























The balls will be generated in a set sequence to focus on specific repetitive movements. A ball will be generated one at a time and continue to be generated from the same side until the user hits the ball into the correct side. The orders in which the balls are generated are: Red, Blue, Red, Green then repeats. Whenever the user correctly hits a ball, a score in the top left corner is incremented. A wrong hit does not decrease the score.

When using the roller-ball device for this game, the main focus will be on hand muscles through radial deviation as well as working on shoulder medial and lateral rotation. However without the device, the focus will be on the forearm muscles through supination & pronation. Regardless of the device, there will also be some shoulder abduction and flexion involved.

The game also attempts to recreate activities of daily living (ADL), specifically simulating the motion of turning objects, such as a doorknob, when the roller-device is not being used. It breaks down the turning motion of the hand and forearm through supination and pronation movements. The movement of the ball also allows the user to develop their hand eye coordination, which can be diminished after the onset of a stroke.

### III. USABILITY STUDY

In order to study the effectiveness of these games as a motivational rehabilitation tool, we have asked 4 volunteers to take part in a usability study. This involved surveying the volunteers to give feedback immediately after playing both games. All volunteers are healthy subjects of both sexes ranging from 22 to 47 years of age. Since none of the volunteers are stroke victims, we have developed a questionnaire. The questions used in the usability study were influenced from other research papers and focused on a users' initial reaction to the game so it can be refined, as can be noticed in Table 1. We would provide brief instructions to each volunteer on how to play each game, and then allowed them to play it independently with our supervision.

All volunteers easily followed the games instructions, and the gameplay was said to be familiar and intuitive. The Mole Attack game ranked as the most popular game with two volunteers claiming it was enjoyable and would play the game again. Both games produced a sense of accomplishment, shown in Fig. 9, with one subject claiming that the scoring system on the Colour Ball game increased her motivation to play. Two of the older volunteers were fascinated

by the augmented reality environment, in which they felt satisfaction when progressing through the gameplay. All members were able to understand how these games are focusing on specific muscles and movements so that they can be applied for therapeutic applications.

The responses given for the games were positive in terms of usability. One of the main advantages of using an augmented reality gaming system for rehabilitation is the increased motivation provided by the interactive game play. This claim was supported by consistent comments from the healthy test subjects.

The most common negative feedback given from the volunteers was that the gameplay wasn't smooth. More specifically, the marker object tends to flicker, which made the game unresponsive at times. Also, when the games are played without the roller-ball device i.e. playing the game with the arm in the air, the volunteers complained that their arm was getting fatigued after prolonged game play.

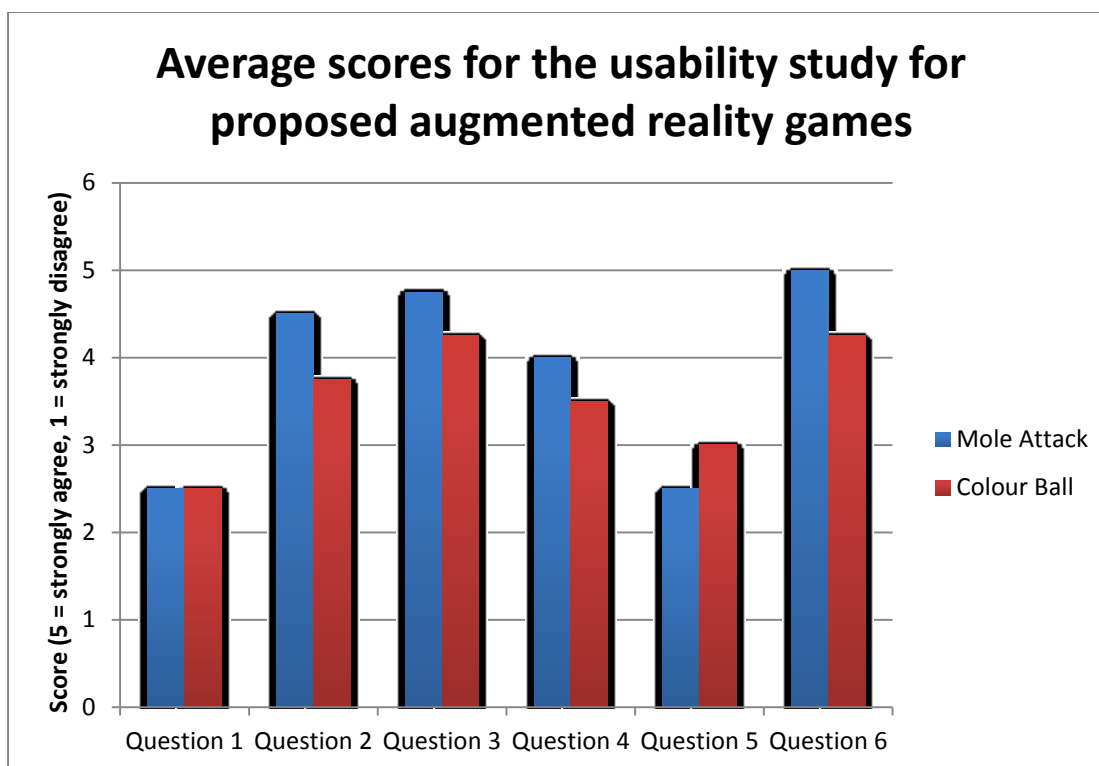
With the colour ball game, two subjects felt that the speed at which the ball travelling was too slow and made the game boring. However, the design choice for this is due to the fact that real stroke victims will need much more time to react to visual cues.

Below is the list of questions that answered by each volunteer immediately after they played each game. Each question is ranked on a scale of 1 (strongly disagree) to 5 (strongly agree).

The user was also asked to give any general comments or feedback.

1. I am familiar with AR technology and systems
2. I felt the game was intuitive and enjoyable
3. I was able to play the game correctly
4. I would play this game again
5. I felt pain/discomfort during the game
6. I can recognise the exercise application of the game

**Table 1. Usability Questionnaire**



**Figure 9. Results for the usability study**

## VI. CONCLUSIONS AND FUTURE WORK

In this paper, two augmented reality based games have been presented. They have been specifically modified to focus on specific upper limb movements for the purpose of stroke rehabilitation. The games have been developed using libraries from the FLARManager framework. The games can be easily accessed using a PC with Flash installed and a simple webcam. The optional use of a hand held roller-ball device allows each game to focus on different movements and muscles, thus increasing the effectiveness of the games. These games aim to improve the user's participation by presenting an interactive way of rehabilitation.

As simple as these games are in design, they still capture the proposed idea that stroke rehabilitation can be enhanced using augmented reality games. The games have been modified to force the user to perform specific movements that are strongly linked with current physical therapy techniques.

The marker tracking capabilities of the FLARManager have proved to not be very robust as the marker tends to flicker at times, thus not providing smooth gameplay. The marker would successfully activate 70% of the time. Future work can involve the use of other augmented reality libraries in order to find the most robust object tracking process to provide smooth gameplay in a variety of lighting conditions. Also, since these games are in 2D, it would be interesting to explore the possibility of working with 3D models to further add depth and interactivity to the gameplay. The future work will include a stroke patients test.

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