Virtual Reality Technologies for Health and Clinical Applications

Eva Brooks
David J. Brown *Editors*

Virtual Reality Games for Rehabilitation

Springer

Virtual Reality Technologies for Health and Clinical Applications

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The series, edited by Paul Sharkey at the University of Reading, UK, comprises four volumes. The first two volumes discuss advances in the field in terms of Physical and Motor Rehabilitation (Vol. 1) and Psychological and Neurocognitive Interventions (Vol. 2). Volume 3 is devoted to Virtual Reality Games for Rehabilitation. Volume 4 underpins the content of Volumes 1 to 3 and is based on the underlying knowledge, expertise, or skills that enable such research and development. Titled Virtual Reality Technology in Health: Design, Technologies, Tools, Methodologies, and Analysis, this volume can be seen essentially as a tutorial guide to the underlying subject matter required to run successful projects. This volume will be highly referenced by the other three volumes and serve as a key technical reference for the interdisciplinary subject as a whole.

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Virtual Reality Games for Rehabilitation

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Introduction

Playing Virtual Reality (VR) games in rehabilitation activities has shown to be effective for improving different kinds of functions, such as motoric in relation to stroke, cerebral palsy, or fibromyalgia syndrome. Such game-based training is considered as motivational and engaging as well as feasible for use in rehabilitation among a diversity of target groups. This book approaches VR from a broad perspective by representing a set of computer-produced images and sounds representing a situation in which a person can take part (https://dictionary.cambridge.org/). Within this broad definition, a variety of games and technologies in rehabilitation settings are considered as VR and include, among others, tabletop games, VR simulations, sensor-based multimodal media technology, commercial games, and serious games systems. Recently, the use and development of both commercial and custom-made VR-based games has increased significantly. This development, together with improved technical performance and accessible prices, supports new attractive game-based solutions for rehabilitation practices (Gustavsson et al., 2021). The use of adaptive, augmented, and game-based environments, as well as multimodal and multimedia interaction tools, are examples of this in different rehabilitation contexts.

The emerging and expanding digital technology solutions are even accelerating at such pace that current technological hypes, such as VR games or Internet of Things, soon can become obsolete. Therefore, we see it as a challenge to explore potentials in new enabling technologies, which require involvement of various disciplines as well as stakeholders across existing disciplines and practices. A current challenge lies in fostering new ecosystems of innovation to harness holistic rehabilitation processes and a development of more inclusive societies.

Including a VR game environment in rehabilitation activities has potentials to create an immersed sense of being in another world separated from reality. Expressed differently, this feeling is often described as experiencing flow, where a person is immersed and focused on the task, forgetting everything else. Movements in VR-based games can also be perceived as more spontaneous and automatic compared to movements in real life, which can be experienced as a positive feeling of being capable in an activity (Csíkszentmihályi, 1996). This is to say that it is pivotal to seriously considering rehabilitation training methods that are motivating and enjoyable (Gustavsson et al., 2021). Motivation and joy are key matters of any training application. For example, direct feedback from a game itself can be important features that can motivate and spur participants to reach beyond the expected.

This book is first and foremost an introduction to a broader, social understanding of designing and using VR games in an era of digitalization. We present some interrelated frameworks that especially focus on the design of game-based applications and on games in use as well as on emerging practices in different rehabilitation fields. Hopefully, we can learn from these examples and get inspired to take even newer steps towards future, democratic, and inclusive solutions of rehabilitation environments including improved designs and uses of VR games.

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References

Cambridge Dictionaries Online. Cambridge University Press. Available from: https://dictionary.cambridge.org/

Csíkszentmihályi, M. (1996). *Creativity: Flow and the psychology of discovery and invention*. Harper Collins.

Gustavsson, M., Kjörk, E. K., Erhardsson, M., & Murphy, M. A. (2021). Virtual reality gaming in rehabilitation after stroke – User experiences and perceptions. *Disability and Rehabilitation, 44*, 6759. https://doi.org/10.1080/09638288.2021.1972351

Sutton-Smith, B. (2008). Play Theory: A Personal Journey and New Thoughts. *American Journal of Play*, 80–123.

Obituary: Penny Standen, Professor of Health Psychology and Learning Disabilities: 1949–2022

Posted by Deborah Kitson in News on Wednesday, 20 July 2022.

It is with great sadness that I have to share the news that Professor Penny Standen, Trustee of Ann Craft Trust, died on 8 July after a brave battle with cancer.

Penny was a supporter of the Ann Craft Trust since its inception in 1992, and she worked with Ann Craft on several research projects. She became a Trustee after her retirement in 2017, and despite her illness she continued in this role contributing and advising on the future direction of the charity until the very last.

Penny was Professor of Health Psychology and Learning Disabilities in the School of Medicine at the University of Nottingham. However, her academic career was nearly over before it began when her car was stolen with the only copy of her thesis on the back seat – in the days before computers. The car and its contents were never found, and Penny had to re-write her entire thesis.

After this unusual start, Penny forged a distinguished academic career, including serving as Head of School of Health Sciences. Throughout her career her main responsibilities were teaching medical students and trainee psychiatrists, supervising PhD students, and carrying out research to improve the quality of life of people with learning disabilities and those who care for them.

A key focus of her research was designing and evaluating information technology for people with learning disabilities and using approaches that involve them in the design process. In this she was helped by the Nottingham International Consortium on Educational Research, a group of people with learning disabilities who provide research consultancy and for whom Professor Standen acted as co-facilitator.

Penny was deeply committed to the lives of people who have a learning disability. She always sought to work *with* – rather than just *for* – people with learning disabilities. In addition to her academic work she was an active supporter of the leaver's group at Shepherd School, now Oakfield, sharing many memorable trips together at international conferences.

Beyond her work, Penny lived a full and varied life. For someone whose PhD was about the behavior of ducks, she imprinted herself on people far and wide. Before becoming an academic she held many different jobs: as a croupier, as a hand model – her hands featured in catalogues holding electrical components – and as a barmaid, where she once served the Kray twins! Penny also loved animals, competing in dressage competitions on her horse "Mrs O" and sharing her home with greyhounds rescued from a life of racing.

Since the sad news of her death, many colleagues within the university and beyond have shared memories of how Penny helped and supported them. Her years of work in medical education meant that during her cancer treatment she would often meet ex-students, many of whom have written on staff noticeboards about how influential she was in enabling them to successfully complete their qualifications.

Many academics across the University and beyond owe their career to Penny's supervision and early career support. The ACT team is grateful for her commitment and contribution to their work. Penny was a great and loyal friend and colleague to so many and will be sadly missed by all.

https://www.anncrafttrust.org/obituary-penny-standen-professor-of-health-psychology-and-learning-disabilities-1949-2022/ (accessed 10/11/2022).

Preface

> I believed that, when most of [the] scholars talked about play, they fundamentally presupposed it to be either a form of progress, an exercise in power, a reliance on fate, a claim for identity, a form of frivolity, an issue of the imagination, or a manifestation of personal experience. My argument held that play was ambiguous, and the evidence for that ambiguity lay in these quite different scholarly ways of viewing play. Further, over the years it became clear to me that much of play was by itself—in its very nature, we might say—intentionally ambiguous (as, for example, is teasing) regardless of [...] general cultural frames. (Sutton-Smith, 2008: 112)

So, what is it to play virtual reality games in rehabilitation activities, then? It is seriousness and frivolity, reality and make-believe, rules and freedom. Within these antinomies lies humans' experience of game play, where dichotomies are resolved through action. A main aim of this book lies in the vital role that practices of games play as drivers for inclusion and participation in everyday, training, and learning activities as well as for new innovations in virtual reality games for rehabilitation. The development and use of both commercial and custom-made games has increased significantly in recent years and have changed the ways we live our lives at an accelerating pace, which has created challenges for implementing them not only efficiently but also in meaningful ways. We can see increased societal interest in well-being, inclusive and equitable quality education, and lifelong learning opportunities for all. Recent years we have also seen a proliferation of concepts and research in game studies, such as serious games, pervasive games, alternate reality games, or playful game design elements for, among others, development of welfare and educational solutions.

This book discusses, and demonstrates, challenges and possibilities in relation to designing, developing, and using games in rehabilitation, both in terms of amplifying abilities and experiences and in terms of establishing inclusive and multimodal design approaches. This is done from diverse and multidisciplinary perspectives, which we mean can carry important potential for developing new knowledge, as well as forms of practice together with new ways of using virtual reality games in rehabilitation.

We would like to acknowledge all researchers that in different ways have assisted in shaping this book. We would also like to direct our sincere thanks to all authors that have contributed to this book. You are all in one way or another colleagues, research partners, and/or like-minded friends. We are grateful for your knowledge, insights, and trust. Last but not the least remains to thank the Springer support staff, especially Pinky Sathishkumar, whose patience and driving meant a lot for the finalization of this book.

Aalborg, Denmark Eva Brooks
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June 2022

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Chapter 1
Games for Stroke Rehabilitation: An Overview

Pratik Vyas, Matthew C. Harris, David J. Brown, and Luke Shires

Introduction

Stroke is the most common disease in the UK with approximately 100,000 strokes every year (Stroke statistics, 2018). The chance of a stroke increases rapidly with age and gender (Patel et al., 2020). Lifestyle choices can also have a significant effect on the chance of stroke. High levels of alcohol intake, smoking, obesity and low levels of physical activity are all considered contributing factors (Rutten-Jacobs et al., 2018). Modern lifestyles are becoming increasingly sedentary, whilst obesity levels are on the rise, leading to increased stroke incidence at a younger age (Kissela et al., 2012).

Stroke is the leading cause of long-term disability (Adamson et al., 2004; Herpich & Rincon, 2020), with a higher disability impact compared to most other chronic diseases. There are estimated to be 1.3 million stroke survivors living in the UK (Stroke statistics, 2018). Stroke is estimated to cost over £45,000 per person in the first year and over £20,000 in subsequent years. The total cost for NHS and social care may be as high as £8.6 billion (Patel et al., 2020).

A stroke occurs when essential oxygen supply through blood to the brain is hindered either by formation of blood clots, causing ischaemic stroke, or by the less common rupture of blood vessel in the brain, called a haemorrhagic stroke (American Association of Neurological Surgeons (AANS), 2022). Blood flow needs to be resumed to normal levels within minutes in order to avoid permanent physiological damage to the brain and other parts of the body. Drugs may be used for the more common ischaemic stroke to quickly clear the clot and restore normal blood flow,

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whilst haemorrhagic strokes are far less common and are more difficult to treat, but surgery may be used to stem significant bleeds. Both types of strokes can result in long-term damage to the brain tissues and the effects can vary significantly between patients. Common symptoms may include altered or damaged sensory perception, reduced motor functions, altered emotional reasoning and damaged cognitive functioning.

Successful rehabilitation following stroke is key to helping stroke survivors regain independence in activities of daily living (ADL), increasing their quality of life. Successful rehabilitation can also allow some survivors to return to work, reducing the economic burden of stroke. Rehabilitation following stroke falls into three stages. The acute phase immediately follows the stroke, whilst the patient recovers in hospital. During the first few days, some brain tissue that was only partially damaged during the stroke may recover; this gives the patient a fast initial recovery rate. After this period, the longer-term impact of the stroke becomes more apparent. Patients are likely to be treated in a dedicated stroke unit and will begin the second phase (termed rehabilitation) as soon as they are physically and emotionally able. The rehabilitation phase is personalised for each symptom of the stroke (Krakauer, 2006). Common areas for rehabilitation include physical, occupational (focusing on daily living activities), speech and vision. Stroke rehabilitation is resource intensive and requires a great deal of one-on-one therapists' contact time. Guidelines recommend a minimum of 45 min therapy per area of treatment for 5 days a week (Intercollegiate Stroke Working Party, 2016). However, UK stroke patients are unlikely to receive more than 2 h of therapy a day during their hospital stay, with fewer therapist face-to-face contact hours compared to other European countries (Luengo-Fernandez et al., 2019).

The third phase is the recovery phase, and it follows hospital discharge where patients may receive therapy by a visiting therapist or outpatient facilities. Allowing the patient to recover at home can provide a more comfortable and relaxed rehabilitation setting. Therefore, early supported discharge (ESD) aims to quickly get patients from hospital back into their home setting. Being in the home may also help the patient focus on recovering the abilities they require the most for their day-to-day interaction with the environment. Evidence suggests that patients who undergo ESD have improved scores on the activities of daily living scale (Rodgers & Price, 2017). However, in the recovery stage, the daily contact time with a therapist is significantly reduced. To overcome the limitation of therapist contact time, patients will often be given a schedule of exercises and repetitions to perform independently every day. Undertaking a high number of exercise repetitions can be tedious and patients may not adhere to them over time. According to Alankus et al. (2010), "only 31% of patients perform the exercises recommended by their therapists". Furthermore, the only record of exercise dosage is that which the patient reports to the therapist.

The post-recovery phase begins when the patient has regained normal functionality, or their recovery rate has plateaued. Most survivors would be expected to reach this stage at around 3–6 months post-stroke. Survivors who have not regained full motor function may have to make lifestyle changes to accommodate their new reduced physical capabilities; many will be dependent on a carer for help with activities essential for daily living. Depression and low motivation is common in stroke survivors as the debilitating effects of the stroke are sudden and can often cause a significant change in a person's life (Fitzsimons et al., 2020). However, research suggests that long-term rehabilitation can be helpful to recovery, both physically and mentally (Luengo-Fernandez et al., 2019).

Whilst the long-term effects of a stroke differ between patients, motor deficits are extremely common and found in most stroke survivors. Motor impairments following stroke are mostly caused by the damage and loss of neural pathways in the brain that control specific joint movements, and the patient may re-learn the lost limb movements by building new neural pathways through repeated exercising (Galeoto et al., 2019). Rehabilitation exercises are designed to encourage a specific set of joint movements, usually the joints that have reduced motor control following the stroke. Because these joints are much more difficult to use, patients can often use compensatory movements, underusing or incorrectly moving their impaired joints to quickly regain functionality. This is generally bad in the long term, and by using compensatory movements, they will not recover and may lead to a non-functioning arm through learnt non-use. Compensatory movements can be unnatural and can lead to strain or injury. As stated by researchers (Wee et al., 2014), "Compensatory movement behaviours may improve upper extremity function in the short-term but be detrimental to long-term recovery". It is therefore important to recognise compensatory movements and provide feedback to the patient during rehabilitation.

Technological systems are used for stroke rehabilitation without the requirement of face-to-face therapist contact, increasing the total amount of available guided therapy time to the patient. Low invasive technologies are deployed in the home (Burke et al., 2009; Brusco et al., 2022), which reduce the requirements for travel to outpatient facilities and allow rehabilitation to continue in a relaxed setting that may be more comfortable to the patient. It allows a patient to continue rehabilitation independently, and by doing so, patients could enter ESD sooner. Further, gamification has shown to have become an important part of these technological solutions and provides a source of engagement and enjoyment. These technological solutions exist on a spectrum from fully mechanical orthoses, e.g. custom fabricated orthoses (Stuck et al., 2014), to fully virtual digital solutions (via an immersive head-mounted display). Mechanical devices are cheaper and can be custom built for any rehabilitation exercise through the use of weights, sensors, levers, etc. However, they require more physical space to store and need to be initially installed and regularly calibrated and provide set functions to the user with limited scope of diversification in exercise. On the other hand, virtual technologies for rehabilitation have evolved a lot in the last decade reducing the barriers to recovery (Galeoto et al., 2019).

Whilst both mechanical orthoses and virtual digital technologies provide a variety of benefits, this chapter focuses on the impact of virtual technologies on stroke rehabilitation. VR is a broad term used to describe a spectrum of systems from non-immersive to fully immersive technologies. Non-immersive virtual environments encompass technologies that usually comprise a 2D environment and provide for an experience of an outsider watching in (like watching television, computer screen, etc.) On the other hand, immersive virtual environments are systems where the users are fully integrated into the environment (often using a head-mounted display). Both kinds of system can allow the user to interact with the virtual environment through tracking the user's movement and by the use of embedded sensors. Such systems might track the user's rehabilitation exercises and use this to provide key feedback and even motivate and entertain them through gamification. In addition to this, further techniques in machine learning are evolving to create personalised gamification experiences during rehabilitation exercises. However, compared to specially built orthoses, commercial off-the-shelf (COTS) VR systems tend to be aimed at the gaming market, rather than at rehabilitation use cases. An exception to this is the GestureTek IREX (GestureTek Health, n.d.), which comes packaged with games that can be customised to the patient's needs. Therefore, this chapter explores the aspects of virtual technologies that can be of advantage to the process of stroke rehabilitation whilst recognising the present challenges and weaknesses present in these systems (Stuck et al., 2014; GestureTek Health, n.d.).

Independent Use

As previously stated, when performing exercises independently, patients may not always perform them correctly. This may happen through compensating for the lack of motion in one joint through moving another (Alankus, 2011). Current thinking in motor learning also suggests that frequent shorter therapy sessions with breaks may potentially be more beneficial to the patient as they promote memory recall (Dobkin, 2004). "Telerehabilitation" is a potential solution that allows rehabilitation to take place over the Internet, allowing the therapists to review the patients' exercises as they complete them at home. In such settings, the therapist can monitor multiple patients at the same time. However, this still requires therapist time and does not guarantee that patients will not compensate during practise outside of these sessions.

Mitigating compensatory movements is currently an open problem but could be solved as technology to track patients' movements becomes more sophisticated. For example, Sarsfield et al. (2019) have developed and evaluated an algorithm capable of segmenting exercise repetitions in real time, enabling responsive feedback for the user. This was possible using a single consumer-level depth sensor and could be used as part of a larger system to give feedback to the patient on their exercises. Further, VR-based therapy has shown promise in having a positive effect on patient recovery with Laver et al. (2017) reporting that VR therapy had shown to be as effective as conventional therapy for improving upper limb function within their study criteria. Artificial intelligence and augmented reality-based solutions are now aiding the creation of virtual technological systems that provide similar services as a therapist. Such digital virtual therapists can help patients and overcome the problem of compensatory movement in stroke patients in non-supervised settings. Thus, virtual technological systems have great potential for independent use, helping patients to achieve the high volumes of repetitive exercises needed for recovery, reducing costly therapist time.

Lewis et al. (2011) present a study attempting to analyse results from patients' perspectives rather than purely clinical statistical methods. Patient feedback identified one particularly interesting suggestion for future directions. The suggestion from the patients was that the virtual technological systems should continue to be developed for use in homes and not just the clinical settings like labs. This is because the patients wanted to continue with community-driven social interaction that they received in clinical settings. This suggests that if virtual technologies are to be used in home settings, social aspects are just as important as the games themselves. Player interaction in commercial games, where Internet-based social gaming has long been established, could form a key area for investigation when applying virtual technologies for stroke rehabilitation. The patient may live alone and can benefit from online community participation. Thus, independent use of a virtual technological system is also important when considering its suitability for use in a home setting (Alankus, 2011; Sarsfield et al., 2019; Lewis et al., 2011).

Home Deployment

Many virtual technological systems use varying novel motion capturing technologies that can have certain environmental constraints, limiting the types of settings and locations that they can be successfully deployed in Laver et al. (2017), and Dobkin (2004). This is particularly important if the goal is to create a home-based recovery system as a clinical setting may allow tighter control over the environment. The following is a list of the key environmental variables that should be evaluated when considering a system's suitability for home use.

- Space requirements for any hardware: A contained system may require its own display device, peripherals and a desk or workspace to set up the equipment. It may not be physically or technically feasible for the end user to set up and take down the system for every use, so the system would take up a permanent space in the environment.
- Space required for usage: Commercial off-the-shelf (COTS) systems, such as game consoles, that take up relatively little hardware space but require a larger area when in use. How much space is required to safely use the device when it is in operation remains dependent on the app being used. Similarly, issues of safety that can result from a user being immersed in the environment remain a concern.
- Required lighting conditions: A variety of tracking methods have been demonstrated to have potential in this application of stroke rehabilitation. Lighting level and colour may affect recognition software and intensity of sunlight could also interfere with the infrared tracking devices that are associated with systems that utilise tracking.

- Cost of the hardware: Beyond the initial development cost, widespread use of the device will have an associated unit cost. The system may also require additional displays, speakers, etc. Integration with displays that may already be present in the home, such as a television, should be considered.

As some studies have already considered the application of COTS video gaming systems for applications in stroke therapy, these systems should set a benchmark for home use as they are designed specifically with this scenario in mind. Whilst what was historically thought of as a COTS game is of little interest for rehabilitation use, there has been a trend towards motion-controlled gaming. These same systems can be used to support remote rehabilitation solutions. The systems that are proposed for stroke rehabilitation should follow the principles of usability. For example, the system must be easy and intuitive to start up and use, especially by non-technically aware patients. It must be completely usable by those with poor limb coordination and motor control, which is challenging due to diversity of ability that different stroke patients present with. Similarly, using the system for rehabilitation, the user must be able to effectively start and stop the system when required and be able to navigate and use all system menus. COTS have a potential downfall in this regard as commercial game consoles can have relatively complex start-up menus before a game can be started. Patients would have to learn to use and navigate these. For bespoke built systems, this is less of an issue, as menu systems can be streamlined based on user feedback and adapted as required. However, no study has yet been found that investigates patient proficiency in starting and using the menu systems of VR rehabilitation systems, as well as focusing on the effectiveness of the rehabilitation aspects.

Marker-less vision systems are of interest as they don't require the user to physically interact with devices. This feature has some advantages as patients with different levels of manual dexterity may not be able to pick up or manipulate all controller peripheral devices. Investigation with the Microsoft Kinect also provides individual hand tracking that does potentially allow for more complex interactions and clinical tracking of the patient's recovery. Sensor-based systems require the user to pick up and manipulate an object that contains one or more sensors that can be tracked. Research using COTS such as the Nintendo Wii fall into this category as the patient interacts with the game by using the Wii Remote. Studies investigating the rehabilitation potential of this system have shown that holding and manipulating the sensor device can be difficult at times for patients (Alankus et al., 2010). The Wii Remote is a relatively complex device, with buttons on both sides that can be hidden from view or accidentally pressed when used. Also the patient is required to keep a closed hand to avoid dropping the device; therefore patients with low hand and arm strength may struggle to do this for an extended period of time. A system where the user is required to pick up a basket with an attached sensor has been presented (Ma et al., 2007). The system is only able to detect arm movement, but it still requires grab and hold movements from the patient so this kind of sensor-based recovery may have advantages in promoting exercises beyond gross arm movement.

Engagement

One of the main justifications of using games for stroke rehabilitation is the potential for games to aid in many encouraging ways (Alankus et al., 2010). The fun aspect and engaging environment that games create is likely to encourage the patient to continue their rehabilitation, even if the activities are perceived as repetitive exercises. However, this is a huge generalisation of the very broad field of games. Some virtual games can promote high levels of engagement and encourage players to use them for hours on end. Additionally, the sheer variety of virtual games developed in the last decade means there is a greater choice of available virtual games to treat each patient's mobility and rehabilitation needs. Some new emerging social games make use of time-based strategies encouraging players to periodically revisit the game. Therefore, there is a need to explore the key concepts in game design and how these can help in the context of stroke rehabilitation.

In a seminal analysis, Csikszentmihalyi (1978) describes some important features for intrinsically motivating activities:

1. The activity should be structured so that the actor can increase or decrease the level of challenges he is facing, in order to match exactly his skills with the requirements for action.
2. It should be easy to isolate the activity, at least at the perceptual level, from other stimuli, external or internal, which might interfere with involvement in it.
3. There should be clear criteria for performance; one should be able to evaluate how well or how poorly one is doing at any time.
4. The activity should provide concrete feedback to the actor, so that he can tell how well he is meeting the criteria of performance.
5. The activity ought to have a broad range of challenges, and possibly several qualitatively different ranges of challenge, so that the actor may obtain increasingly complex information about different aspects of himself.

An alternative framework has been produced, with each section explained in detail (Malone, 1981) (Fig. 1.1).

Researchers Burke et al. (2009) have identified two principles of game design that they believe to be relevant to rehabilitation games, the main points of which have been condensed below:

Meaningful play:

- The player should be able to perceive how their actions affect the game.
- Use of feedback to show how their actions have affected the game. Feedback can be conveyed orally, visually and/or haptically and be in the form of achievements, graphs, scores, etc. as well as in-game incentives, such as new skills or game elements. These incentives can increase motivation and provide a desire to complete tasks.
- It is mentioned that in COTS games, players exhibiting poor gameplay are expected to be penalised in some form to encourage them to learn from their

- **I. Challenge**
  - A. Goal
    1. Personally meaningful goals
    2. Obvious or easily generated goals
    3. Performance feedback
  - B. Uncertain Outcomes
    1. Variable difficulty level
       - a. Determined automatically
       - b. Chosen by learner
       - c. Determined by opponent's skill
    2. Multiple level goals
       - a. Score-keeping
       - b. Speeded response
    3. Hidden information
    4. Randomness
  - C. Toys vs. Tools
  - D. Self-esteem
- **II. Fantasy**
  - A. Intrinsic and extrinsic fantasies
  - B. Cognitive aspects of fantasies
  - C. Emotional aspects of fantasies
- **III. Curiosity**

  Optimal level of informational complexity

  - **A.** Sensory curiosity

    Audio and visual effects
  - **B.** Cognitive curiosity
    1. "Good form" in knowledge structures
       - a. Complete
       - b. Consistent
       - c. Parsimonious
    2. Informative feedback
       - a. Surprising
       - b. constructive

Fig. 1.1 Framework for a theory of intrinsically motivating instruction. (Adopted from Malone, 1981) mistakes; by not including incentives for successful gameplay, the player is less likely to engage effectively with the game. However, in the case of rehabilitation games, it is recommended to handle failure more conservatively, with the initial goal to be engagement and thus reward all engagement with success; the difficulty should be paced so failures do not catastrophically affect the flow of the game and handled in a positive manner to keep the patient engaged and motivated.

- Providing a virtual representation of the patient has been positively received by stroke patients as it allows instant and continuous visual feedback. Any interactions with game elements should be clearly presented, such as highlighting the item, playing a sound, etc.
- It is common to use scoring mechanisms as a means to observe improvement over a period; it may be beneficial to reward the player for range of movement or time engaged in play, etc.

Challenge:

- A new player generally desires a low level of challenge to meet their low level of ability/familiarity with the game.
- Many games use levels to structure difficulty requiring the player to reach the necessary skill to advance to the next level, which may build upon skills learnt in previous levels or require the acquisition of new skills to complete.
- Another approach to maintaining a level of challenge is to dynamically adjust the difficulty based on the performance of the player.
- An approach taken by a physiotherapist to maintain challenge is also described: "A physiotherapist will usually begin by conducting a series of assessments (e.g. Action Research Arm Test, Motricity Index, Line Cancellation Test) to ascertain both the person's physical and cognitive abilities – these will provide data on, inter alia, the person's grip and pinch strength and gross movement in the affected limbs. Informed by this data, the physiotherapist will then devise a set of tasks for the person to practise. The physiotherapist typically works closely with the person with stroke, monitoring engagement and progress. As the rehabilitation continues over a period of weeks, the physiotherapist can increase the difficulty of the tasks to ensure that an optimum challenge is presented to the user". This approach corresponds to the third bullet point of the challenge table as the difficulty of the tasks is adjusted based on the patient's performance.

However, there is a need to explore these key concepts further in the context of stroke rehabilitation. An activity is said to be intrinsically motivational if there is no obvious external reward associated with the activity (Malone, 1981). A game might be played because it is engaging, rather than because there is any reward for playing it. Conversely, an extrinsically motivated activity is one that leads to a reward such as money or food. In cases where a game is being designed for stroke rehabilitation, the activity could be both intrinsically and extrinsically motivating.

Engagement Using VR Vs Conventional Therapy

Unlike traditional regular physical therapy with simple physical equipment, a gamified approach (which could use virtual/augmented reality or motion control systems) has the potential to be more intrinsically motivating (if designed correctly). Simply using VR is unlikely to be more motivating than conventional therapy if the software deployed on the system does not conform to the features described by Csikszentmihalyi or Malone (above).

Further work on this subject (Westera, 2015) discusses both the extrinsic and potential intrinsic motivating factors in serious games. It is identified that extrinsic reward systems are associated with shallow learning rather than deep processing (Habgood & Ainsworth, 2011); this may mean that when serious games are used with stroke patients, compensatory movements may be used to “cheat” with regard to performing the exercises correctly to get to the reward faster. If extrinsic reward systems are used, they should be relevant to the tasks at hand. If these issues are carefully considered, serious games have the potential to be motivating for stroke patients. Motion-controlled interactive games (such as the Kinect or Wii) or headset-based AR/VR technologies have the potential to be used in conjunction with gamification approaches. These interactive technologies encourage the physical activity needed for rehabilitation whilst also having the potential to deliver the motivational benefits of gamification. In addition to this, they can provide environments with a high level of control of the parameters for each user (Johansson, 2011). Laver et al. (2017) and Domínguez-Téllez et al. (2020) conducted systematic reviews and found that VR interventions can be effective when used in conjunction with conventional therapies.

Feedback to Patients

Burke et al. (2009) discuss two principles of game design for creating what they refer to as “meaningful play” and “challenge”. “Meaningful play” differentiates game-based rehabilitation from regular physical therapy in that game-based approaches should relate the user’s actions to the system’s outcome. Regular physical therapy may not provide the user with direct feedback on their progress developing their skills. Digital game-based feedback could be in the form of numerical scores, progress bars, etc. These elements can motivate users to continue playing. In addition to positive feedback, negative feedback and failure are often used in successful commercial games. Burke et al. (2009) argue that the goal of a game designed for rehabilitation should be to reward all engagement with success. Stroke survivors might not be familiar with games, so they may not engage with the game if the reward mechanism involves punitive measures.

Another factor to consider is the difficulty of the game and “Challenge” that users face: A stroke patient will get bored if they do not feel sufficiently challenged. If the challenge is too difficult, they will become frustrated. Stroke survivors may have more difficulty in interacting with the game if their symptoms are more severe. Rand et al. (2004) found that commercial motion-controlled games had potential for use with stroke survivors, although they found that many of the games were too fast paced for many of the participants. This has changed in recent years and many more options are now available (Laver et al., 2017). Therefore, the best approach may be games designed with stroke survivors in mind, with support for different levels of severity.

An approach to support stroke patients suffering symptoms of differing severity is to use dynamic difficulty adjustment (Hocine et al., 2015). This is where the game dynamically adjusts to the user's abilities and performance within the game.

Evaluating Engagement

There are several ways of evaluating a game design with regard to engagement and motivation. Brockmyer et al. (2009) developed a questionnaire and analysed the data with Classical Test Theory and the Rasch rating scale model (Snyder & Sheehan, 1992) to quantify a player's absorption, flow, presence and immersion to determine their level of engagement. A more recent study by Rogers et al. (2020) recorded brain activity using electroencephalography (EEG) to determine a player's engagement in real time whilst using a tabletop VR system. This was correlated with presence questionnaire scores. The suggestion that simply using games to encourage patient engagement needs careful evaluation. Whilst stroke is more common in the elderly, all age groups, genders and personality types can suffer a stroke. So, creating a single experience that promotes high levels of engagement in a wide range of patients would be challenging. Furthermore, maintaining engagement would be a challenge considering that game therapy must be started early on in the rehabilitation process and continue beyond the traditional 6-month recovery period. A major shortcoming evidenced in current literature regarding the application of games for stroke rehabilitation is that most studies tend to be relatively short term (Laver et al., 2017). This does not give a meaningful insight into how engagement and enjoyment changes over time. Usually, any evaluation takes the form of asking the participants to simply comment at the end of the study on whether they enjoyed the games or not.

The second issue evidenced in the current literature from this perspective is that most studies are focused, justifiably, on measuring the effectiveness or feasibility of using the technology surrounding games for rehabilitation. Studies of effectiveness are important to identify if game-based systems have any scope for rehabilitation; therefore it is natural that they would precede studies focused specifically on the design of games for stroke rehabilitation. Whilst the potential for different technologies to be used for rehabilitation is an important issue, if they are to be used to drive game-based experiences, more advanced game design principles will have to be employed and investigated. This currently seems to be the missing step required to move these systems away from technology-driven prototypes and into patient-focused systems for rehabilitation (Galeoto et al., 2019).

An important stage in determining the level of engagement is to compare stroke survivors' playing experiences to those of a non-impaired group. Measures of presence and enjoyment were recorded in three groups of players using two games built for the (now obsolete) COTS gaming system, the PlayStation EyeToy (Rand et al., 2004). These included a healthy young group who closely matched the system's target market, a group of healthy elderly players and a group of seven stroke survivors. The results raised two points of interest. Firstly, that the results for engagement, enjoyment and exertion are largely similar between the healthy young and elderly groups, all scoring highly. The player performance is identical for the Wishy-Washy game, whilst the younger group performed significantly better at the Kung-Foo game. Despite the better score in this latter game, it does not seem to have created any significant difference in enjoyment between the two groups. This suggests that the novel interface method and simple game design could allow greater accessibility for groups that would not traditionally be interested in video games.

The second point is that when looking at the stroke survivor group's levels of engagement and enjoyment, these are significantly higher than both healthy groups. The stroke survivors rated both games 5 out of 5 for enjoyment whilst giving a Scenario Feedback Questionnaire (SQF) score of 27 out of 30. This is even more fascinating when comparing the stroke survivors' scores to the other groups. Even though stroke survivors scored lower points in the game, they were still engaged with it. Clearly there are some unique attributes of the stroke survivor group that explains these high levels of engagement compared to the healthy groups. It is suggested that because the players understand the therapeutic value of the games, they are simply happy to engage in any activity that will help recovery, although at the time of the study it was unknown whether there would be any therapeutic benefits. This might indicate that patients were simply willing to engage hoping that they would benefit.

Designing games for people with a physical disability will also surely present some unique challenges. Making commercial games accessible for disabled users is an area that has been largely ignored in the past according to some researchers (Schrier & Gibson, 2011). In recent years there has been some drive to promote accessible design (Paiva et al., 2021). A previous study has provided an adaptive challenge level to keep the game within the limits of the patient's capability whilst maintaining interest (Burke et al., 2009). Unfortunately, this study only tests the player's engagement with the games developed specifically using these suggestions. This gives absolutely no basis for comparison to games that do not make use of these design ideas. Therefore, it is very hard to weigh up the merits of each suggestion. It should be mentioned that modern game design has already adopted all these ideas in current commercial games, highlighting the need to properly apply modern game design theory from the commercial sector in games for rehabilitation.

In summary, the review of the state of the art so far indicates the following emerging trends:

- Intrinsic motivation of games may not be the driving factor for stroke survivors who want to engage with them.

- Stroke survivors are a large and varied population. Therefore, a one-size-fits-all approach to game design might not be appropriate.
- Although there are some studies (Alankus et al., 2010; Tamayo-Serrano et al., 2018) that investigate what types of games would be of interest and engaging to stroke survivors, research in this area requires further analysis. Particular exploration of emerging markets such as Facebook games that are popular amongst the non-traditional gaming demographic should be investigated.
- Tracking recovery information to give meaningful feedback could be an important motivator for patients and may reinforce the actual reason they are engaging with the game.
- Social aspects present in recreational therapy (RT) provide important motivators for participation and may help fulfil patient needs beyond recovery.
- Borrowing social mechanics from commercial games should be investigated. Games that allow patients to socialise outside a clinical setting could provide more reasons to participate.

Control over the Parameters

In terms of physical interaction with devices, two categories emerge, each with its own advantages and disadvantages. Vision-based systems rely on camera devices and tracking algorithms to detect motion from the user and sensor-based devices, where the user must physically hold and manipulate a sensor device. A second category of marker-based vision systems has been identified in the past, although due to advancements in computer vision technology, these no longer have any significant advantages.

Both kinds of VR system provide the benefit (over mechanical systems) of allowing a practitioner to adjust the parameters in the game to patients' needs. Since the effects of stroke differ between patients, a patient might find an activity too difficult and become frustrated. In the same way, another patient might find an activity too easy and become bored (and also not see any improvement in their condition). A trained practitioner could adjust the types of exercises and repetitions to avoid this. This was an approach adopted in a previous study (Alankus, 2011); games focusing on arm movements were chosen based on a set of exercises that a therapist would have recommended as part of standard therapy. This resulted in the participant experiencing improvements in their ability to use her affected arm.

Control over parameters has developed in the domain of games for stroke rehabilitation. An early example has been the vision-based system applied in the PlayStation EyeToy. This consisted of a low-cost camera peripheral connected to a PlayStation 2 game console. The device was only able to sense motion by looking for changes in pixel values between frames. It also allowed for playing whilst seated, essential for many stroke patients with mobility problems. The EyeToy is now discontinued, and buying an EyeToy and PlayStation 2, as well as the accompanying games, proved to be very expensive with advent of better technologies. However, if we were to consider using the lessons learnt to build a similar bespoke device, a simple colour camera provides key advantages. Significant costs will likely come from what kind of computational device will be used to perform the games processing and if any display equipment is also required.

Following EyeToy, commercial technological devices like the Microsoft Kinect for Windows became available. This camera-based device with primary input consists of infrared light projected depth sensors that allowed the device to work regardless of ambient room lighting or even in complete darkness. The Kinect for Windows and official SDK provided the ability to develop bespoke applications and therefore overcome the disadvantages of COTS games for stroke rehabilitation. The Kinect consists of two raw visual streams of data. The first is an RGB image and the other is a depth image; this is similar to an RGB image, but instead of encoding the colour value at each pixel, a greyscale value based on the depth is stored. These data streams can be used to implement tracking algorithms to detect users, objects and actions. The depth stream has some advantages over conventional colour-based tracking as the difference in depth value makes background segmentation much more straightforward. Microsoft's SDK also has a built-in skeletal tracking algorithm that outputs a series of joint positions and orientations. However, following the commercial discontinuation of the product, development of the technology has slowed.

The technology of skeletal tracking used by Kinect remains appealing, providing joint positions and orientations in real time; the tracking as applied in Kinect did however have some disadvantages; specifically, the skeletal joint estimations are not always accurate and jitter can occur, especially when occlusion occurs between the camera and the joint. For the hand it currently only detects three locations, centre of hand, tip of hand and tip of thumb, but Microsoft has demonstrated a fully articulated hand-tracking algorithm (Microsoft Handpose, 2014) that may be released to the SDK in the future. Currently, unless bespoke hand-tracking algorithms are created, the default tracking is unable to track useful grabbing and fine motor control gestures. The Kinect SDK provided a seated tracking mode as well as standing (Fig. 1.2). This could be useful for tracking patients that are unable to stand unassisted and allows them to perform upper limb rehabilitation in a seated position.

To overcome the drawbacks of the commercial technologies at the time, Pareto et al. (2011) used a desktop-sized workbench environment that could be set up in a patient's home who required no more intervention. The workbench is connected to the Internet so a therapist can monitor the patient's performance from a distance. The desktop-sized workbench is relatively low in space footprint and requires no maintenance from the patient. The system uses a large amount of specialist hardware, with stereoscopic display used for a game display, a standard display for telecommunication with the therapist, a robotic haptic stick for 3D space tracking and force feedback and an electronic Grip-it device, used to measure the grip force of patients. As specification of each hardware item is unknown, a real price cannot be calculated, but the cost is certainly significantly higher than COTS and low-tech systems.

The Nintendo Wii was another commercial gaming system that was designed with motion input as the primary form of interaction rather than a secondary add-on