Designing engaging, playable games for rehabilitation

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ABSTRACT

Stroke is a leading cause of severe physical disability and can result in of a range of impairments, including loss of balance, attention and concentration deficiencies, pain, weakness and paralysis. This paper reports on the design of serious games for upper limb rehabilitation following stroke. In particular, we focus on identifying principles of video game design which are important in the context of rehabilitation and show how these principles can be implemented. We also report on an evaluation of the games for playability, usability and engagement.

1. INTRODUCTION

Stroke is the leading cause of long-term disability; the World Health Organisation reports that annually some 5 million people are left permanently disabled through stroke. Stroke can often cause severe physical disability such as attention deficiency, pain, weakness and paralysis, often on one side of the body. Many hospital-based rehabilitation programmes focus on rehabilitation of the lower limb, in order to promote mobility. Our interests lie in rehabilitation of the upper limb (hand and arm), which can remain weak in up to 66% of stroke survivors. It has been shown (Wade *et al*, 1985) that early and intensive practice of active functional tasks in an enriched environment show more positive outcomes for upper limb rehabilitation. Patient motivation has also been recognised as important for therapeutic outcome and many studies have consistently linked motivation to better therapeutic outcomes (Maclean *et al*, 2000). Motivation is, however, a complex subject which has been shown to be linked to both personality traits and the social environment (Maclean *et al*, 2002).

Recently there has been a great deal of interest among health professionals in the use of computer games for rehabilitation. Video games have long been known to be engaging to play, with gamers often playing for hours at a time, seemingly unaware of the passing of time. If rehabilitation games can be created which exhibit similar high degrees of engagement it is possible that therapeutic outcome will improve. Recently, companies such as Sony and Nintendo have developed commercial games combining entertainment with exercise – for example, the Sony Eyetoy games and Nintendo Wii Fit. Research has indicated, though, that people with motor function problems can have problems playing commercial games out-of-the-box (Rand *et al*, 2004). This raises the prospect of games being designed specifically for rehabilitation.

A number of systems have been reported which use virtual environment technology for various rehabilitation applications, including phobias, post-traumatic stress disorder and motor function (upper and lower limbs). Some of these have used virtual reality technology to immerse the user in the virtual environment; others use standard display technology (computer monitors and TVs). Technology to track the user’s movements is also common, particularly for motor function rehabilitation. The tracked data is often used to drive a graphical representation of the user or part of the user in the virtual environment, enabling the user to achieve a high degree of control and impact onto the virtual world. What the user does in the virtual world is clearly dependent on the rehabilitation objectives. Activity can be structured around a simulation of conventional functional-based tasks or be more game-like, where the functional tasks are couched in the

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context of a game. Several reviews have reported on published work in this area and we refer the reader to (Sveistrup, 2004) and (Weiss *et al*, 2004) for further reading.

While a number of bespoke rehabilitation systems have been built which use games to present the activity to the user, there has been little discussion of the key principles of game design that are important for this context. The aim of our work is to identify core game design principles for rehabilitation and realise these in a collection of games for rehabilitation of the upper limb motor function. In this paper we review our ideas for rehabilitation game design and detail the implementation of one of our games for upper limb motor function rehabilitation. Further, we report on the evaluation strategy for our games, focusing on playability, usability and engagement. The paper is organised as follows. In Section 2 we discuss a number of video game design principles important for rehabilitation. Section 3 details the implementation of one of the games developed by our group. Section 4 reports on evaluation of the games and conclusions appear in Section 5.

2. GAME DESIGN THEORY, ENGAGEMENT AND REHABILITATION

Video games are renowned for their ability to provoke high levels of engagement amongst game-players and Rizzo and Kim (Rizzo *et al*, 2005) suggested that the designers of rehabilitation systems could benefit from analysing the principles of game design. It has been reported that users of rehabilitation games enjoy game-like challenges (when they are present) and it would seem that these are perhaps easier to create in computer-based intervention than in traditional rehabilitation. This enjoyment may translate to improved engagement and self-motivation which are recognised as important for adherence to a programme of rehabilitation therapy. Other work in this area includes that of (Goude *et al*, 2007), who proposed a conceptual model that supports game idea generation, task design and categorisation of existing games in relation to stroke rehabilitation, but only a subset of the taxonomy is published. (Flores *et al*, 2008) criticised existing gaming scenarios for rehabilitation for being designed solely to test the overall functionality of the interface hardware and suggested that more attention needs to be given to supporting motivation for active participation. (Colombo *et al*, 2007) suggested that the difficulty level of the motor task, the awareness of the performance obtained and the quantity and quality of feedback presented to the user can influence patient motivation.

In (Burke *et al*, 2009) we identified three principles of game design which we feel have particular importance to rehabilitation: *meaningful play*, handling *failure* and setting an appropriate level of *challenge*.

Meaningful play emerges from a game in the relationship between a player’s actions and the system’s response. Central to creating and maintaining meaningful play is the concept of *feedback*, the methods by which the game responds to the changes or choices made by the player. Feedback can be aural (sound effects, verbal dialogue), visual (text, images, score indicators) and haptic (vibration). It is important that a user of rehabilitation games is aware of their progress towards goals (short-term and long-term) in order to achieve effective engagement.

A game responds to player actions in order that the player is aware of the impact of their actions on the game world. In this way the game encourages the player to learn what actions result in progress through the game and what actions do not. Feedback has particular importance for rehabilitation, where the concept of progress through the game may differ from that in traditional video games. Failure, for example, has always been a prominent aspect of video games, not only present but expected by players – players are often given a number of ‘lives’ which represent the number of chances they have to complete a task without dying. Failure to complete a task within this number of lives may result in “game over”, meaning the player has to start the game (or game level) from the beginning. For motor function rehabilitation games, where the affected limbs are being mobilised, there is a risk that if the player were to experience failure during their initial play, they may attribute this failure to poor motor function and this could result in poor game engagement. Clearly this needs to be tested with users, but we suggest that failure in rehabilitation games should be handled conservatively – since engagement is a pre-requisite for positive therapeutic outcome, *all* engagement should be rewarded, at least initially. By handling failure in a positive way players may be more likely to remain engaged with the intervention. This does not mean that the game shouldn’t offer challenge and drama, since these are important reasons for games being engaging in the first place.

The level of *challenge* a game offers a player is a major influence in how engaging the game is to play. Previous work has reported that users of rehabilitation games have difficulty with COTS games where the level of the environments cannot be graded (Rand *et al*, 2004). The range of motor function among people with stroke, for example, varies greatly and what might be easy for one person is impossible for another. For optimal engagement, games should present an ideal level of challenge for each individual player; neither too difficult that it becomes frustrating, nor too easy that it becomes boring. Traditional video games have different ways of varying challenge for players. Prior to commencement, games often ask players to select a level of difficulty, for example: easy, medium, hard, insane. This determines the pace of the game, number of enemies, number of opportunities for the player to acquire health or weapons etc. In motor function rehabilitation games the initial configuration will affect the pace, size of game elements, distance from user, etc. While data acquired from standardised assessment tests prior to game-play may help in understanding the patient's level of motor function, it is difficult to map values from these tests directly to game configuration. We have developed a configuration tool as part of our library of games where the user's range of movement is assessed using the same interaction technology as used to play the games. Data from this tool is then used to position game elements so that they are all initially reachable by the user on start-up. As the game progresses, the game adapts the challenge dynamically by changing the pace and game element positions and size, as described earlier.

As the game progresses, players will often face levels of increasing difficulty, designed to present more of a challenge as they become more familiar and skilled with the game. In commercial games, completing a level is possible only once the player understands enough of the game mechanics and has acquired the necessary knowledge and skills (including controller skills) to progress through the level to the end. Other games may not have recognisable levels as such, but the challenge might increase as particular points in the game are reached, indicating that an appropriate level of understanding and acquisition of skills has been achieved. We have investigated the use of adaptivity to automatically control the game difficulty, by altering programmable elements of the game in response to the performance of the player. For players that are struggling, the pace of the game slows and game elements become larger and easier to reach. On the other hand, for players that are coping easily with the challenge, the game speeds up, game elements become smaller and harder to reach.

3. VIDEO CAPTURE GAMES FOR STROKE REHABILITATION

Our group has designed a number of games for upper limb rehabilitation post stroke, using the principles described above. The games use a low-cost webcam to capture player movements and image analysis software to track the hand. All software was written in C# in Microsoft's XNA framework. Four games were designed in the arcade style (i.e., short, easy to learn). Two were one-handed games, where the affected limb was used to play; a third game was two handed and a fourth game was also two handed but required the hand movements to be synchronised. The user, wearing a different coloured glove or mitt on each hand, faces the computer monitor, where his/her image appears in the background (behind the rendered game elements). The different coloured gloves allow the software to track each hand's movements. To play, the user touches a game element (sprite) with either one or both hands, as appropriate for the particular game. All the games are adaptive – they get easier or harder depending on the performance of the player. To illustrate how the game design principles discussed in Section 2 were applied we discuss the design of one of the games in detail. Details of the other games can be found in (Burke *et al*, 2009) and videos can be seen at this link: *http://www.vimeo.com/4279126* . Appendix A shows screenshots of the configuration tool and the games.

In *Bubble Trouble*, a game designed to improve gross movement of the upper limb, virtual bubbles appear on the screen at random positions within the player's range of movement (as determined by the configuration tool) for a short length of time, and the goal is for the player to burst these bubbles by touching them before they disappear. The game has two variations, supporting single-handed play and two-handed play. In the single-handed version the affected limb is used. In the two-handed version, each bubble is colour-coded to match the colour of its respective glove; an arrow (pointing left or right) inside the bubble also depicts which hand the bubble should be burst with. The game has a programmable time limit (set on startup), and the number of bubbles burst within this time limit determines the player's final score. The player cannot fail in the game, rather a poor performance would be reflected with a lower score; however, messages at the end of the game are positive and encouraging regardless of the score. Distinctive and easily identifiable visual and auditory feedback is used to create meaningful play, such as a popping noise for bursting a bubble, a buzzer sound for missing bubbles, bold visual messages for hits and misses, colour coding of sprites, particle effects and score charts. Adaptivity is used to present a level of challenge suitable for the player by dynamically altering the pace, positions and size of bubbles according to the player's performance.

4. USER EVALUATION

Although the goal for any motor function rehabilitation system must be improvement in the affected limb(s), it is necessary to run large-scale user trials over a period of several weeks in order to evaluate the effectiveness of any intervention on motor function outcome. Unfortunately this was outside the scope of the project at this time and so we elected to focus on the evaluation of the usability and playability of the games. Subsequently we identified an additional requirement to evaluate the effectiveness of the engagement quality of the games. As with the design of the games, the evaluation protocol was developed after discussion between colleagues from various departments within the University of Ulster: health and rehabilitation sciences, computer science and psychology. Approval for a 3-phase protocol was sought and granted from the University's Research Ethics Committee.

Phase 1 saw the games evaluated by 10 health people, recruited from the students and staff of the School of Computing. The games were initially demonstrated by members of the research team; the participants then played each game twice. The main instrument used to collect quantitative data was a usability and playability questionnaire (Desurvire *et al*, 2004) which was scored on a visual-analogue scale from 0 to 10. Results indicated that the majority of participants (70-80%) enjoyed all of the games. Players also felt that the games were varied, had good replay value, responded consistently and were easy to play due to the intuitive control mechanisms. More than 80% of players reported noticing that the games adapted to their performance and all liked this feature, suggesting that the games would be less enjoyable without adaptivity. One user did express the view that the change in the pace of the games when adaptivity was present was too aggressive and that the change of pace should be more 'gentle'. These results helped inform minor improvements to the games, most notably the addition of improved feedback – audio feedback and larger graphical cues when game elements were hit and missed.

Phase 2 of the study recruited 3 people with stroke from a local stroke club. One of the participants was in a wheelchair. Following demonstration by a member of the research team, participants played the games once, in their home (each game was played for 90 seconds). The same playability questionnaire was used as in Phase 1 and a further instrument for measuring self-reported exertion (Borg CR10 scale) was used. Results of this Phase were published elsewhere (Burke *et al*, 2009) but in summary all participants were successful in being able to play the games and reported that they found them challenging, fun and varied. All participants, though, reported that the adaptivity changed the pace of the games too aggressively, in particular that the games speeded up too quickly when they were performing well.

In Phase 3, 2 people with stroke were recruited to play the games for a period of 3 weeks (3 times per week). The main focus of the study was to evaluate usability, playability and engagement with the games. At the end of the intervention participants filled out the same usability and playability questionnaire as Phases 1 and 2 and also an Intrinsic Motivation Inventory (IMI) (Ryan, 1982). The IMI elicits data about a player's self-report of intrinsic motivation (which we interpret as a reliable measure of engagement). Participants also had a chance to give more general comments on their experiences. We also collected in-game data which enabled us to study patterns of scoring and gameplay speed (the average speed at which the game elements e.g., bubbles, moved). Since game elements speed up or slow down through game adaptivity, gameplay speed gives an additional measure of user performance.

Player A was a 70-year old, right-handed, female with a right hemiplegic stroke 2 years previous to the study. Her upper limb Motricity Index (Collin *et al*, 1990) scores prior to the intervention were 63 (right) and 100 (left). She generally used a wheelchair, although she was mobile with a stick at home. She was not receiving any therapy at present. The usability and playability questionnaire results indicated that the player enjoyed playing the games (rating 10 out of 10) and also found them enjoyable to replay (9/10). The player felt highly involved in the games (9/10), felt that the games responded consistently and found the feedback to be effective. She felt the controls were intuitive and that the input device was easy to use. The player also indicated that she preferred adaptive difficulty in comparison to altering the challenge manually (9/10). In-game scores and gameplay speed graphs are shown for the one-handed *Bubble Trouble* game in Appendix B below – results indicate a small rise in scores over the 3 weeks for all 4 games. Similarly, the gameplay speeds again show a small rise over the 3 weeks. Player A was generally enthusiastic and well motivated, although her limited range of movement did cause her frustration at times. She commented that the games were 'interesting, fun and encouraged me to move my arm'. Results from the Intrinsic Motivation Inventory are presented in Table 1. The interest/enjoyment subscale is considered the self-report measure of intrinsic motivation and Player A scored this as 61%.

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Player B was a 48-year old, right-handed male with a right hemiplegic stroke less than 1 year previous to the study. His upper limb MI scores prior to the intervention were 70 (right) and 100 (left). He was mobile and was not receiving any therapy at present. The usability and playability questionnaire results indicated that the player found the games enjoyable to play (8/10), replayable (9/10) and consistent (8/10) and effective (8/10) in response to the player's actions. The player did indicate that the games could have been more varied to avoid fatigue (5/10) and that games were sometimes too fast (5/10). He felt that the controls were intuitive (8/10) and that the input device (gloves) was easy to use (9/10). He also approved of the adaptivity feature (9/10). In-game scores and gameplay speed graphs are shown for one of the games in Appendix B– results indicate a small rise in scores over the 3 weeks for all 4 games. Similarly, the gameplay speeds again show a small rise over the 3 weeks. Player B was generally enthusiastic and well motivated. He commented that 'the games help me relax and know my limitations'. Results from the Intrinsic Motivation Inventory are presented in Table 1. The interest/enjoyment subscale is considered the self-report measure of intrinsic motivation and Player B scored this as 84%.

Table 1. *Intrinsic Motivation Inventory Scores.*

	Interest/enjoyment	Perceived competence	Effort/importance	Pressure/tension	Value/usefulness
Player A	61%	38%	75%	28%	75%
Player B	84%	69%	75%	25%	88%

Although both users were able to play the games, Player A self-reported perceived competence was much lower than that of Player B and this is corroborated by the graphs in Appendix B. For Bubble Trouble (one-handed) Player A's scores were in the range 77-87 compared to Player B's range 88-96. To what do we attribute the improvement in both players scores over the 3 weeks is a difficult question. There may be a learning effect, where the player gets better through familiarity with the game over time, or it could be due to an improvement in the player's motor function. Clearly larger studies, evaluating motor function before and after intervention, are required to answer this question more fully. Player A's interest/enjoyment score was also less than Player B's, though still a reasonable 61% (versus 84%) and both players rated the games value/usefulness highly (75% and 88%), their effort/importance highly (75% and 75%) and pressure/tension lowly (28% and 25%). This data would appear to indicate that both players were intrinsically motivated to continue playing the games and this was confirmed through observation by the research team.

5. CONCLUSIONS

We have presented ideas for the design of games for upper limb motor function rehabilitation following stroke. In particular we identified the concepts of meaningful play (feedback) and challenge to be particularly important for the design of games for rehabilitation. Evaluation of a number of games developed incorporating these principles show that the games were indeed usable and playable by people with stroke. Further, the games seemed to stimulate a high level of interest and enjoyment by the participants, which may indicate the games are engaging to play. We hope to conduct larger studies which would improve the generalisability of these promising early results.

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Appendix A: screenshots of the games

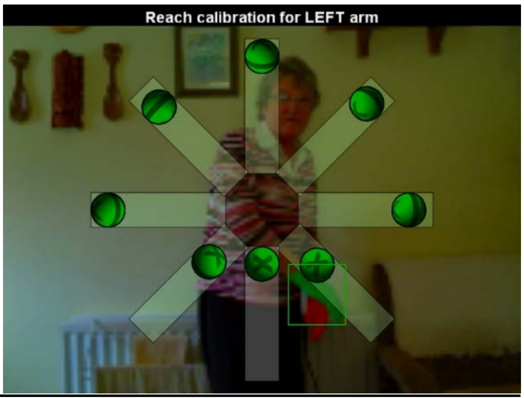


Image 1. *Range-of-movement configuration.*

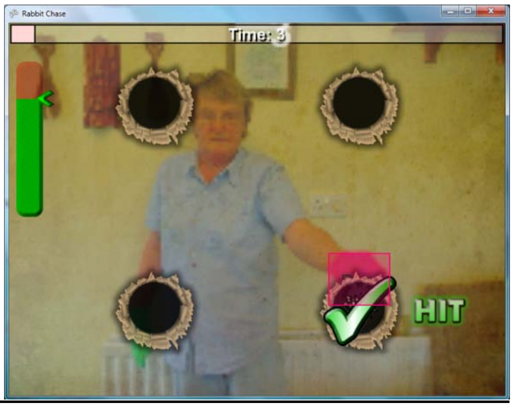


Image 2. *"Rabbit Chase", one handed game.*

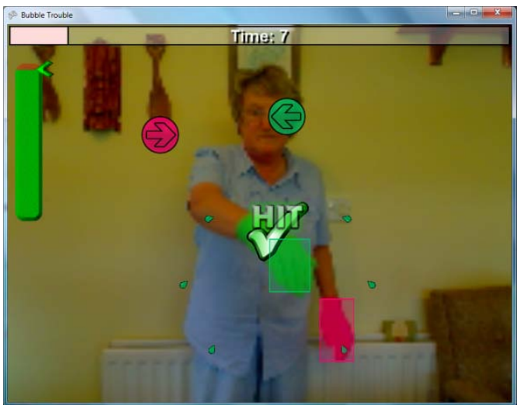


Image 3. *"Bubble Trouble" (Two handed version).*

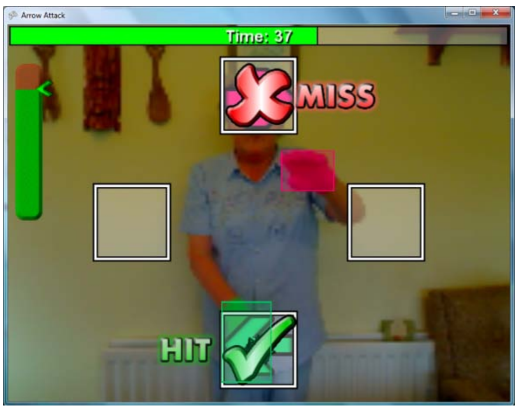
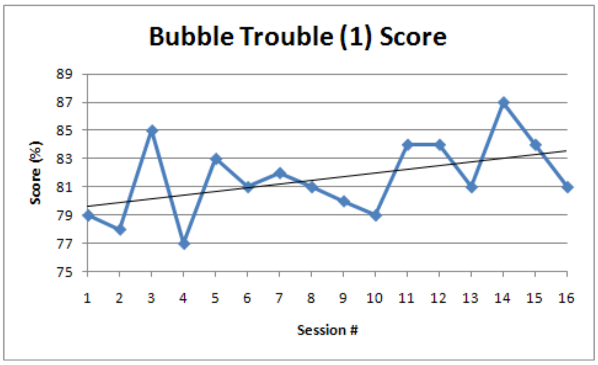
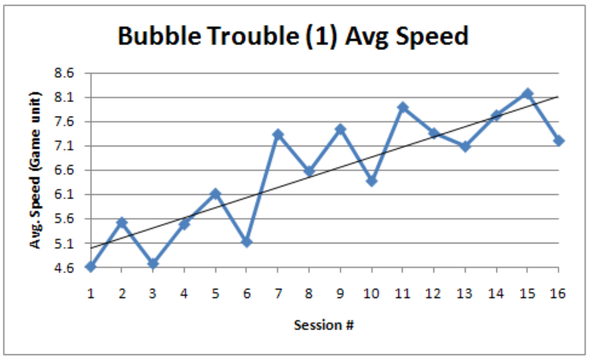


Image 4. *"Arrow Attack", two handed game.*

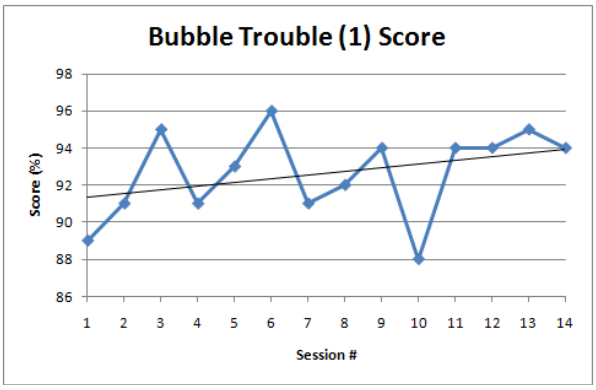
Appendix B: Games Scores and Play Speeds



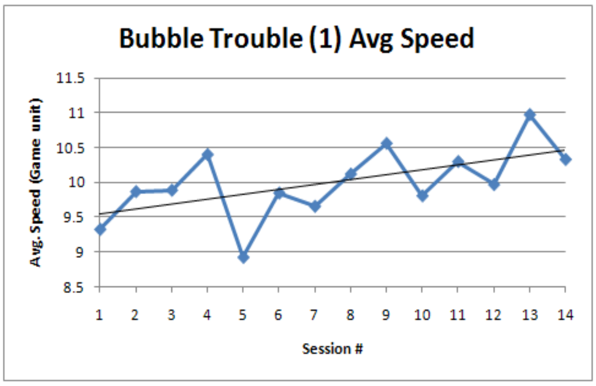
Patient A scores for Bubble Trouble game



Patient A game speed for Bubble Trouble game



Patient B scores for Bubble Trouble game



Patient B game speed for Bubble Trouble game