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Serious Games for Upper Limb Rehabilitation Following Stroke

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Abstract—**Stroke is a leading cause of severe physical disability, causing a range of impairments. Frequently stroke survivors are left with partial paralysis on one side of the body and movement can be severely restricted in the affected side's hand and arm. We know that effective rehabilitation must be early, intensive and repetitive, which leads to the challenge of how to maintain motivation for people undergoing therapy. This paper discusses why games may be an effective way of addressing the problem of engagement in therapy and analyses which game design patterns may be important for rehabilitation. We present a number of serious games that our group has developed for upper limb rehabilitation. Results of an evaluation of the games are presented which indicate that they may be appropriate for people with stroke.**

Keywords: serious games, rehabilitation, stroke, virtual reality, video-capture, Nintendo Wii

I. Background

Stroke is a leading cause of severe physical disability in the UK, causing sufferers a range of impairments such as attention and concentration deficiencies, balance loss, pain, weakness and paralysis. These impairments can result in the person with stroke losing their ability to perform day-to-day activities independently [1]. Such activities include bathing, dressing, eating, and using the toilet, as well as more complex tasks called "instrumental activities of daily living" (IADLs), such as housekeeping, using the telephone, driving, and cooking. It is often the case that impairments occur mainly on one side of the body; the upper limb of the affected side remains weak in up to 66% of stroke survivors.

In the early stages after stroke, rehabilitation takes place in hospital. As the therapy progresses, patients are often required to travel to specialised units for supervised outpatient therapy. Eventually home-based programmes, perhaps with visiting professionals, allow the person to develop skills in their home environment. Rehabilitation programmes are usually devised by a professional working closely with the stroke survivor, agreeing on what goals are realistic to work towards for that particular person. It has been shown [2, 3] that early and intensive practice of active functional tasks in an enriched environment show more positive outcomes for upper limb rehabilitation - it has been suggested that this may stimulate neural reorganisation of the cerebral cortex leading to recovery, or partial recovery of the upper limb. Rehabilitation therapy should begin as early as possible once the person's condition has stabilised, however this can be an issue for a number of reasons: the person has just experienced major trauma; he or she may have paralysis in one or more limbs; he or she may have difficulty speaking; and in many cases they will be unable to do simple tasks they may have took for granted just a few days earlier. It is not uncommon for stroke survivors to experience depression and therefore may find it difficult to concentrate on a therapy programme. Whilst these programmes attempt to stimulate the person with a variety of rehabilitation exercises, people with stroke commonly report that traditional rehabilitation tasks can be mundane and boring due to their repetitive nature. Other problems with rehabilitation include: treatment is often administered on a one-to-one basis, and therefore healthcare costs are high; people with stroke travelling to attend a clinic in the later stages of rehabilitation means that travel costs are high; lack of computational sensing and measurement in traditional therapy may result in errors when interpreting evaluation data [4].

The remainder of this paper is organised as follows. Section 2 gives a short summary of technologies used in stroke rehabilitation systems. Section 3 discusses games for rehabilitation. In Section 4 we analyse aspects of games design theory which are important for rehabilitation. A number of serious games which our group has developed are presented in Section 5, along with preliminary results from an evaluation of some of the games with healthy users. Conclusions are in Section 6.

II. Technology for Stroke Rehabilitation

Literature has shown that technology (such as virtual reality (VR) and imaging systems) has potential benefits to therapy and is an interesting and effective way of providing rehabilitation to people with stroke [5]. Programmable systems can allow novel and interesting rehabilitation tasks to be created. These systems can encourage the person to become more motivated, involved and immersed in their rehabilitation which can lead to improved performance [6]. Virtual

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environments can also provide safe and customisable training, which can be tailored to a particular person's abilities; performance can be monitored and positivity encouraged [5]. If the technology is suitable for home deployment then this could support increased levels of therapy for the stroke survivor. In this case, performance data (such as the number of sessions attempted, length of exercise session and success rate) could be recorded at home, uploaded to a remote clinical site via the Internet and analysed by a therapist [4]. Many VR and imaging systems, however, have high cost, are large/difficult to move and require specialist expertise to set up and operate – all these factors prohibit such systems from being suitable for home rehabilitation.

As mentioned above, both VR and imaging technologies have been applied to the field of physical rehabilitation. In VR-based systems, electromagnetic sensors (attached to the user) are typically used to track the position and orientation of a patient's limbs in real-time. This data is used to drive a graphical avatar in a goal-directed virtual environment, designed to encourage user engagement using hand and arm movement. Datagloves can be used to track finger movement. These and other similar systems are not only expensive to buy, but require considerable expertise (and time) to set up and use.

Alternatively, video capture systems such as the IREX system allow unencumbered movement – the user typically sits or stands in front of a camera and image-processing software is used to recognise arm and hand movements. The user often wears coloured gloves or other markers to enable data acquisition. Currently most video capture systems track movement only in a single plane.

The virtual environments from these systems are rendered to display devices such as computer monitors, projector screens or head-mounted displays. The choice of hardware technology can affect both the user's sense of presence [7] and performance ability [8]. A review of VR systems for stroke rehabilitation can be found in Weiss *et al.* [18].

III. GAMES FOR REHABILITATION

In addition to the bespoke VR and video-capture solutions discussed above, commercially available video game software and console platforms have also been used in motor rehabilitation. Morrow *et al* [9] report on a system which uses the Microsoft Xbox games console to host the software. This low-cost system uses a very low-cost Essential Reality P5 dataglove to capture user hand movements, although it is noted that both hardware and kernel-level software modifications were required. Rand *et al* [10] report using the Sony EyeToy, a webcam made for the PlayStation 2 games console. The Nintendo Wii has also sparked a great deal of interest for use in a rehabilitation setting – it uses a wireless controller (the Wii remote), with built-in infra-red sensing camera for pointer functionality and accelerometer for tilt sensing, which players use to interact with the game. There are potentially a number of advantages in using such off-the-shelf games hardware for rehabilitation, provided it can be used effectively. Game consoles are relatively cheap compared to the specialist VR or imaging solutions described above and bring the cost within personal reach for most people. Also, if games consoles can be used out-of-the-box, the requirement for a technical expert to be present at the therapy session may disappear – there is no operating system to install or maintain and the hardware remains viable for a number of years. All these factors bring the goal of home-based therapy closer.

While the rationale for the majority of games developed for consoles is purely entertainment, for example soccer games, driving games or first-person-shooters, recently a number of games have been targeted at the keep fit market, with Tai-Chi and Yoga-based games available for both Nintendo and Sony products. Nintendo, who make the Wii Sports game, have recently introduced Wii Fit, which uses a balance board for exercise-related games. Other games blur this distinction between entertainment and exercise – in "WishyWashy", for example, a mini-game for the Sony EyeToy, the goal is to clean the dirty windows as quickly as you can by waving your arms, using your hands as cloths. Clearly some of these games, while not designed especially for rehabilitation, may in fact be suitable. One study [10] tested two EyeToy games with both healthy and stroke users and found that although both groups greatly enjoyed the games, the majority of stroke users did experience some difficulty and required assistance from the therapist to complete the games. The authors identify the inability to grade the level of the games as a particular limitation and also mention insufficient data recording in the games. More recently a larger study of stroke users with severely impaired hand functions confirm the potential use of EyeToy games as an effective therapy to improve upper extremity-related motor functioning [11].

Recently our research group organised an informal two-day evaluation of commercial games (including the Sony EyeToy and Nintendo Wii) with a group of health professionals working in stroke rehabilitation. Feedback from this evaluation confirmed Rand's findings – although there was a great deal of potential in these off-the-shelf games for stroke rehabilitation, the pacing of the games is too fast for all but the most able of stroke users. Games designed specifically for stroke rehabilitation are likely to be more effective than games designed for entertainment or exercise for use by the general population.

Developing games to run on commercial games consoles has traditionally been the preserve of professional game studios, with development licences costing tens of thousands of pounds. The release in 2007 of Microsoft XNA Game Studio Express, however, allows authoring for the standard Microsoft Xbox 360 platform for members of the Xbox Creator's Club, at a cost of $99 per year. A similar development platform for the Nintendo Wii (WiiWare) has recently been announced, although at the time of writing interested parties must apply to Nintendo for Authorized Developer Status. Other (free) third-party software allows applications to use the Wii Remote on the PC. These recent development are beginning to offer the potential for games to be developed for game consoles (or for PCs, using commercial game controllers) by individuals rather than commercial game developers. This opens up possibilities for bespoke rehabilitation games to be authored for low-cost systems which could easily be situated in clinical settings and even the home environment.

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Many computer-based rehabilitation systems are based around a functional activity, such as grasping and moving an object, or making a meal etc. It has been suggested [5], however, that integrating gaming features in VR-based rehabilitation systems could enhance client motivation. Other researchers [12] report an increased motivation in adults when using a virtual environment integrated with gaming features. There are many properties of games which are interesting for rehabilitation – computer games are often highly engaging, even addictive in nature, with so-called 'hardcore' gamers spending much of their leisure time engaged in play. We know that for optimal outcome, rehabilitation should be intensive and games may therefore offer a unique environment in which high quality rehabilitation can occur. Games are good at providing feedback which enables players to measure their progress in achieving set goals, or the development of their skills over time and good feedback also helps keeps the player engaged.

IV. Game Design Theory and Rehabilitation

We have identified two principles of game design which have particular relevance to rehabilitation: meaningful play and challenge.

A. Meaningful Play

Salen and Zimmerman [13] suggest that the goal of successful game design is the creation of meaningful play. Meaningful play emerges from a game in the relationship between a player's actions and the system's outcome. The interaction relationship should be both discernable, in that a player can perceive how their choice is affecting the game, and integrated, in that the choice does not only affect the game in the immediate term, but also at a later stage of the game. Recognition of the effect a particular choice has can be conveyed to the player through feedback, without which that choice loses significance due to a lack of visible meaning. Game designers do not design play directly, but structure the environment in which play must take place.

Feedback enables a player to measure their progress in achieving their goals, or progression in their skills over time. Feedback is how the game responds to the changes or choices made by the player and is central to creating and maintaining meaningful play. It can be aural, visual and haptic and can be used to signify correct or incorrect actions or responses. Numerical scores, progress bars, character dialogue, controller vibration/force and sound are all obvious forms of feedback in a game. Alternatively, feedback can occur through the player acquiring new skills or game elements – improving player health or weapon armoury, for example, or through the acquisition of more intelligence or special powers such as X-ray vision or invisibility. Such gratifying incentives can lead to increased motivation and enjoyment, creating a greater desire to complete particular tasks and reach certain goals. Player attributes (health, special powers etc) can also be decreased or removed on poor gameplay, actions which encourage players to learn from their mistakes. Without quantifiable advantages for completing tasks successfully and conversely exposing a recognisable disadvantage for poor gameplay, the player is less likely to engage effectively with the game [14].

How feedback is achieved is largely game-dependent but we can make some general observations with regard to games for rehabilitation. For rehabilitation, failure can be an important issue. In off-the-shelf commercial games, failure is often not only present but expected - in driving games, for example, a player may crash his or her car many times, causing the game (or level) to be restarted before game play can continue. In first person shooters, the player character may well lose several lives during exchanges of fire with non-player characters. In games designed for rehabilitation, however, we believe that failure should be handled much more conservatively. The goal of a game designed for rehabilitation should initially be to encourage engagement and subsequently to reward all engagement with success. This is not to say that the player character should never die, rather that the game should initially be paced so that the player with stroke is encouraged to play without catastrophic results. Stroke survivors may not have been players of video games prior to their trauma. They may be unfamiliar with the equipment, are going to have limited mobility in their affected limbs and consequently the risk of users not engaging with the game is high. By handling failure in a positive way rehabilitation players are more likely to remain engaged and not feel that failure in the game stems from their poor physical abilities as a result of stroke.

In many rehabilitation systems users with stroke see a virtual representation of themselves (avatar), or part of themselves (just the tracked limbs) in the simulation. These virtual limbs then track the movement of the user's limbs in the physical world – users with stroke have described such feedback in positive terms, for example, "It really helped me focus on my bad arm". In these systems, then, feedback is instant and continuous – users are aware when they are moving their limbs or resting them. Feedback should also clearly show when a user's actions results in interaction with a game element – perhaps the element lights up, changes colour, or an audible sound is played. It is important to remember that a user with moderate or severe dysphasia may only be able to move their arm within a small range and may not be able to achieve very much in the physical world. Computer-based environments allow such patients to achieve much more, provided the game is structured appropriately.

Finally, scoring mechanisms are commonly used in commercial games to reflect player actions and can be used similarly in a rehabilitation setting. Since it is anticipated that the user will be playing the game(s) over a period of weeks or months these scores can be saved and trends observed. It may be beneficial to reward atypical player actions – for example, rewarding range of movement or time engaged in play as well as rewarding the more usual successful actions that the game requires for play (such as the number of hidden elements that are found, or number of kills). A graduated scoring mechanism may also prove helpful in maintaining engagement and promoting meaningful play – in a throwing game, for example, points could be awarded for picking up the game element to throw as well as actually throwing it. Similarly, the target could be made sufficiently wide so that it is impossible not to score some points, with more points being awarded for getting closer to the centre of the target.

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B. *Challenge*

At the start of a new game, a player generally desires a low level of challenge to meet their correspondingly low level of ability/familiarity with the game. The more the player plays the game, the more his or her skills and familiarity increase and so the player requires a higher level of challenge if he/she is to continue enjoying playing. If the game is too difficult for the player, either through their lack of ability with the game interface/controller or poor feedback they can become frustrated and quit. Similarly, if the game is not interesting or challenging enough, the player can become bored. Clearly both of these scenarios are unwelcome in any context, including rehabilitation.

Games are usually designed so that difficulty gradually increases as the game progresses. However, this can be difficult to achieve, considering that a game designer cannot possibly know in advance every player's individual level of skill. Some player's skills may exceed the challenges the game has to offer, or the game's initial difficulty level may be too high for inexperienced game players. In commercial games a variety of mechanisms are used to maintain an optimum challenge. Many games use levels to structure difficulty. Completing a level is possible only when the player understands at least part of the game mechanics and has acquired the necessary knowledge and skills (including controller skills) to progress through the level to the end. The next level then builds on these skills, requiring either acquisition of new skills or honing of existing skills as the difficulty of the game increases and in this way the challenge presented to the player changes in a way that ideally keeps the player interested and feeds his or her enjoyment. Other games may not have recognisable levels as such, but the challenge might increase as particular points in the game are reached, again, indicating that an appropriate level of understanding and acquisition of skills has been achieved. A different and more controversial approach to maintaining an appropriate level of challenge in a game is to dynamically adapt the game difficulty according to the player's in-game performance and abilities. Such adaptivity requires player actions to be captured and analysed as the game is played - game elements change dynamically to maintain an appropriate level of challenge, making the game easier or harder as dictated by the user's performance. Examples of commercial games using adaptivity include Max Payne (published by Gathering of Developers) and F.E.A.R. (Vivendi).

Rehabilitation must be targeted to the individual needs of the person with stroke – there will be a wide range of abilities and tasks which are impossible for some can be trivial for others. 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 practice. 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.

Games for rehabilitation offer the potential to increase or decrease the level of difficulty to an almost infinite degree, provided that games are designed with that functionality. Typically games are harder when the pace of the game is faster (the player has less time to react) and conversely easier when the pace is slower. The speed at which game elements (e.g., characters) move in the game can affect the pace of the game. Also, pauses between game play can alter the pace. Games designed for upper limb motor rehabilitation will, clearly, require the movement of various limbs (hands, arms) to point to, reach for, touch, grasp and move game elements. The position of these game elements can be altered to make them easier or more difficult to reach in order to suit the capabilities of the player. Targets can be moved closer to the median line of the player or conversely farther away, making them reachable only by greater extension of shoulder and elbow joints. Game elements can also be made larger (easier to touch) or smaller (harder to touch, requiring more accurate movement). Games which target bimanual movement will require synchronisation of left and right hand/arm movements: perhaps one hand can be holding a game element while the other interacts with it (e.g., holding a telephone in one hand and dialling with the other).

The data acquired from the initial user assessment tests can help to ensure that the initial game challenge presented to the user is neither too trivial nor impossibly difficult. However, it is difficult to map scores from user assessment tests directly to elements of the game design. While there are many standardised tests available, physiotherapists will often choose one particular test with which they are comfortable or indeed use a non-standard test. Initially, the difficulty of the game needs to be chosen conservatively in order that the user is carefully introduced to the system, minimising the risks of failure. Once the user becomes more familiar with the system, games which are adaptive may offer the best solution to maintaining an appropriate level of challenge. If players are scoring highly and successfully completing tasks within the available time it is likely that the level of challenge is too easy – the player's cognitive and motor skills surpass the challenge offered by the game. Conversely, if players are not scoring well and regularly failing to complete tasks then the game is clearly too difficult. In these cases, game adaptivity, which allows dynamic adjustment of game elements to either make the game easier or more difficult by changing the game elements as described above (altering the timing, positioning and size of game elements) may be beneficial.

V. Stroke Rehabilitation at the University of Ulster

Our research group at the University of Ulster has developed several systems for upper limb stroke rehabilitation through the integration of 3D virtual environments and sensor and camera technology. This section describes a variety of games our group has developed using VR, webcam and Nintendo Wii technologies.

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A. VR Games

Early work in our group [16] developed a number of systems using magnetic sensor-based VR equipment to track upper limb movement in the real world. A range of tasks were designed for the virtual environment which mimicked real-world functional activities, such as reaching, grasping, moving and releasing a variety of everyday objects. Both functional and game-like scenarios were designed. We outline two of the game-like systems here - further details of these simulations can be found in [16].

(i) *Catch task for bilateral rehabilitation* – In this task, a real-world (physical) basket is held by the user to catch falling objects in the VE. The user holds the basket (which has magnetic sensors attached to it) with both hands, with the goal of catching falling oranges which fall randomly onto a target area in the VE (Fig. 1). A virtual basket tracks the movement of the real basket in the VE. Various parameters in the game such as the falling speed of oranges, locus of oranges, and the size of oranges can be adjusted to allow for differences in individual capabilities. All sensor and game data (e.g., scores) are also recorded to disk, allowing for post-session analysis. The game was written in C++ and used the open-source object-oriented graphics rendering engine (OGRE) together with Ageia's PhysX engine (now owned by nVidia) using the nxOgre wrapper.

Figure 1: Catching oranges game

(ii) *Adaptive 'whack a mouse' game*– This game is designed to encourage movement and to improve the accuracy and speed of the user's upper limb movement, as well as improving visual discrimination and selective attention (Fig. 2). In level 1 of the game a mouse appears at a random location on the table, and remains at that position for a few seconds before moving on to a different random position. The user attempts to hit the stationary mouse with a virtual hammer which is controlled by a sensor attached to the user's hand. In level 2, a dog also appears randomly, which the user must avoid hitting, encouraging visual discrimination from the mouse. Both the length of time that the mouse is stationary and the locus of positions of the mouse and dog adapt dynamically to user performance by evaluating in-session data such as time taken for task completion, accuracy rate and stimuli-response time. The initial configuration of the game is based on assessment of the user's capabilities prior to the session starting. This game was authored in Sense8's WorldUp software.

Figure 2: Whack a mouse game

The above games used specialist and expensive VR equipment (Ascension Flock of Birds and MotionStar tracking systems, together with a range of HMDs). More recently our group has been exploring lower-cost options for rehabilitation systems which may be suitable for home-based therapy.

B. Webcam Games

Two games have been developed which use standard webcam technology to capture video data of user movement. The games were built in Microsoft's XNA platform for Windows, using the C# .NET framework. DirectShow libraries are used in order to allow the games to communicate and interface with any USB web camera. The games can be rendered to any PC display device, ranging from an LCD monitor to a projector screen. The system was tested on two webcams of differing resolutions (160x120 and 640x480) with no significant change in performance.

The games are designed to promote gross arm movements in order to aid upper limb rehabilitation. The first game, "Rabbit Chase", was developed for single arm rehabilitation (either right or left arm). The second game, "Arrow Attack", was developed for bimanual rehabilitation (both arms). These games are controlled by the player moving his or her hands. In order that the hands can be tracked, the player either wears a glove or holds an object of a single consistent colour, such as a piece of card (the *marker*). The colour of the glove or card is chosen so as not to conflict with the background colour. Prior to the games commencing, a short calibration process takes place whereby the user covers a small square area on the screen with the marker in order for the game to identify the marker's colour. The position of the marker can then be tracked in 2D space using an RGB colour segmentation algorithm on the image feed from the webcam.

The games also support user profiling. Profiles allow the storing of information about the user, such as their name, skill level (which determines the speed of the games), the length each game should be played for and the user's progress over multiple game-play sessions measured by their scores (Fig. 3). This can help the user assess their progress through multiple sessions over a long running period of time, as well as giving

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the user (and therapist) a baseline score from which the user can try to improve. The initial skill setting can be set by a therapist to allow for an appropriate level of challenge for the user's impairment.

There is also an option to enable an adaptive difficulty mechanism. When this option is selected, the game automatically speeds up or slows down depending on the user's performance. This is achieved by altering the speed of the rabbit (in Rabbit Chase) or the arrows (in Arrow Attack). This can help maintain an appropriate level of challenge which alters accordingly as the user's level of skill improves or deteriorates as the game progresses.

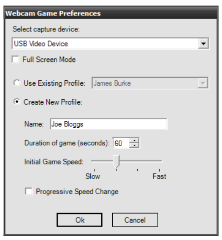

Figure 3: Profile & configuration dialog

Both games were designed by taking core game design principles into account and mapping them to rehabilitation, such as the importance of feedback in response to the player's actions to create meaningful play and presenting an appropriate level of challenge for the player's skills. The games also allow the player to be seated or standing, permitting people with stroke who require support or who are unable to stand to use the games. A further benefit of the webcam interface is that the user is not required to have any experience with operating a computer – the system could easily be adapted that once it is switched on, no further interaction with the actual computer is required as all input (navigation, selection and play) is done through movement detected by the camera.

Webcam Game 1 – "Rabbit Chase"

"Rabbit Chase" is played using one marker on either the left or right hand as appropriate, with the goal of catching a rabbit as it peers out of one of 4 holes displayed on screen (Fig. 4). The rabbit stays at a hole for a short amount of time (depending on the current pace of the game) before running to the next hole (chosen at random). The player can see the rabbit as it runs between holes and so can anticipate its next location. The webcam's image feed is displayed in the background so that the player can see themselves and is aware of their position in relation to the game. The goal is to touch the correct hole at the same time as the rabbit peers out of it. If the player touches the target at the right time, the hole and the rabbit both change colour and a buzzer sound is played. There is no penalty for touching the wrong hole; however the player's score will not increase unless the correct hole is touched. The player's current score and time remaining are also displayed on the screen. The aim of the game is for the player to score as highly as possible before the time runs out. An example video can be seen here: http://uk.youtube.com/watch?v=GmbU2lUlZ5U

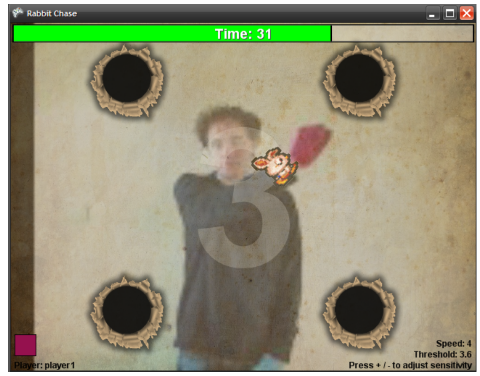

Figure 4: Rabbit Chase game

Webcam Game 2 – "Arrow Attack"

"Arrow Attack" (Fig. 5) requires the player to track two arrows, one pointing left and one pointing right, and touch the arrows as they reach each box using the correct hand. Since the game requires differentiation between the left and right hand marker, the player uses two markers of differing colour. The arrows are also coloured according to the colour of the markers in order to aid the player in distinguishing which arm to use. The game's concept is similar to that of "Rabbit Chase" whereby the arrows will move between the boxes, with the next box chosen at random; however the box selection is limited so that the game will never require the user to fully cross their arms as this could cause unnecessary complications and stress for more impaired players, as well as causing the game to become too difficult. The interface is also similar to "Rabbit Chase", with the player's score and time remaining displayed on-screen, as well as a buzzer sounding and the box changing colour to indicate a point scored. An example video can be seen here: http://uk.youtube.com/watch?v=FADD1oP66Zg

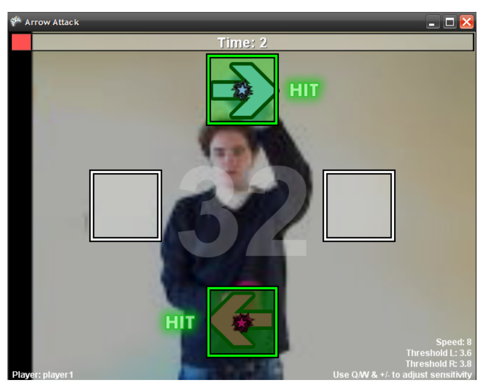

Figure 5: Arrow Attack game

C. *Nintendo Wii Remote Game*

This game allows the user to play a "virtual vibraphone" instrument (similar to a xylophone) through the use of Nintendo Wii remote controllers. The controllers are

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interfaced to a PC through Bluetooth using a C# library [17]. A bird's-eye view of the instrument is shown on-screen, and the user has control of a virtual mallet, represented by a 2D sprite, with which to play the instrument (Fig. 6). The user can move their mallet simply by pointing the Wii remote at the vibraphone bar they desire to play. A note can then be played by pressing a button on the controller. Multiple Wii remotes can be used to allow a user to play two notes simultaneously, or for multiple users to play the instrument together. The result is an intuitive and fun virtual instrument.

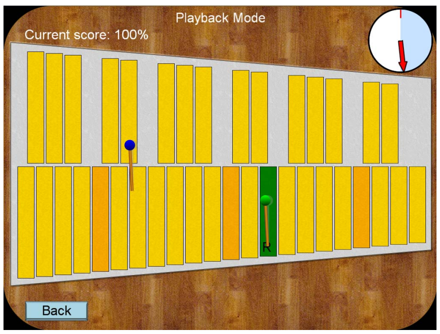

Figure 6: Vibraphone game

The application allows for two modes: *Record*, whereby the user can play a tune on the vibraphone and then save it to disk, and *Play*, where the user can playback previously saved tunes or tunes stored in a tunes database. The *Play* mode also turns the simulation into a game by adding a time limit within which the tune must be played. This time limit is determined by the number of notes in the tune, with a certain number of seconds being allowed per note. During this time, each note will highlight which bar on the vibraphone must be hit and which hand it must be hit with (demonstrated using colour, blue for left and green for right, as well as 'L' or 'R' written on the bar); the game will not progress to the next note until the correct note has been hit. The user's score is also displayed on the screen as a percentage value, determined by the number of correct hits they have achieved out of the total number of hits attempted. The aim is to complete the tune as accurately as possible within the amount of time allocated. At the end of a tune being played, the player's score is shown on the screen, along with a rewarding or encouraging message, depending on how well the player scored.

This game has the potential for wrist and arm rehabilitation, with different tunes being used to emphasise movements in the affected arm – for example, ones which favour the left hand or right hand. When the player selects the *Play* mode, the contents of the tunes database is displayed in a list. Along with the name of the tune, the game also displays whether the tune places emphasis on the right arm, left arm, or both equally, and how much the notes in the tune differ in range; this information is important as it determines how much movement is required to play the tune and on which arm most exercise would take place. As yet there is no adaptation to the player's skill, other than allowing a variety of tunes, some of which may be more difficult than others. In future development it is possible that different level of difficulties could be implemented which give less time in which to play a tune, or require maintaining a particular level of accuracy in order to complete the tune (similar to *Guitar Hero*).

D. Discussion

Each of the games described above illustrates how game design principles can be applied in different ways in a rehabilitation context. In the Vibraphone game, for example, meaningful play emerges from visual and auditory feedback which also serves to create discernable outcome for the player's choices (highlighting bars; playing audible notes; different colours representing different hands; buzzer sounding and colour changes on incorrect choice; onscreen player score and timer and playing of rewarding/encouraging messages). Setting an appropriate level of challenge is achieved by analysing the data recorded when the user plays the test tune and configuring the length of time for the user to play the tune. Hitting an incorrect note, or the correct note with the wrong hand, does not result in the game being interrupted – although the user is made aware of the invalid action the game continues until the time elapses.

In the video capture games meaningful play is again created through visual and auditory feedback based on the user's actions – coloured markers, scoring, audible buzzers, sprites changing colour. By being adaptive, both games can dynamically analyze in-game user performance and alter the pace of the game as required, thereby attempting to maintain an appropriate level of challenge. As the game elements are programmable – size of targets, position of targets and length of time between game play – this allows for future versions of these games to reposition and resize elements within the game according to the user's abilities and impairments.

E. Usability Study

We conducted a small usability study which consisted of 10 able-bodied users (volunteers from the undergraduates in the Faculty of Computing and Engineering at the University of Ulster) playing the 2 webcam games and the vibraphone application. First the games were demonstrated to users by a member of the research team. Each participant then played each game twice and filled out a playability questionnaire (which includes usability) [19] for each. Users answered questions on a visual-analogue Likert scale. The majority of participants enjoyed all of the games, with "Rabbit Chase" being the most enjoyable (80% either agreeing or strongly agreeing that the game was enjoyable) and "Arrow Attack" being the least enjoyable (70%). The majority of 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. Interestingly, the adaptivity feature in the two webcam games was also approved of by all participants who noticed that adaptivity was present (more than 80% of users). They indicated that the games would be less enjoyable without adaptivity, suggesting that adaptivity helps maintain an appropriate level of challenge once players became accustomed to playing the games. One user did

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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'. Users were neither in agreement nor in disagreement when asked if they would prefer to be able to alter the pace of the games manually.

Over 80% of the users thought that feedback was effective. However, some players reported that it was difficult to see their score during game play so perhaps a graphical view of the score would be more effective. With the vibraphone game a few users stated that they found the controls to be too sensitive to hit individual bars. This could perhaps be solved by adding a smoothing algorithm to the controls, as well as making the vibraphone bars larger (although this would mean that fewer bars would be visible on the screen).

On average 90% of users agreed that the input devices (glove and webcam, or Wii remote) were easy to use. 57% of users agreed that the input devices were intuitive and added to the enjoyment of the game. This indicates the games were accessible and playable using the novel interfaces provided.

It is clear from the trial that while in the main feedback was positive, certain features of the games require improvement, such as slowing the webcam games' adaptivity feature so that it is not as aggressive, as well as implementing better feedback to ensure the player is completely aware of the response the games make according to their actions and choices, allowing for meaningful play to emerge. Work is underway to make these improvements. Conducting this study with able bodied users has allowed us to improve the design of our games before running usability studies with people with stroke. The screenshots and videos of the games in this paper reflect a number of these improvements. We hope to start recruiting people with stroke to the study in January 2009. Recruits to this study will be screened by a therapist to determine their eligibility; those eligible shall then be observed playing the games and give their own feedback on their play experience.

VI. Conclusions and Future Work

We believe that games have much to offer rehabilitation systems in general and stroke rehabilitation in particular – well-designed games can be highly engaging, even addictive and if they promote limb movement the benefits to the person with stroke could be significant. In this paper we have analysed game design principles for upper limb stroke rehabilitation and presented several games for upper limb motor rehabilitation developed using low-cost interaction devices. Preliminary studies show encouraging results and positive feedback with regards to our games and we are currently recruiting people with stroke from a local stroke group to evaluate the games.

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