherapy benefits that would otherwise require force feedback in the glove or another device, though we only developed games for coarse arm movement. The games proved fun, but there was potential for these to be enhanced. One of the issues for developing games in a research project is that there is generally not enough time, expertise and development resources allocated to make a game close to commercial quality.
During the next phase of stroke rehabilitation research, we decided to adopt COTS game hardware and controllers as these were mass-produced for use in the home and so were cheaper due to economies of scale, and generally more useable than a bespoke controller would be. Free and less expensive commercial level game development engines were beginning to emerge towards 2010 and decided to adopt a new 'indie' game development toolset, Microsoft's XNA, that enabled a rapid prototyping and development process. A higher aesthetic gameplay quality also became more affordably achieved. A trial using Nintendo's highly accessible Wiimote was an obvious option at that time, as the Wii game console had massive popularity with over 100 million units sold worldwide. Indeed, several stroke survivors in our current trial have referenced the Wii in

feedback to our physio team when discussing our new system. We created several Wiimote controlled XNA games (Appendix C, (J. W. Burke, Morrow, McNeill, McDonough, & Charles, 2008)), which were designed in the spirit of the casual games that made the Wii console popular. A wireless connection and ease of use of the controller were a key benefit, as well as that many people were already familiar with this controller. However, potential intermittent loss of controller tracking and the cost of developer licenses were drawbacks of this approach at that time. Thus, webcam tracking of natural hand motion was investigated instead.

Four webcam games were created for upper arm rehabilitation (gross movement), *Rabbit Chase*, *Arrow Attack*, *Bubble Trouble*, and *Double Bubble Trouble* (J. W. Burke et al., 2009b). In each game the user reached and touched a target, in some cases they had to use both hands to hit two separate targets, and in Rabbit Chase they had to hit a rabbit before it got back to its rabbit hole. A webcam tracked their hands and distinguished right from left hands through the user wearing different coloured gloves (green and red). Range of movement was calibrated before each game, and difficulty adapted based on performance by increasing game complexity, speeding up the action, or making targets smaller. These games were popular with healthy and impaired users with most participants saying that the games were both useable and playable (fun and easy to play). In a three-week trial, results also suggested that the games could motivate better rehabilitation adherence. This has been one of our key goals in our research. As with any object detection task, occlusion could be an issue, and with RGB colour recognition, lighting conditions could affect detection reliability.

Experiments with webcam games were followed up with an experiment to investigate augmented reality (AR) games (J. W. Burke et al., 2010). Also using a webcam for motion tracking, this time the webcam detected patterns on the top of physical blocks (black and white QR codes). This method had the advantage of the previous approach in that users would reach, grasp, and move a physical object. The QR code enables the software to recognise the black position and track it as the user moved it. On-screen, the plain physical block was superimposed by suitable virtual 3D models such as aeroplanes to fit game themes and enhance immersion. Four games were created: *Break-a-Ball*, *Whack Attack*, *Target Trails*, and *Ping Pong*. The design of these was influenced by popular games: Breakout, Whack-a-Mole, Guitar Hero, and Pong, respectively. In each of the games the player held and moved a physical block to control the position of a 3D object or character on the screen. The advantages of this form of AR were that the user would feel the weight and texture of the object, thus potentially enhancing proprioceptive effects of rehabilitation. The weight of the object could also be used for strength conditioning for able participants. This method of hand tracking had similar issues to the previous approach including loss of tracking due to occlusion, the casting of shadows on the QR code, lack of sharpness of the captured images because of motion blur. Loss of tracking could affect scores and so were frustrating for users. Predictive tracking or sensor redundancy might help with this issue. Results were encouraging in the same areas as the previous experiment. Participants also reported a positive change in their ability to grip objects. Profiling and adaptive difficulty proved as important as with previous experiments as users demonstrated improvement over time.

Around 2012/2013, we got access to the Leap Motion sensor/controller beta hardware. We were keen to investigate this sensor as it uses an infrared-based depth camera to accurately detect hands and finger positions for gestural control systems. The Leap is highly responsive (can capture up to 200 frames per second), high spatial precision (0.01 mm), and is much less affected by changing light conditions. We ran an initial trial with eight practising physiotherapists and occupational therapists in which they provided feedback on three simulated common clinical tasks: *Cotton Balls*, *Stacking Blocks*, and the *Nine Hole Peg Test*. In this first trial, the Leap was table-mounted, and a standard screen was used rather than VR. The tasks involved lifting virtual balls from one box to another, stacking square blocks one upon another, and lifting and placing nine virtual pegs into holes. Feedback was very positive from most participants, saying that this approach could be motivating for patients, especially young people and in a home setting. We deliberately virtualised clinical tasks as we felt that clinicians would be more comfortable with this, though ironically, it was suggested that games would be more engaging for patients to maintain their exercise. We learned several important things from observation. Table mounting of the Leap was troublesome as it required a person to begin with their hand above the sensor, for those who did not completely perceive what the sensor did this could be confusing. If their hand was too close to the sensor, it couldn’t be tracked, and similarly, hand tracking could be lost for the same reason. This issue may be mitigated through improved guidance, sensor mounting above the table pointing downward, or placed under a thing glass table (untested). Training for this setup is crucial, particularly due to the disconnect in relating their actual hand movement that of their virtual hands on a 2D screen. As the new generation of commercial VR HMDs became available, Leap Motion provided a software update to allow the Leap Motion sensor to be HMD mounted. This provided a generally better way to track hands, i.e. by looking at them, and within VR people experienced more agency and feeling of embodiment.

Our next two experiments over 2015-2016 (Appendix C: 6 and 7) used the Leap Motion in an HMD mounted position. The first experiment also used a Kinect for body position tracking and Myo armband sensor for additional arm tracking (also compared 2D screen vs VR). In the second experiment, we only used the Leap sensor as the HMD was used in place of the Kinect to infer body position, and the Myo sensor proved tricky to put on and calibrate. Our preference was for a technical set up with minimal physical footprint in a person's home. Our results over the two experiments were encouraging, with most users finding the experience enjoyable and the system useable. Performance improved in VR and participants considered the tasks to be easier to perform in VR, with visual and audio cues proving to be beneficial to improving performance. Some users said that VR helped them focus more clearly on tasks. Fatigue was evident for healthy and impaired users. Rest periods were more critical for impaired users than we had thought (from the technical team perspective), as were the importance of carefully designed induction, training, system calibration (to individuals) and guidance (in-game). Tracking of hands was challenging as a contrast between the table and hands could be an issue, and clenched/stiff hands proved hard to track with the built-in Leap Motion software (which is signed for healthy hands) – resulting in less reliable tracking in some cases. As in all experiments with the Leap sensor, hands that move outside the sensor range (left or right) can't be tracked (or similarly if the head points away from the hands). Ideally, a technical strategy needs to be in place to keep displaying the hand until tracking resumes, instructions for the user to move their hands back in front of them, and perhaps predictive motion. A second Leap sensor may also be used on a different axis. Though technical and clinical challenges (e.g. issues for people with visual or cognitive impairment) were identified, the formal and informal outcomes of these experiments encouraged us to continue to evolve the system with new technologies and our software enhancements.

Approach to Design and Development in a Large-Scale Project

Our current trial is the central focus for phase 3 of an EU project called Magic. Our existing VR rehab system was enhanced through phases 1 and 2 and extended with the addition of mirror therapy (Ramachandran & Rodgers-Ramachandran, 1996). VR mirror therapy enables patients with very limited or no movement in one arm/hand to be still able to undergo rehabilitation with their other arm. Up to 150 stroke survivors are currently being recruited in Northern Ireland and Italy, and the experiment implemented using a method that supports evolutionary design and development within a user-centred software life cycle model. The overall goal of the project is to develop technology that can improve a stroke survivors' capability to engage in activities of everyday life with the assistance of rehabilitation technology in the home. Outcome measurements include clinical measures of improved performance, usability statistics, and engagement statistics. As the technical group of the consortium, our focus was on creating the most useable, accessible, technically reliable, beneficial, and fun experience. Subjective responses from users in structured interviews (as well as feedback from clinicians) have provided us with significant beneficial information already on the project (ending March 2020). In the following section, we discuss how we applied the lessons that we have learned over the years to the design and development of VR stroke rehabilitation software.

Implementing PACT-B

In this chapter, we have presented an approach in which behaviour change techniques are mapped to our recent PACT framework (PACT-B) to improve adherence to rehab. Here we summarise how we have used this in practice within our current VR upper limb mirror therapy stroke trial. This trial is part of a funded EU 2020 pre-commercial procurement project called Magic, and as such has a more commercial emphasis, and has proved beneficial in sharpening our focus on creating a system that is fit for purpose.

It is necessary to take a user-centred approach to system design and development; remembering who the system is for and develop an increasingly accurate understanding of variation in clinical capability and needs, and different personal hopes, goals and expectations. Interested parties can be quite diverse, including creative artists/designers, programmers, physios/OTs, nurses/doctors, psychologists, stroke survivors and their carers, family and friends, clinical administrators, purchasing officers. Loud voices from one context should not monopolise the creation process. For example, in our experience it is quite common for a person to use an individual opinion to extrapolate to a general population view of a feature – e.g. "my son doesn't like this feature, and he's a gamer" is only anecdotal evidence. Assignment of an experienced project manager and the application of robust processes are invaluable for operating within a complex co-design scenario, to account for all voices in a balanced and effective way. Fig 5. Illustrates how integrating BCTs may be included as part of a design process (with a few examples). For example, the intensity required for upper arm rehab needs to be intense to maximise the opportunity for optimal recovery. Five hours a day, over 5 weekdays is very tough. So, encouraging a stroke survivor to engage in personal goal setting, and providing positive feedback can be very supportive. Good structure and tailored levels of repetition help guide them through programmes, so they don't have to think about it. Presenting engagement with exercise in a positive manner to show continual improvement and so providing an opportunity for user enjoyment. We need to encourage regular system use, as we don't want people to dread logging in but rather look forward to it. Receiving reward and positive reinforcement helps them look forward to it, and social support such as friend networks, multiuser meetups and exercise session can be an enticement to use the system. Giving them responsibility within a social setting is empowering and has consequences if they do not fulfil their role. Comparison with their past performance and collaborative tasks with other stroke survivors or carers helps maintain traction with system use (like exercise challenges and adventures in Fitbit smartwatches).

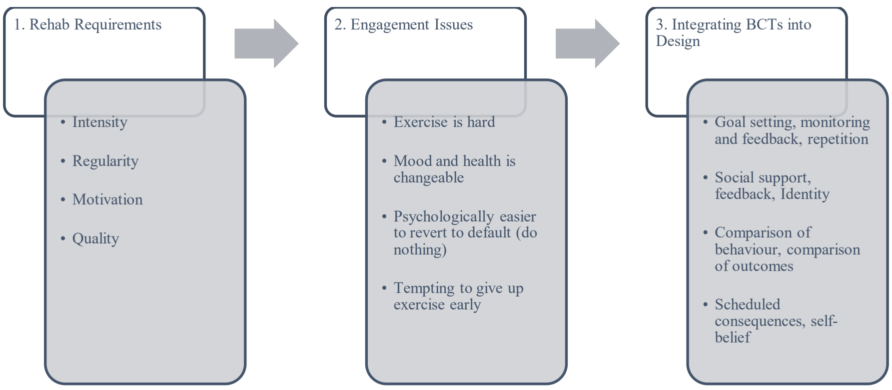


Fig. 5 Process of mapping BCTs to patient and clinical needs to improve rehabilitation retention

We use gamification, and various other positive psychology approaches such as persuasion within our design to reinforce productive behaviour. Gamification provides rewards/feedback that motivates, encourages and guides a person in their exercise. Users of the system can gain points and achievement badges for using the system regularly, for effort and improvement of physical performance in VR tasks.
Our experience is that it is best to create several games that cover a range of genres and from very casual and short, to a game with more depth and strategy. It is challenging to account for the full range of disabilities of stroke survivors within one game. Add to this that different exercise programmes suggest different types of gameplay. For example, coarse arm movement suits games such as Whac-Mole; moving an arm to hit a mole appearing at different locations in front of the player (in the space defined by a person's range of motion). Precise hand and finger exercise are often suggestive of games with repetition of tasks; e.g. tap a finger to open a door, open and close a hand to blow up a balloon. Knowledge of the six-game design c's and core game design patterns are essential in matching physical motion and cognitive difficulty to gameplay features. Progression in a serious game is important but can be challenging to design as a person may "flatline" their improvement graph after a while. It is perhaps best to represent progress both as improvement in gameplay and physical performance (so long as these are distinguishable), and through positive feedback on consistent engagement. Throughout, information messages are required, to help training, to provide health messages, and for positive encouragement. A person's rehab journey is their personal story. This personal story can form the basis for empowering narratives, primarily if a stroke survivor is engaged in the imagining of their future narrative.
The following is an outline of the process of system development that we now tend to adopt, including the integration of BCTs, gamification, effective game design best practice, and a strong focus on usability.

1) *Establish a core team.* Identify the people required to help the project be successful, including experts for key roles. Ideally, a group of stroke survivors and clinicians are identified who can help throughout the design and testing processes. Best practice is to recruit at least one stroke survivor and one practising physio or OT to

be part of the core design team. A working group can be established, comprised of these end-user representatives, researchers, developers, designers, and project managers. A working group makes collective decisions and project management.

2) *Requirements gathering*. This process and the data obtained inform subsequent decisions and processes, particularly design. For upper limb stroke rehabilitation, requirements would account for the variation of user movement, user fatigue and attention issues, cognitive, and other potential stroke effects. Usability of user interfaces and any hardware (such as controllers) is crucial. Clinical requirements for rehabilitation must be gathered, summarised, and understood in terms of their integration into games. Technical aspects such as computing specification and any network/cloud services must be accounted for. Collection and processing of demographic data, technical background of the user population, and entertainment preferences can inform design choices. The overall goal and objectives for the use of the system should be agreed, and the scope of the project limited on this basis. Requirements may be gathered in the usual way and illustrated through high-level visual graphics, rich pictures, user stories and other similar methods. Workshops are useful to refine requirements through iterative activities and group discussions. Existing team bespoke or commercial software may be used to aid communication and help improve understanding of potential opportunities. Risk management is a crucial part of planning, and cost, aspects of project failure, and the possibility of changing requirements must be accounted for. An Agile software development approach appropriate for health VR game technology development since the approach is necessarily a co-design / co-development process which requires regular feedback from a range of different experts and laypeople.

3) *Tools, technology platform and asset identification*. Based on requirements, scope and objectives, a technology platform can be identified for the system software and VR games (assuming VR is the most appropriate solution). For our current trial several VR HMDs including the Oculus Rift and HTC Vive, were tested by us and stroke survivors at various local stroke organisations. Though the Vive provided, arguably, more robust tracking (fewer occlusion issues) and more flexible operation (e.g. trackable objects), the Oculus Rift proved more user-friendly and useable for stroke survivors. The Oculus also has a less obtrusive set up in a home, is easier

to put on (due to the head strap operation) and was found by users to be more balanced and lighter to wear on the head. Several stroke users, particularly older females, preferred the idea of the Oculus in their home. From a technical point of view, our team had tested both systems and felt that most of the requirements could be met on both VR systems. We had already committed to using the Unity development tool due to its widespread use, ease of programming and level of developer support. Unity can be used to create VR environments for all the leading commercial HMDs. Graphics and audio tools should also suit the team (or recruitment requirements). Most of the asset creation tools that we use are free and are widely adopted by developers. A decision should be made, based on team talent and a cost/benefit analysis, about which game or system assets should be purchased and which should be created in-house. For our Magic project, we bought most of the game environment assets to build our own bespoke game areas, as for our system, this was more cost-effective than contracting several creatives. Our team realises the gameplay and creates the game levels as due to our experience in serious VR game development. Project and development management tools are essential, as is the training of the team in their use. Apart from conventional office and email software, we use Excel for hardware and user feedback tracking, Asana for software development management, TeamViewer to remote login to user systems (for support), OneDrive for secure document storage, and Azure for GDPR compatible website hosting.

4) *Design*. Design is often rushed or completed through development, which is generally a mistake as project resources (time, people, money) may be committed too early to a flawed design. This careful design is the same for any software design, but there are a few differences between designing for VR stroke rehab compared mainstream software and games. Game design is a creative process and generally considered not very successful in being completed "by committee". However, in the case of a serious game, a designer needs to understand clinical requirements and variability in patient capability. Brainstorming, interviews and other information transfer methods help the designer to appreciate restrictions on input control and to understand appropriate approaches to UI graphics and interaction design. It helps the designer learn about setting suitable game difficulty, gameplay

pacing, and setting the length of game sessions. If requirements are well detailed and understood by the designer, then input from other team members during the design process is focused on providing periodic advice and feedback after each design Agile "sprint". The design process should be considered as multiple cycles of design/evaluation tuples. Where the evaluators are clinical team members or external clinical groups, stroke survivor team members or external stroke groups, as well as other people with experience on playing or designing games. Some feedback sessions can be informal and short; others can be more structured with more people involved. Design is often more difficult than expected. Communication of ideas can be tough to a multi-disciplinary team, so a "lo-fi" approach to tool adoption is recommended. We have found the following stages to be quite beneficial:

a. Brainstorming with whiteboard sessions as a core team group. Agreement should be reached on the high-level structure and main components of the software and games. Build a shortlist of suitable games of a variety of gameplay styles, covering the range of rehab exercises required, and accounting for a range of different abilities.
b. Paper prototypes are very effective. That is, the system and VR games are illustrated on paper with text, sketches and diagrams. Sketching designs helps communication and allows very rapid turnover of ideas. Works well for teams.
c. A PowerPoint game design document. There are many other approaches but the use of PowerPoint helps develop a mindset of rapid and iterative design, and presenting the design more like a short, comprehensible pitch document. It is very unusual/unlikely that a first design document will accurately represent the final design, but rather a design document should be considered as a living document that is regularly updated. Thus, it should be easy to update and accessible to read. PowerPoint has a range of easy to use tools that help swiftly create a presentable design. Narration tools within PowerPoint are a bonus, for articulating the key ideas verbally.
d. Rapid building of small functional prototypes. For example, test core gameplay, input control, and UI design. Games are often "grey boxed" (i.e. no graphics or audio) to assess

if the game mechanics are fun and useable. Quickly creating throwaway portions of games and system software facilitates an early evaluation of functionality, usability and user experience. This helps refine architectural design and refine features before committing to full-scale development. For games it is good practice to follow this up with a fully working game portion that illustrates just enough to evaluate whether the core idea is working well. This test point is called the Vertical Slice.

5) *Further Team Recruitment*. It is better to expand the team after requirements and design are well established. Consider that a casual game such as the original Angry Birds cost approximately £100k to make, and usually game development costs significantly more than this. A VR system with embedded rehab games comprises a wide range of features (variety of games, information systems, cloud services) and so requires a broader range of talent to create and careful testing. So, recruitment must be undertaken carefully, staged if possible, and hiring people with more than one role in the team (e.g. documentation and testing, graphics and level design). In our current Magic project required expertise includes game coding, system development, UI and game design, level design, 2D and 3D graphics, web client and server development (including database expertise), upper arm stroke rehabilitation, ethics, user services (deployment, call support), game and system testing.
6) *Development and Testing*. If early prototyping is effective in mainly tying down the system features, then development can be completed in a phased release manner. This process involves the sequenced development of separate independent subsystems (e.g. game 1, database, web dashboard). Testing, redesigning and fixing any issues with one subsystem before moving to the next, though if the team is large enough, some subsystems could be developed in parallel. Interoperability between systems can be tested throughout, and end-users can also test partial systems, e.g. games playtested and optimised for usability and enjoyment. When the full system is completed, it requires more in-depth technical tests (e.g. stress tests, unit code tests), and user testing (stroke survivors, clinician, healthy laypeople). If design still needs some real-world evaluation to improve, then an evolutionary development

strategy would be more appropriate than a staged release approach, involving short cycles of system building, evaluation/tests, and redesign.

7) *Support and Maintenance*. Any system used over some time requires a strategy for end-user support, especially if they are using it at home independently. System flaws or bugs are quite common, especially the first deployed version. We support users via phone (they have a number to call), we have embedded support via calling in our rehab system, we can remotely access their computer via Microsoft Team Viewer, and we maintain an online software patch update server (to update home systems remotely). We also supply a web dashboard for clinicians to be able to monitor system use and patient data. A patient's rehab programme can be tailored to each person via the web dashboard. Our rehab system is adaptive, and rehab tasks and their difficulty are intelligently adapted based on user profiles.

Discussion

In this chapter, we presented a range of research and design principles that help guide the design of VR games for upper arm stroke rehabilitation and related this to our own experience. The core ideas are likely to apply to several other areas of physical rehabilitation.

Questions have arisen during our research and development. For example, who is the designer? The people that our system matters most to are stroke survivors; it is, therefore, essential that they have a say on how a system should operate and on game design features. However, we would only ever be able to recruit a small group of representative people, who may not represent the general view of the wider stroke community, and we have found that viewpoints vary between different countries. In gaining opinions from stroke survivors, some areas are more important to receive feedback than others. For example, ideas about VR hardware preferences for use in the home is useful. We found that people cared about how a system looked in their house, e.g. did it make it looked cluttered. Usability of hardware is also essential, e.g. ease of setup and start-up, ease of putting on VR headset. Listening too carefully to a small group of people about game preferences is fraught with problems; opinions are helpful, but an experienced designer must also account for general appeal, fun, and rehab worthiness. The game designer has needs to be an experienced moderating voice in design.

Clinicians provide valuable information on exercise requirements and well and physical, mental and cognitive limits. A person must be pushed in their rehabilitation for it to be effective but within bounds. This emphasis is a critical design issue. Games typically use repetition in gameplay, and arguably rehab requires more emphasis on repetition, with precise doses and careful set minimum/maximum periods. This scope is challenging for the game designer who attempts to make these repetitions enjoyable in gameplay. For example, we have made an Angry Birds styled game, in which a player performs rehab hand gestures (e.g. pinch) to fire projectiles at a castle and defeat an enemy repeatedly. We have found that working out an appropriate gameplay pace is also challenging, even though we intelligently adapt this through monitoring player performance. For a serious game, the Flow channel (see above), varies a lot between different people based on their prior game/technology experience and cognitive/mental capability. If tasks are too challenging a player becomes disillusioned, too easy, then they become bored. We have also found that, for a well-designed game, many stroke survivors learn how to play quite rapidly and so having enough content to prevent them from being bored is also an important goal. Content is expense. Therefore, smart design strategies are required to be able to reuse graphics, level areas, and code in several games. Another strategy is to make an "infinite scrolling" game, where the game potentially continues indefinitely. Content is procedurally placed in the game levels, and so design effort is more on procedural code design and less on graphics and level design. The third common gameplay component is in setting appropriate times for play sessions. The procedural content approach helps solve the development cost issue, but in our game River Run, we spent some time in design brainstorming how an infinite scroller type game can be limited to a maximum playtime. Rest periods are required and also a person's overall time in VR should be limited. One obvious approach is to have sections of the river run divided into periods suitable for each player; they continue along the river after rest periods and on starting the game again in a new VR session. If a person runs out of game lives (or player character health), then they must restart the river again – where there are several (potentially infinite) rivers to master.

We are often asked questions about or challenged on the use of VR rather than Augmented Reality or standard 2D monitors. While the use of games

to help motivate people used be an issue for some observers in that past, we feel that most people are much more respective to what games can offer. However, VR is relatively new, and while the novel is quite exciting to many people, there can be reluctance among other people. We have found in practice that most people accept the technology quite well after a period of use, and many people enjoy the experience of putting it on and becoming immersed. AR allows a person to see their real environment while also seeing virtual objects and characters. AR has much potential for supporting stroke survivors and may be used for some people who do not like the experience of being immersed (i.e. not having a positive lusory attitude). AR may be more effective in encouraging a user to interact with real-world objects that are overlaid with information or virtual targets, as we have shown previously (J. Burke et al., 2010). However, VR allows us to immerse a person in a controlled environment, with controlled lighting and minimal distractions. This tailored approach can be necessary for many stroke survivors, and we have feedback from some patients in our current trial that they appreciate being able to 'escape' to VR. We have some evidence (D. E. Holmes, Charles, Morrow, McClean, & McDonough, 2016) that healthy and impaired users enjoy the experience of VR and that it helps them feel more in control of their virtual tasks in comparison to completing them on 2D displays.
In the PACT framework, and during our broader discussion on design, we highlight the importance of people, aesthetics, context and technology to a design and development process. PACT-B reflects the focus of our recent work, which has a more deliberate emphasis on embedding behaviour change techniques into our system and game design. BCTs have much in common to game design patterns, gamification, and learning theories, but have more emphasis on a person taking ownership and being mindful of their engagement.
The technology landscape is changing rapidly, with new AR and VR HMDs being released regularly. Any physical rehabilitation solution needs to be mindful of this and be able to avail of new and improved features when they become available, e.g. wireless HMDs streaming high frame rate visuals from a PC or cloud servers (e.g. Google Stadia). AR HMDs that can become VR by darkening their lenses glass. More accessible controllers and higher quality hand/finger tracking. Higher bandwidth 5G mobile networks and broadband internet will hopefully support lower cost connected health hardware that supports more people recover effectively at home. Social support is a crucial area for stroke rehabilitation in the home

and VR provides unique opportunities via a faster network to connect people.
Nonetheless, the design challenges will be the same. Intense rehabilitation has been shown to increase the chance of improved recovery significantly. However, it is practically impossible for a person to maintain the dose and quality of exercise unsupported within the home. VR rehabilitation can support stroke survivors by structuring their rehab, providing targeted feedback and intelligent adaptive processes, helping to motivate them with social factors, gamification and fun tailored games.

References

Allport, G. (1937). *Personality*. New York: Holt.

Bartle, R. (1996). Hearts, clubs, diamonds, spades: Players who suit {MUDs}. *Journal of {MUD} Research*, *1*(1). Retrieved from http://web.cs.wpi.edu/~ypisan/virtualworlds/readings/hearts-clubs.pdf

Bartle, R. (2003). *Designing virtual worlds*. New Riders Games.

Bateman, C., & Boon, R. (2006). *21st Century Game Design*. Hingham, Massachusetts: Charles River Media, Inc.

Bjork, S., & Holopainen, J. (2004). *Patterns in Game Design*. Charles River Media.

Botvinick, M., & Cohen, J. (1998). Rubber hands "feel" touch that eyes see [8]. *Nature*. https://doi.org/10.1038/35784

Boureaud, J., Holmes, D., Charles, D., Morrow, P., McClean, S., & McDonough, S. (2016). Application of a Rehabilitation Game Model to Assistive Technology Design,. *International Conference on Disability, Virtual Reality & Associated Technologies*, 1–4.

Briggs, K. (1976). *Myers-Briggs type indicator*. Palo Alto, CA: Consulting Psychologists Press.

Burke, J., McNeill, M. D. J., Charles, D. K., Morrow, P. J., Crosbie, J., & McDonough, S. (2010). Augmented Reality Game Design for Upper-Limb Stroke Rehabilitation. *2nd IEEE International Conference on Games and Virtual Worlds for Serious Applications (VS-GAMES 2010)*, 75–78. Retrieved from http://eprints.ulster.ac.uk/24858/

Burke, J. W., McNeill, M. D. J., Charles, D. K., Morrow, P. J., Crosbie, J. H., & McDonough, S. M. (2009a). Optimising engagement for stroke rehabilitation using serious games. *The Visual Computer*, *25*(12), 1085–1099. Retrieved from http://eprints.ulster.ac.uk/9734/

Burke, J. W., McNeill, M. D. J., Charles, D. K., Morrow, P. J., Crosbie, J. H., & McDonough, S. M. (2009b). Serious games for upper limb rehabilitation following stroke. *Proceedings of the 2009 Conference in Games and Virtual Worlds for Serious Applications, VS-GAMES 2009*. https://doi.org/10.1109/VS-GAMES.2009.17

Burke, J. W., McNeill, M. D. J., Charles, D. K., Morrow, P. J., Crosbie, J. H., & McDonough, S. M. (2010). Augmented reality games for upper-limb stroke rehabilitation. *2nd International Conference on Games and Virtual Worlds for Serious Applications, VS-GAMES 2010*. https://doi.org/10.1109/VS-GAMES.2010.21

Burke, J. W., Morrow, P. J., McNeill, M. D. J., McDonough, S. M., & Charles, D. K. (2008). Vision based games for upper-limb stroke rehabilitation. *Proceedings - IMVIP 2008, 2008 International Machine Vision and Image Processing Conference*. https://doi.org/10.1109/IMVIP.2008.16

Caillois, R. (2001). *Man, Play and Games*. University of Illinois Press.

Cattell, R., & Drevdahl, J. (1955). A comparison of personality profile (16 PF) of eminent researchers with that of eminent teachers and administrators, and of general population. *British Journal of Psychology*.

Charles, D., & McDonough, S. (2015). A participatory design framework for the gamification of rehabilitation systems. In *Recent Advances on Using Virtual Reality Technologies for Rehabilitation*.

Costikyan, G. (2013). *Uncertainty in games* (1st ed.). MIT Press.

Crawford, C. (1984). *The Art of Computer Game Design*. Retrieved from http://www.vancouver.wsu.edu/fac/peabody/game-book/Coverpage.html

Crosbie, J., Lennon, S., Basford, J., & McDonough, S. (2007). Virtual reality in stroke rehabilitation: Still more virtual than real. *Disabil Rehabil*, *29*(14), 1139–1146.

Csikszentmihalyi, M. (1991). *Flow, The Psychology of Optimal Experience*. New York: Harper Perennial.

Dale, E. (1963). *Audio-visual methods in teaching* (Rev. ed.). New York: Holt Rinehart and Winston.

Deci, L, E., & Ryan, M, R. (2010). *Self-Determination. The Corsini Encyclopedia of Psychology 1-2* (I. B. Weiner & W. E. Craighead, Eds.). Hoboken, NJ, USA: John Wiley & Sons, Inc.

diSessa, A. (2000). *Changing minds: Computers, learning and literacy*. Cambridge, Mass: {MIT} Press.

Eysenck, H., & Eysenck, S. (1965). *The Eysenck personality inventory*.

Ferro, L. S., Walz, S. P., & Greuter, S. (2013). Towards personalised, gamified systems. *Proceedings of The 9th Australasian Conference on Interactive Entertainment Matters of Life and Death - IE '13*, 1–6. https://doi.org/10.1145/2513002.2513024

Fogg, B. J. (2009). *A Behavior Model for Persuasive Design*.

Gee, J. P. (2003). *What video Games have to Teach us about Learning and Literacy*. London: Palgrave, Macmillan.

Gee, J. P. (2005). Learning by Design: good video games as learning machines. *E-Learning*, *2*(1), 5.

Giroux, M., Barra, J., Zrelli, I.-E., Barraud, P.-A., Cian, C., & Guerraz, M. (2018). The respective contributions of visual and proprioceptive afferents to the mirror illusion in virtual reality. *PLoS ONE*, *13*(8 : e0203086.).

Herbert, B., Charles, D., Moore, A., & Charles, T. (2014). An investigation of gamification typologies for enhancing learner motivation. *Proceedings - 2014 International Conference on Interactive Technologies and Games, ITAG 2014*. https://doi.org/10.1109/iTAG.2014.17

Holmes, D. (2014). Rehabilitation Gaming Model (RGM).

Holmes, D. E., Charles, D. K., Morrow, P. J., McClean, S., & McDonough, S. M. (2016). Using fitt's law to model arm motion tracked in 3D by a leap motion controller for virtual reality upper arm stroke rehabilitation. *Proceedings - IEEE Symposium on Computer-Based Medical Systems*, *2016-August*. https://doi.org/10.1109/CBMS.2016.41

Hunicke, R., Leblanc, M., & Zubek, R. (2004). MDA: A formal approach to game design and game research. *Proceedings of the AAAI Workshop on Challenges in Game AI*, 4.

Hurn, J., Kneebone, I., & Cropley, M. (2006). Goal setting as an outcome measure: A systematic review. *Clinical Rehabilitation*, *20*(9), 756–772. https://doi.org/20/9/756 [pii]\r10.1177/0269215506070793

Intercollegiate Stroke Working Party. (2012). National clinical guideline for stroke. *London: Royal College of Physicians*, (July), 232.

Jerald, J. (2015). The VR Book - Human-Centered Design for Virtual Reality. In *The VR Book - Human-Centered Design for Virtual Reality*. https://doi.org/10.1145/2792790

Jung, C. (1923). *Psychological types: or the psychology of individuation.*

Keirsey, D., & Bates, M. (1984). *Please Understand Me: Character and Temperament Types*. Prometheus Nemesis.

Kjetil Raaen, I. K. (2015). Measuring Latency in Virtual Reality Systems. *14th International Conference on Entertainment Computing (ICEC)*, 457–462.

Kolb, D. (1983). *Experiential Learning: Experience As The Source Of Learning And Development* (Vol. 1st). New Jersey: Prentice Hall Inc.

Koster, R. (2004). *Theory of Fun for Game Design*. US: Paraglyph Inc.

Laver, K. E., George, S., Thomas, S., Deutsch, J. E., & Crotty, M. (2015). Virtual reality for stroke rehabilitation. *Cochrane Database of Systematic Reviews*, (2), CD008349. https://doi.org/10.1002/14651858.CD008349.pub3.www.cochranelibrary.com

Laver, K., Lange, B., George, S., Deutsch, J., Saposnik, G., & Crotty, M. (2017). Virtual reality for stroke rehabilitation. *Cochrane Database of Systematic Reviews*, (11), CD008349. https://doi.org/10.1002/14651858.CD008349.pub4.www.cochranelibrary.com

Lazzaro, N. (2004). Why We Play Games: Four Keys to More Emotion Without Story. *Game Developer Conference (GDC)*, 1–8. https://doi.org/10.1111/j.1464-410X.2004.04896.x

Levin, M. F., Weiss, P. L., & Keshner, E. a. (2015). Emergence of virtual reality as a tool for upper limb rehabilitation. *Physical Therapy*, *95*(3), 415–425. https://doi.org/10.2522/ptj.20130579

Luomala, K., & Campbell, J. (1950). The Hero with a Thousand Faces. *The Journal of American Folklore*, *63*(247), 121. https://doi.org/10.2307/537371

Malone, T. W., Lepper, M. R., Snow, R., & Farr, M. (1987). Making Learning Fun: A Taxonomy of Intrinsic Motivations for Learning. In *Aptitude, Learning and Instruction: {III.} Conative and affective process analyses* (pp. 223–253). {NJ:} Erlbaum: Hilsdale.

Marczewski, A. (2013). A User Type Framework for Gamification Design.

McAllister, G., & White, G. R. (2015). *Video Game Development and User Experience*. https://doi.org/10.1007/978-3-319-15985-0_2

McBean, D., & Wijck, F. van. (2013). Movement And Coordination. In *Applied Neurosciences for the Allied Health Professional* (pp. 53–63). Churchhill Livingstone Elsevier.

McGinnis, T., Bustard, D. W., Black, M., & Charles, D. (2008). Enhancing e-learning engagement using design patterns from computer games. *Proceedings of the 1st International Conference on Advances in Computer-Human Interaction, ACHI 2008*. https://doi.org/10.1109/ACHI.2008.43

McNulty, P. A., Thompson-Butel, A. G., Faux, S. G., Lin, G., Katrak, P. H., Harris, L. R., & Shiner, C. T. (2015). The efficacy of Wii-based Movement therapy for upper limb rehabilitation in the chronic post-stroke period: A randomized controlled trial. *International Journal of Stroke*, *10*(8), 1253–1260. https://doi.org/10.1111/ijs.12594

Michie, S., Atkins, L., & West, R. (2014). *The Behaviour Change Wheel*. Silverback Publishing.

Michie, S., van Stralen, M. M., & West, R. (2011). The behaviour change wheel: a new method for characterising and designing behaviour change interventions. *Implementation Science : IS*, *6*(1), 42. https://doi.org/10.1186/1748-5908-6-42

Michie, S., West, R., Campbell, R., Brown, J., & Gainforth, H. (2014). *ABC of Behaviour Change Theories*. Silverback Publishing.

Oblinger, D. (2008). *Emerging technologies for learning*.

Oblinger, D., Oblinger, J., & Lippincott, J. (2005). *Educating the Net Generation*.

Prensky, M. (2001). *Digital Game-Based Learning*. McGraw-Hill Education.

Prensky, M. (2006). *Don't bother me, Mom, I'm learning!: How computer and video games are preparing your kids for 21st century success and how you can help!.* St. Paul, MN: Paragon House.

Ramachandran, V. S., & Rodgers-Ramachandran, D. (1996). Synaesthesia in phantom limbs induced with mirrors. *Proceedings of the Royal Society B: Biological Sciences*. https://doi.org/10.1098/rspb.1996.0058

Rand, D., Kizony, R., & Weiss, P. L. (2004). Virtual reality rehabilitation for all : Vivid GX versus Sony PlayStation II EyeToy. *5th Intl. Conf. on Disability, Virtual Reality & Associated Technologies*, 87–94.

Sakata, S., Grove, P. M., Hill, A., Watson, M. O., & Stevenson, A. R. L. (2017). *Impact of simulated three-dimensional perception on precision of depth judgements, technical performance and perceived workload in laparoscopy*. https://doi.org/10.1002/bjs.10528

Salen, K., & Zimmerman, E. (2003). *Rules of Play- Game Design Fundamentals*. Cambridge: {MIT} Press.

Schell, J. (2008). *The Art of Game Design: A book of lenses*. Retrieved from http://www.amazon.com/The-Art-Game-Design-lenses/dp/0123694965

Shaffer, D. (2005). Epistemic games. *Innovate*, *1*(6). Retrieved from www.innovateonline.info/index.php?view=article&id=79

Slater, M., & Wilbur, S. (1997). A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments. *Presence: Teleoperators and Virtual Environments*. https://doi.org/10.1162/pres.1997.6.6.603

Squire, K., & Jenkins, H. (2004). Harnessing the Power of Games in Education. *Insight*, *3*(5), 7–33.

Stewart, B. (2011). Personality and play styles: A unified model. *Gamasutra, September*.

Stroke Association. (2009). Targeted arm & hand training at home: Reach-to-grasp.

Suits, B. (1990). *Grasshopper: Games, Life and Utopia.* Boston: David R. Godine.

Webster, D., & Celik, O. (2014). Systematic review of Kinect applications in elderly care and stroke rehabilitation. *J.Neuroeng.Rehabil.*, *11:108. do*, 108–111.

Wulf, G., Chiviacowsky, S., & Lewthwaite, R. (2012). Altering mindset can enhance motor learning in older adults. *Psychology and Aging*, *27*(1), 14–21. https://doi.org/10.1037/a0025718

Appendix A: Linking Gamification Types and Systems, Game Design Patterns, and Behaviour Change Techniques.

Table A1 Disrupter Gamification Type**.**

Gamification Element	Game Design Patterns
Anarchy	Betrayal, Player Elimination.
Light Touch	Bluffing, Damage, Limited Planning Ability, Paper-Rock-Scissors, Randomness, Red Herrings, Role Reversal, Secret Alliances, Uncertainty of Information.
Anonymity	Asymmetric Information, Bluffing, Cards, Fog of War, Handles, Paper-Rock-Scissors, Role Reversal, Secret Alliances, Stealth.
Development Tools	Constructive Play, Character Development, Tools.
Voting/Voice	Betrayal
Innovation Platform	Player Constructed Worlds, Player Decided Results, Player Defined Goals, Player-Decided Distribution of Rewards & Penalties, Reconfigurable Game World

Table A2 Free Spirit Gamification Type**.**

Gamification Element	Game Design Patterns
Exploration	Area Control, Exploration, Game State Overview, Manoeuvring, Movement, Movement Limitations, Privileged Movement, Traces, Controllers, Imperfect Information, Inaccessible Areas.
Branching Choices	Analysis Paralysis, Asymmetric Goals, Attention Swapping, Betrayal, Cognitive Immersion, Freedom of Choice, Illusion of Influence, Limited Set of Actions, Planned Character Development, Risk/Reward, Roleplaying, Stimulated Planning, Trade-offs.
Easter Eggs	Pick-Ups, Resource Locations, Secret Resources, Easter Eggs
Unlockable/ Rare Content	Progress Indicators, Resource Generators, Rewards, Surprises, Ultra-Powerful Events
Customisation	Camping, Construction, Player Defined Goals, Player Constructed Worlds, Player-Decided Distribution of Rewards & Penalties, Reconfigurable Game World
Creativity Tools	Creative Control, Empowerment, Player Constructed Worlds, Player Decided Results, Player Defined Goals, Player-Decided Distribution of Rewards & Penalties

Table A3 Philanthropist Gamification Type**.**

Gamification Element	Game Design Patterns
Access	Asymmetric Goals, Buttons, Tools, Controllers
Meaning/Purpose	Identification, Perceived Chance to Succeed

Caretaking	Helpers, Safe Havens, Tension, Tied Results, Mule
Collect & Trade	Bidding, Collecting, Contact, Converters, Enclosure, Gain Ownership, Negotiation, Pick-Ups, Reconnaissance, Safe Havens, Tools, Trade-offs, Trading.
Sharing Knowledge	Cooperation.
Gifting/Sharing	Cards, Cooperation, Card Hands.

Table A4 Player Gamification Type**.**

Gamification Element	Game Design Patterns
Points/ Exp Points (XP)	Budgeted Action Points, Characters, Consumers, Container, Outcome Indicators, Score
Physical Rewards/Prizes	Chargers, Illusionary Rewards, Individual Rewards, Non-Renewable Resources, Pick-Ups, Player Decided Distribution of Rewards & Penalties, Power-Ups, Renewable Resources, Resource Generators, Resource Locations, Resources, Rewards, Secret Resources, Symmetric Resource Distribution.
Leader boards/Ladders	High Score Lists, Red Queen Dilemmas, Tiebreakers.
Badges/Achievements	Characters, Ownership, Producers
Virtual Economy	Arithmetic Rewards for Investments, Budgeted Action Points, Consumers, Container, Geometric Rewards for Investments, Investments, Limited Resources, Ownership, Pick-Ups, Renewable Resources, Resource Locations, Rewards.
Lottery/Game of Chance	Betting, Leaps of Faith, Luck

Table A5 Socialiser Gamification Type**.**

Gamification Element	Game Design Patterns
Social Status	Handles, High Score Lists, Individual Penalties, Individual Rewards, King of the Hill, Near Miss Indicators, Privileged Abilities, Privileged Movement, Public Information, Red Queen Dilemmas, Shared Penalties, Shared Resources, Shared Rewards, Social Statuses, Status Indicators.
Social Network	Alliances, Asynchronous / Synchronous Games, Collaborative Actions, Communication Channels, Indirect Information, Individual Penalties, Inferable Goals, Last Man Standing, Multiplayer Games, Negotiation, Public Information, Secret Alliances, Social Dilemmas, Social Interaction, Spectators, Symmetric Information, Tiebreakers, Tied Results.
Social Pressure	Betrayal, Uncommitted Alliances

Competition	Agents, Balancing Effects, Capture, Combat, Competition, Conflict, Early Elimination, Eliminate, Last Man Standing, Multiplayer Games, Player Killing, Race, Time Limits, Tournaments, Varied Gameplay.
Social Discovery	Communication Channels, Social Organizations.
Guilds/Teams	Agents, Alliances, Betrayal, Collaborative Actions, Dynamic Alliances, Multiplayer Games, Player Decided Results, Secret Alliances, Shared Penalties, Shared Resources, Shared Rewards, Social Interaction, Social Organizations, Symmetric Information, Symmetric Resource Distribution, Team Balance, Team Development, Team Play, Tiebreakers, Tied Results, Tournaments, Varied Gameplay.

Appendix B: Grouping of Individual BCTs (Michie, van Stralen, & West, 2011).

Group No.	Group Label	BCTs
1	Goals and Planning	1.1. Goal setting (behaviour) 1.2. Problem solving 1.3. Goal setting (outcome) 1.4. Action planning 1.5. Review behaviour goal(s) 1.6. Discrepancy between current behaviour and goal 1.7. Review outcome goal(s) 1.8. Behavioural contract 1.9. Commitment
2	Feedback and Monitoring	2.1. Monitoring of behaviour by others without feedback 2.2. Feedback on behaviour 2.3. Self-monitoring of behaviour 2.4. Self-monitoring of outcome(s) of behaviour 2.5. Monitoring of outcome(s) of behaviour without feedback 2.6. Biofeedback 2.7. Feedback on outcome(s) of behaviour
3	Social Support	3.1. Social support (unspecified) 3.2. Social support (practical) 3.3. Social support (emotional)
4	Shaping Knowledge	4.1. Instruction on how to perform the behaviour 4.2. Information about Antecedents 4.3. Re-attribution 4.4. Behavioural experiments
5	Natural Consequences	5.1. Information about health consequences 5.2. Salience of consequences 5.3. Information about social and environmental consequences 5.4. Monitoring of emotional consequences 5.5. Anticipated regret 5.6. Information about emotional consequences
6	Comparison of Behaviour	6.1. Demonstration of the behaviour 6.2. Social comparison 6.3. Information about others' approval
7	Associations	7.1. Prompts/cues 7.2. Cue signalling reward 7.3. Reduce prompts/cues 7.4. Remove access to the reward 7.5. Remove aversive stimulus 7.6. Satiation 7.7. Exposure 7.8. Associative learning
8	Repetition and Substitution	8.1. Behavioural practice/rehearsal 8.2. Behaviour substitution 8.3. Habit formation 8.4. Habit reversal 8.5. Overcorrection 8.6. Generalisation of target behaviour 8.7. Graded tasks
9	Comparison of Outcomes	9.1. Credible source 9.2. Pros and cons 9.3. Comparative imagining of future outcomes

10	Reward and Threat	10.1. Material incentive (behaviour) 10.2. Material reward (behaviour) 10.3. Non-specific reward 10.4. Social reward 10.5. Social incentive 10.6. Non-specific incentive 10.7. Self-incentive 10.8. Incentive (outcome) 10.9. Self-reward 10.10. Reward (outcome) 10.11. Future punishment
11	Regulation	11.1. Pharmacological support 11.2. Reduce negative emotions 11.3. Conserving mental resources 11.4. Paradoxical instructions
12	Antecedents	12.1. Restructuring the physical environment 12.2. Restructuring the social environment 12.3. Avoidance/reducing exposure to cues for the behaviour 12.4. Distraction 12.5. Adding objects to the environment 12.6. Body changes
13	Identity	13.1. Identification of self as role model 13.2. Framing/reframing 13.3. Incompatible beliefs 13.4. Valued self-identify 13.5. Identity associated with changed behaviour
14	Scheduled Consequences	14.1. Behaviour cost 14.2. Punishment 14.3. Remove reward 14.4. Reward approximation 14.5. Rewarding completion 14.6. Situation-specific reward 14.7. Reward incompatible behaviour 14.8. Reward alternative behaviour 14.9. Reduce reward frequency 14.10. Remove punishment
15	Self-Belief	15.1. Verbal persuasion about capability 15.2. Mental rehearsal of successful performance 15.3. Focus on past success 15.4. Self-talk
16	Covert Learning	16.1. Imaginary punishment 16.2. Imaginary reward 16.3. Vicarious consequences

Appendix C. Experiments and Trials

Exp.	Equipment	Summary
1	*VR with Ascension Flock of Birds and MotionStar. G*love tracking. (2005 - 2007)	Three games were made using a combination of the Ogre game engine with the PhysX physics engine integrated into it, and Sense8's WorldUp software. It was shown physically based VR can contribute to an effective post-stroke motor therapy system, which provides realistic and motivating tasks that can automatically adapt to individual patient's capabilities. VR HMD heavy and gloves difficult to put on and use.
2	*Nintendo Wiimote Tracking.* Two Wiimotes with Bluetooth connection to a PC and monitor. (2007)	Several prototypes constructed including a Vibraphone music game in which the player hits the musical bars by moving their handheld Wiimotes to control the virtual hammers. Trial with healthy users (n=10). A majority of users enjoyed the games, each scored 70%+. A majority of users found the control easy to use but at times the sensitivity of the controllers was too fine.
3	*Webcam Games.* PC with DirectShow capability for capturing webcam video images. (2009)	Four casual games in the mode of Sony's PS2 EyeToy games using a webcam to track natural hand motion, and the hand used as a game controller. Experimental focus was on engagement, motivation, and improvement of performance in games. Healthy users and stroke survivors (including a 3-week trial). Results from each of these phases indicate that the games were usable and playable by the participants; results from the 3-week trial showed that the games were also motivating.

4	*Augmented Reality Games.* QR markers on objects for tracking and Vuforia AR SDK. (2010)	Four bespoke casual AR games with webcam tracking of QR marked objects. The same method and experimental procedure as in 3. The 3D games elicited reach, grasp and release movements were presented through three phases including a 3-week trial. Results indicated positive system usability and increased motivation with rehabilitation.
5	*Leap Motion Controller Games.* Leap Motion to sense hand motion. (2013)	Three hand focused rehabilitation tasks: Cotton Balls, Stacking Blocks, and the Nine Hole Peg Test tasks were evaluated by practising physiotherapy and occupational therapists (n=8). Investigating suitability of Leap Motion tracker for rehabilitation. In general, clinicians thought the prototypes provided a good illustration of the tasks required in their practice, and that patients would likely be motivated to use the system, especially young patients, and in the home environment.
6	*VR Game with Sensor Redundancy.* VR ready PC, Oculus DK1, Desk mounted Leap Motion, Myo armband, and Kinect V2. (2015)	This game included a plain room with simple reach and touch tasks for objects in random positions within the room. Healthy adults (n=26) volunteered for single sessions. 77% of the participants commented that their experience using the VR headset was enjoyable and 43% of participants thought that their performance had improved over time. There were no reports of motion sickness. Visual and audio spatial cures helped performance. Only 19% of participants found their experience to be frustrating at times, mainly due to loss of hand tracking. 27% of the participants mentioned that they became fatigued at points during the experiments, which is not necessarily an issue if they get adequate rest.
7	*VR Game with Head Mounted Leap Motion hand tracker.* As above but the Leap Motion tracker was head mounted on the VR HMD. (2016)	Stroke survivors (n=6) who had enough motor capacity and strength to lift their arm from a desk, could follow a two-step command and no underlying separate learning difficulties or arm impairment. Single session per person. Usability scores were quite good, though 75% said they got frustrated with accessing close targets and if tracking of their hand was temporarily lost. Tracking hands of disabled stroke survivors with the Leap depth camera proved challenging. Two participants said that the Oculus gave them better clarity to see the objects. All participants stated that they felt their movement performance had improved with the VR headset. One participant said that VR help her concentrate on tasks.
8	*Full Rehabilitation system.* As above but using the commercial release of the Oculus Rift CV1 and excluding Myo and Kinect. (2018)	The follow-on experiment from 3 and 4 was with healthy users (n=10) with a VR system containing calibration and home areas and three prototype games ahead of our current major trial. Each participant took part in a total of ten sessions over five weeks (two sessions a week. Most users improved performance over time and became accustomed to using VR. Usability scores were high though the HMD became warm and more uncomfortable after a while. Detailed feedback was received about the games, with the more orthodox game, Cannon Grab, being the most popular. The repetitive Fetch game and more complex Knights being less popular.
9	*Magic Glass Rehabilitation System.* HTC Vive & and Oculus Rift with head-mounted	Within the EU Magic PCP project, taking our rehabilitation system TRL 4 (Technology Readiness Level) though to TRL 7. Utilising PACT-B approach (see above) in system design and development and through the current trial (target n=150 post-stroke 0 - 6 yrs.). Through this project 6 new VR environments and 6 new games were constructed based on

Leap Motion. VR ready PCs and laptops, plus custom VR table. (2018 - 2020)	previous experience and ongoing user testing and feedback. The trial is still underway, but the interest in using the system is high as we approach our 90th recruit. The main user comment currently is that they would like more progression in games, and more game alternatives. As they have to play the games frequently, it is easier for them to become bored. We have learned that clear instructions for games are crucial and that balance needs to be struck between providing a tailored rehab programme and facilitating user choice.