

Evaluation of User Satisfaction and Learnability for Outdoor Augmented Reality Gaming

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Abstract

We have developed an outdoor augmented reality game, *Sky Invaders 3D*, which is designed to be played by the game playing public. We conducted a user study to measure how much users enjoyed playing an outdoor AR game, and how intuitive it was. We compared 44 participants on one of two games, an outdoor AR game, or a desktop PC equivalent of the same game. We found the AR game was rated by the participants as significantly more enjoyable by the users and more intuitive to use.

Keywords: augmented reality, gaming, evaluation, enjoyment

1. Introduction

To date there have been few investigations into the appeal and ease of use of Augmented Reality (AR) systems, but the current assumption is that people will want AR interfaces for particular applications. There are a number of motivating application domains, such as architecture, surgery, military, entertainment, and maintenance (Azuma 2001). The investigations into these domains have primarily focused on the addition of functionality for the user, and we believe that AR holds great promise in providing a useful and engaging interface to these domains.

The aims of this investigation are as follows: 1) to determine a user's engagement (enjoyment) with playing outdoor AR games and 2) to assess the cognitive complexity for novice users of outdoor AR games. To this end, we studied a number of people playing a first-person shooter game, *Sky Invaders 3D*, in an outdoor AR mode, and the same game in a traditional desktop PC mode. To our knowledge, this is the first formal study into the user acceptability of this new form of technology.

In conjunction with A-Rage Pty. Ltd., we have developed an electronic proof-of-concept demonstration outdoor AR game, *Sky Invaders 3D*. Figure 1 depicts the A-Rage gaming hardware with a user playing the *Sky Invaders 3D* game. The system uses optical see-through HMD technology, which allows for the computer generated

images to be projected on top of the physical world using an optical combiner. This display gives the user the impression that virtual objects are situated in the physical world.

This paper begins by discussing some previous work in the area, followed by a description of our *Sky Invaders 3D* game. We then describe the user study that we performed, and the results are then presented. The paper finishes with some concluding remarks.

2. Background

This section provides an introduction to AR games, both indoor and outdoor variants. This is followed by a brief overview of methods for evaluating games.

2.1 AR Gaming

There have been a variety of different augmented and mixed-reality entertainment systems created in the past, all varying in their motivations and approach. Indoor AR gaming is the most mature domain at present, and this section presents a brief overview of indoor and outdoors versions of AR gaming.

2.1.1 Indoor AR Games. An early example of an indoor AR game is AR Mahjong (Szalavari 2002) that allows for multiple people to play a virtual game of Mahjong. AquaGauntlet (Tamura 2001) is a multiplayer game where users wear a video see-through HMD and shoot monsters in a room. When players observe their teammates they appear with an augmented helmet and gun. AquaGauntlet was based on an earlier version called RV-Border Guards (Ohshima 1999). AR2Hockey (Ohshima 1998) allows two players to sit at a regular table wearing HMDs and hold physical mallets. These mallets allow



Figure 1. Outdoor AR game hardware

users to play a game of air-hockey in a traditional fashion with a virtual puck. A second approach to a virtual air-hockey game HSE Hockey employing the Hi-Space table from the University of Washington (May 2004). The Hi-Space table employs a rear-projected screen mounted at desk height, and interaction is performed by directly mediated interaction.. Nilsen et al. have developed AR Worms (Nilsen 2004), an AR version of the popular desktop Worms game by the publisher Team 17. Users see a 3D landscape rendered on a table and they battle against their opponents by controlling a team of Worms. TouchSpace (Weihsua 2002) is a gaming system that uses many different forms of mixed reality (augmented, virtual, and tangible) to increase user enjoyment. The game is situated in a large room in which users must walk around, interacting with both physical and virtual objects, experiencing optical see-through AR, handheld AR display, and immersive virtual reality. MIND-WARPING (Starner 2000) is another game which makes use of mixed realities and mobile platforms. The authors created a multiplayer game in which one mobile user wears a wearable computer, and the other uses a desk-based interface to battle against each other.

2.1.2 Outdoor AR Games. Only a small number of AR games have been created to work in an outdoor environment. ARQuake (Thomas 2000) was the first outdoor AR game, where Thomas et al. converted the popular desktop video game Quake to work with their AR backpack system. The game took uses positioning from a GPS unit and orientation from a digital compass, so the game environment could be explored by physically walking and looking around. Human Pacman (Cheok 2004) allows multiple users to play outdoors in an AR environment, emulating the game play of the original 2D arcade game Pacman. Players can be either ghosts or the Pacman, with the ghosts chasing the Pacman around the game area while the Pacman tries to collect the virtual cookies. AR Moon Lander (Avery 2005) places an outdoor user in control of a lunar lander module which they must try to safely land on the ground. This game is different from the previously mentioned because a GPS is used to snap to approximate areas in the environment, making it suitable for use on very low-cost hardware. Real Tournament (Wu 2004) is a non-HMD form of a outdoor AR game. This game was designed to be played in a public park, with the users having to locate and capture virtual monsters. Players operate a custom device containing a PDA, electronic compass, GPS, and wireless card encased in a water pistol shell.

2.2 Indoor/Outdoor Differences

Locating games indoors greatly simplifies the development process for many reasons: commercially available accurate trackers designed for indoor virtual environments can be easily integrated; users are typically tethered and restricted to a fixed area indoors, HMDs are mainly designed for indoor operation; and the availability of powerful desktop workstations with 3D graphics cards to support high quality rendering. An indoor setting is by its very nature a highly controlled environment, thereby relieving the developers from the difficult conditions associated with working outdoors (Azuma 1999), such weather, poor lighting conditions, and lack of power outlets.

2.3 Game Evaluation

The games industry is now worth a considerable amount of money, and manufacturers invest considerable resources to ensure that games will be enjoyable and therefore successful in the marketplace. The Rapid Iterative Testing and Evaluation method (RITE), defined by Microsoft, is a method of rapidly evaluating games (Medlock 2002) and allows for problems to be very quickly remedied and then re-evaluated. Conventional testing techniques involve many play-testers all playing the game, and then examining the problems discovered and remedying them. The RITE method dictates that changes are made as soon as the problems are identified, and then further testing (in some instances with a single test participant) is done with the updated version. This method allows for the updates to be rapidly re-evaluated.

Heuristics are sometimes employed in conjunction with user testing as a tool for evaluating games and their playability. Desurvire et al. (Desurvire 2004) present a set of heuristics gathered from literature and playability experts which can be used to evaluate the playability of a game. The authors discovered more user problems using their heuristic evaluation than from user testing.

The modified Repertory Grid Technique (RGT) presented by David and Carini (Davis 2004) provides a quantitative evaluation without the limitations that closed questionnaires provide. The RGT involves developing evaluation criteria based on comparing one game against two others, and finding similarities and differences between them. This can prove time consuming and tiring, so the constructs are discovered by interviewing the participant. The participant then rates the game in each of the criteria.



Figure 2. Photo of the Sky Invaders 3D game

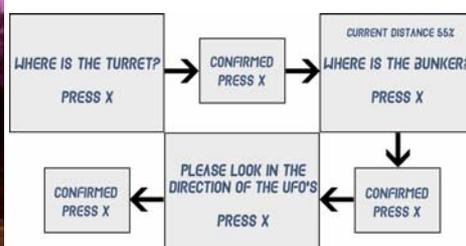


Figure 3. GPS calibration screens



Figure 4. Player's gun and an approaching fleet of UFOs

Cheok et al. performed a user evaluation on their Touchspace game (Weihua 2002). Forty volunteers were selected to play the game, and then completed a questionnaire on how they felt about the physical interaction, social interaction, and the HMD. The questions relating to the physical interaction in the game compared Touchspace with conventional screen-based computer games. Cheok et al. found that the users generally felt that they were more entertained by physically moving around compared to traditional computer games, and that the participants had a much more exciting experience. However, this study only asked users to compare their experience with conventional screen based computer games, not against any game in particular. There were also only two questions asked of the participants relating to enjoyment of the game.

Previously we performed a set of informal studies into the usability and playability of our ARQuake game (Thomas 2002). One area of investigation was comparing playing the game along different points of Milgram's Reality-Virtuality Continuum (Milgram 1994): virtual reality, augmented virtuality, and augmented reality. The results are in the form of feedback from users operating ARQuake in an outdoor setting. The users overall reported they enjoyed ARQuake, and a number of design and implementation concerns were reported.

3. AR Sky Invaders 3D Game

We have recently developed a new outdoor AR game called Sky Invaders 3D. The goal of Sky Invaders 3D is to protect the Earth from invading aliens by shooting down waves of UFOs. The game was originally designed as an AR game, and a desktop computer game version controlled with a mouse has been implemented for the purposes of comparison in this paper. This section of the paper describes the operations of both versions of the game.

3.1 Outdoor AR Sky Invaders 3D

The outdoor version of Sky Invaders 3D requires the player to use head rotations to aim and view the game overlaid over the real environment. A photo of this game taken through an optical-overlay HMD is shown in Figure 2. The game-play of Sky Invaders 3D is based on that of the 1978 arcade game Space Invaders. The user plays most of the game from the *turret* location, where they are armed with one of three different types of guns. As the user rotates their head around, this movement is reflected in changing the game's viewpoint and the gun is aimed in that direction. The gun is slaved to aim at the centre of the user's view through the HMD. Figure 4 depicts the image displayed on the HMD, and shows the player's gun, aiming crosshair, and an approaching fleet of alien UFOs. The black background shows the physical world using the see-through feature of the HMD. The game controller is used as an input device, and the user only operates a single button that is used to fire the gun. Using both the head and the hands to control the game requires users to have quick hand reflexes while rotating their head, in order to accurately aim at the invading UFOs.



Figure 5. Multiple approaching fleets of UFOs

To increase the immersion within the virtual environment, there are multiple fleets of UFOs converging on the user from three directions: front, left and right, as shown in the panoramic image in Figure 5. This requires the user to constantly be looking around to locate objects to aim at and fire upon. Initial tested versions of the game found that if all of the UFOs (the objects of interest) were located directly in front of the user, the user would perform very little head movement, and there was a very minimal sense of being immersed within the virtual environment.

When the system starts the user is presented with the main menu, and they choose the *NEW GAME* option to start a game. An introduction movie is then displayed to the user describing the goal of the game and how to operate it. The user is presented with a set of prompts to calibrate the location of the user with the GPS receiver. These screens are shown in the flowchart in Figure 3. The user must first stand at the desired location of the gun turret. When the fire button on the handheld controller is pressed, this location is stored in the game. The user then walks over to the desired position of the bunker, and this is stored in the game in the same way. These two locations must be at least 5 meters apart in order for the GPS to be able to clearly distinguish between the two locations. During the game the user is *snapped* to either the turret or the bunker position, and slight variations in the GPS position have no effect (if the user wanders too far away from the turret or bunker, an out-of-bounds visual is presented to the user and the game pauses). After initialising the positions, the user must then calibrate the direction the game will be played. This is done by looking in the direction the user would like the UFOs to attack from. The system then can correctly align the turret and bunker models over the desired real-world locations. When the game actually starts, the user is located inside the bunker. From here they can watch an introduction movie on the television screen, which gives the user reinforcement instructions and hints on how to play the game. The game timer is started when the user moves to the gun turret location to begin firing at the UFOs. The user has three minutes to defeat all the oncoming UFOs.

During the game, the UFOs also fire projectiles at the player. To take cover, the user can walk or run into the bunker, which can be seen from the outside in the centre of Figure 5. When the user walks over to the bunker location in the real environment, the user's virtual location is snapped into the bunker. From within the bunker the user can replenish their ammunition and health by pressing the fire button at each of the containers in two corners of the bunker.

In addition to the regular UFO opponents, each fleet has an extra *mothership* UFO flying above them. These motherships move in patterns, and may sometimes fly a

large circle around the player, making them harder to shoot. If these are successfully hit, then the player's weapon is upgraded. Initially the player is only able to use a cannon, which is shown in Figure 4. This gun has a very slow firing rate, and the projectiles move at a slow pace. If one of the motherships is hit, the weapon is upgraded to a ray-gun. This weapon fires at a faster rate, but the projectiles are smaller than the cannon's. The final upgrade is a machine-gun, which has the fastest firing rate and more ammunition.

3.2 Desktop Sky Invaders 3D

The PC version of Sky Invaders 3D is displayed on a conventional monitor, and controlled using a mouse and keyboard. The mouse movements control the orientation of the game, with left and right mapping to the players heading, and up and down mapping to pitch. Roll cannot be controlled, but it is not required to play the game. The left mouse button is used to fire the weapon, and the left and right keyboard keys move the player between the bunker and the turret locations.

4. User Study

In our user study, each participant played only one version of the game, either the PC or the AR version. Both versions of the game were instrumented to record the scores and time to complete the game. Our study investigated the following hypothesis:

- Research hypothesis 1 - The use of augmented reality enhances the enjoyment of playing a computer game.
- Null hypothesis 1 – Participants will enjoy a traditional indoor workstation method of interaction with Sky Invaders equal to an AR version of Sky Invaders.
- Research hypothesis 2 - The participant of an AR game will find the game intuitive to learn and play.
- Null hypothesis 2 – Participants' performance will not improve over four sessions lasting three minutes each of play of an AR version of Sky Invaders.

4.1 Research Hypothesis 1

A between-subjects design was used for Research Hypothesis 1. The 44 participants were randomly split into an PC group and an AR group. We unequally assigned participants to PC and AR versions of the game at a ratio of roughly 1:4 (9 and 35). This allowed us to gather a greater amount of data on the AR game which increased our ability to test the *intuitiveness* hypothesis, and to gather qualitative feedback on AR gaming. We used a t-test to assess that PC-vs-AR questionnaire responses differed in terms of aggregate rating of enjoyment.

4.2 Research Hypothesis 2

This hypothesis examined game scores achieved by the AR group in playing the game for up to four sessions. If a participant completed the game (achieved the maximum final score of 1600) on their first or second game, then they played only two sessions; otherwise they played up to two further sessions to try to achieve the maximum score. We used a t-test to assess that mean score improvement between sessions is non-zero.

4.3 Participants

We recruited 44 students from the School of Computer and Information Science as participants of this study. Thirty-five participants were randomly assigned to play the AR game; nine undertook the PC version. One outdoor participant was delayed due to equipment failure and dropped out before providing data. Participants were majority male, with two females in the outdoor group and one female in the indoor group. The exclusion criteria for participants were as follows: 1) The participants do not suffer from epilepsy. 2) The participants have full use of arms and legs. 3) The participants can carry a weight of 10 kilograms in a backpack on their back.

4.4 Procedure

The participants played the Sky Invaders game four times. During a session the indoor participants followed the following procedure: 1) Read an information sheet and sign a consent form. 2) The researcher read a description of how the game operates. 3) All questions to the researcher about the game were recorded by the researcher. 4) Play the game until the time limit was reached or the game was completed. 5) Play the game a second time until the time limit was reached or the game was completed. 6) A two minute rest period. 7) If the game had not been completed, play the game a third time until the time limit was reached or the game was completed. 8) If the game had not been completed, play the game a fourth time until the time limit was reached or the game was completed. 9) Completed the questionnaire.

During a session of the AR game, participants were asked to perform the same tasks as the PC participants, with the following two exceptions: 1) The participant

	AR		PC	
	M	SD	M	SD
1) The pace of the game is appropriate	4.12	1.09	3.78	0.97
2) The controls for the game confused me	1.47	0.90	1.78	1.09
3) There were parts of the game that didn't make sense	1.74	0.93	1.33	0.50
4) If I were interrupted while playing the game, I would have been annoyed	3.76	0.99	3.22	0.97
5) I enjoyed playing the game	4.32	0.81	3.89	0.78
6) I could easily aim the gun	4.21	1.15	3.33	1.32
7) I found the instructions helpful	4.38	0.85	3.89	0.78
8) I found it difficult to switch from the gun placement to the bunker	3.00	1.35	1.56	1.01
9) I knew when I was out of ammo	4.50	0.83	4.22	1.30
10) I would recommend this game to a friend	4.41	0.89	3.44	1.01
11) This game is not for me	2.06	1.28	2.89	1.36
12) I would be bored with the game after 15 minutes	3.18	1.09	4.00	1.22
13) it was hard to see the enemy	2.50	1.33	1.89	1.05
14) I enjoyed the sound effects	3.56	1.08	3.78	1.56
15) I would like to turn the music off	2.59	1.28	2.00	1.41
16) the sound helped me understand the game	3.76	1.05	3.89	0.93
17) I did not know when the game ended	1.21	0.54	1.78	1.56
18) I understood if I won	4.56	1.02	4.56	0.88
19) I would like to play this game again	4.35	0.85	3.44	1.01

Table 1. Questionnaire Results
(M = mean, SD = standard deviation)

would go outside with the researcher and don the gaming hardware. 2) The description of how the game operates was provided by the pre-recorded movie in the game itself. Because the game is played on a university campus, with many multi-story buildings around, a player has to be careful to avoid being too close to large buildings. The GPS signal is attenuated by large buildings which reduces the accuracy of the receiver. For this reason, the participants were verbally instructed on the best locations to calibrate the gun turret and bunker.

All questions that the participants had while playing will be recorded by the researcher. The participants also provided written feedback on a questionnaire form.

5. Results

Table 1 summarises the survey responses for the AR and PC participants. Of 111 games mentioned by the participants as their favourite games, 39% of these were first-person-shooter games, 21% strategy games, 12% racing games, 12% adventure games, 4% arcade style games, and 12% from other miscellaneous categories. The most commonly mentioned games were Warcraft 3, Unreal Tournament, Quake, and Command & Conquer, recorded by 7, 6, 6, and 5 participants respectively.

Response scores for questions 4, 5, 10, 11, 12, and 19 were averaged (with the scores inverted for questions 11 and 12) to form an overall *Game Enjoyment* score. Game Enjoyment was significantly higher for the AR group (mean 3.94 and standard deviation 0.71 for AR, versus mean 3.19 and standard deviation 0.84 for PC, $\text{Prob}(t) < 0.01$).

Of the 34 AR participants, 10 played the minimum 2 sessions, 10 played 3 sessions, and 14 played the maximum 4 sessions; 7 of the PC participants played 2 sessions, and 2 participants played 4 sessions. 2 of the participants who only played 3 sessions, and 8 who played 4 sessions did not win the game. Scores for the AR participants generally improved over sessions, although with a substantial variance. The mean inter-session score improvement per AR participant was 276 points (standard deviation 470 points). Despite the high variance, the mean AR score improvement was significantly different than zero improvement. ($\text{Prob}(t) < 0.01$). Figure 6 graphs the individual AR participant scores by session, illustrating the overall upward trend and individual variances.

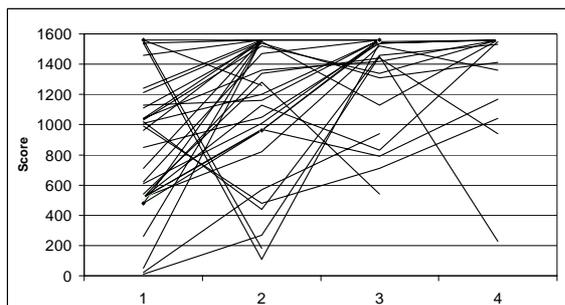


Figure 6. Scores for participant user over 4 games

6. Discussion

The results presented in the previous section demonstrated a clear improvement in enjoyment for the AR version of the game over the PC version, and the participants were able to quickly understand how to operate an outdoor AR gaming system. In this section we will discuss some of the factors leading to these results, and explore the comments made by the participants.

6.1 Participant's Engagement

Of the participant population, the majority enjoy playing the first-person genre of games. Our findings of 39% are similar as reported for the popularity of first-person shooting/action games in the United States, with 36% (Entertainment Software Association 2004). The Sky Invaders game was therefore an appropriate game genre for evaluation in terms of our participant population. This sub-section will explore in detail what participants did and did not enjoy about the outdoor Sky Invaders 3D game.

6.1.1 Survey Question Results. A survey form was filled out by each of the participants after playing the Sky Invaders game indoors or outdoors. The survey consisted of 19 questions counter-balanced with positive and negative responses. In this section we will reflect on the results of these responses.

The participants found the pace of the game to be appropriate. The game was designed for head movement as the primary means of aiming the gun. The speed of the moving ships was calibrated to make a challenging game for outdoor AR, however the speed is not as appropriate for the easier to aim PC version of the game.

The participants reported enjoying playing the game, with an increased level of enjoyment for the outdoor AR configuration. As previously stated, the Sky Invaders game has been tailored for use with an outdoor AR configuration, but participants for both AR and PC configurations reported enjoying the game. The participants would recommend outdoor AR Sky Invaders to a friend, and they would play the game again. The counter balanced negative questions reinforced that the participants enjoyed the outdoor version of the game.

The instructions provided enabled the participants to rapidly gain a level of experience starting from a novice. Some difficulties were experienced switching between the turret and bunker, and can be directly attributed to the use of the GPS system. The accuracy of the GPS system varied over the entire experiment, and at times of poor accuracy the ability to move between the bunker and gun placement was impeded slightly. This can be improved by a more complete calibration phase that better takes into account the current accuracy of the GPS satellite configuration. Another improvement we think will help is for the user to place markers on the ground to better physically define the physical locations of the turret and bunker.

The participants found the controls and the overall game easy to understand. The feedback provided by the game was appropriate and understandable. The surround sound in the game is a key engagement feature, and the

participants reported that this added to the enjoyment of the game.

6.1.2 Recorded Comments of Participants. Comments by the participants were recorded during the testing and on the survey form. The researcher recorded comments on paper while the participant was playing the game, and the participant recorded their own personal comments on the survey sheet. There were sixteen total comments recorded. We differentiated comments and questions to the researcher. Comments by the participants were viewed as statements, and questions were directed at the researcher for further instruction. The questions asked by the participants will be discussed in the next sub-section. In this sub-section we present comments from the user and discuss them to provide insight into areas of improvement for outdoor AR gaming.

Two people commented that the GPS was “too slow” and “the turret moved a few meters further away”, indicating that the GPS accuracy was fairly low while they were playing. It was observed that at certain times during the day the GPS quality would be less than at other times, which is explained by the GPS satellite constellation varying over time. Multiple participants commented that some form of physical marker on the ground would be useful to help find the bunker/turret while playing.

There were four comments related to the HMD. Because of the brightness of the sun when low on the horizon in the afternoon, one participant said that they had to hold their hand over the visor to avoid the glare. Other participants commented that the HMD did not fit them correctly, and it was observed that multiple other participants had problems with the HMD falling down. This was likely because when it was fitted it would sit correctly on their head, but as they began moving around outdoors it would work its way down, as it was not fitted as tightly as the participant anticipated would be needed.

One participant found the sound effects to be sufficiently loud that they cut out the real-world audio, and that the display area on the HMD was darker than the rest of the visor, which detracted from the realism. There were fewer positive comments written on the feedback forms, but verbal comments to the experimenter following the experiment suggested that nearly all the participants enjoyed the game and had a unique gaming experience. One participant commented that the technology was “great”, even though the game was very basic compared to modern desktop games. Another participant suggested there should be more levels in the game. This indicates they would like to see the game further developed, and that it could be made to be even more fun.

6.2 Cognitive Complexity

During the testing, the experimenter recorded questions asked by the participants during the testing phase of the experiment. This was to gauge the complexity of learning to use the system. We endeavoured to understand how difficult it would be for a novice user to learn to play and use an outdoor AR game. As previous mentioned, the experimenter gave the participant a very rudimentary introduction to the game. The bulk of the instruction was provided by the game, with the rest left to the intuitive

nature of the system. Table 2 lists the types and total number of questions asked by the participants of the researcher during the testing.

Type	Number
Understanding the use of the GPS	4
Getting started in the game	2
Aiming the gun	2
What happens at the end of the game	1
Game-play	7

Table 2. Type and number of questions asked by participants during the testing

Of the 34 participants testing the outdoor AR version of the game, only seven asked questions for further instruction, and a further three for clarification about the game-play. This demonstrates that the concept of outdoor AR gaming is intuitive and simple for users to learn. This is reinforced by the fact that 24 participants managed to gain a perfect score for at least one game within this twelve minutes of first usage. We envisage that this level would be the first and easiest level of an extended game, with the initial level provided for the player to quickly gain a basic understanding of how to play the game. The upward trend in Figure 6 clearly shows the participants having an overall improved performance with increasing amount of game-play. This also demonstrates that the participants were able to gain further skills in the game and system over repeated use. Overall, we feel that these results demonstrate that the concept of outdoor AR is graspable for novice users.

Four of the participants had some form of trouble understanding the use of the GPS positioning system within the game. The following individual questions for help were required: 1) where to place the turret and bunker, 2) how to move to the gun turret to shoot, 3) the distance to walk when calibrating, and 4) the direction to walk to get to the gun. It was commented by a number of participants that placing markers on the ground would help overcome some of these problems. We postulate this would also improve the sense of presence for the game. Two participants had some difficulty getting started in the game; the two questions were “So what do I do?” and “I assume the star button is X?” Two participants had some difficulty with the aspects of aiming, and these questions were “I couldn’t find the pink ones” and “how do I pick up the health?” Finally one participant had a question about restarting a new game.

Seven participants had questions associated with game-play such as “Do I have to shoot all of [the UFOs]?” which had been answered in the instructional movie. This indicated that although most participants watched the movie, many did not fully understand it, or did not pay attention to it. Regardless of this, we observed that most participants managed to comprehend all the aspects of the game after their first or second attempt. The participants that took longer than this to win the game did so due to their inability to shoot all the UFOs quickly enough, or not ensuring they had sufficient health while playing, rather than misunderstanding how to operate the game.

Some of the other questions that the participants asked which were not as clearly covered in the instructional movie were: "How many guns do I get?", "Can [the UFOs] hurt me when I'm in the bunker?", "Are there more pink [motherships]?" and "What do I do when I run out of ammo?". There were also some questions about the game which were not clearly outlined in the instructions, which many participants worked out themselves while others needed guidance on. These were questions such as "What do I do now?" and "Do I have to shoot all of them?"

The Sky Invaders 3D game has a three minute time-out, which means that the participant must destroy all of the UFOs before that time. In order to achieve this, the participant must usually make a conscious effort to shoot the enemy at a faster rate than they would otherwise do, and travel quickly to and from the bunker. It was encouraging to see many of the participants realize this fact, and start to move much more quickly around the game area while they played. About five of the participants got very involved in the game, and would run very swiftly between the turret and bunker, and moved around while shooting the UFOs as though they were really fighting off alien invaders. This type of energetic behaviour was not observed with any of the desktop version participants.

7. Limitations

While this study clearly presents that users found increased enjoyment playing the outdoor AR game over the desktop PC version, it is difficult to claim that this rule can be expanded to cover all AR games. It will always be the case that a poorly designed AR game will be less enjoyable than a well designed desktop PC game. Some games will always be less suitable to play in AR, such as a strategy game which may take an entire day to play. Our study does however show that given a simple first-person-shooter game implemented the same on both a desktop PC, and a wearable AR computer – the AR experience was more enjoyable.

The novelty of using an AR system (especially with users who have not used AR before) would have an effect on our results. Participants may have recorded higher than usual enjoyment simply due to the novelty of using the system. Novelty is a compelling enjoyment factor for this new form of gaming. For example, the Sony Eye-Toy is a very novel gaming system, and the Eye-Toy continues to grow in the market place. Users do not always grow out of novel gaming environments.

A future study could include requiring users to play multiple AR games, many times each, over a few weeks. After this period the novelty of using AR would be removed. They could then be asked to play a new AR game, and a desktop equivalent, and then complete a questionnaire similar to the one presented in this paper.

8. Conclusion

Based on the results of our user study, we can categorically state the following: 1) outdoor AR can improve the enjoyment of a gaming experience, and 2) outdoor AR gaming is intuitive and easy to learn for

novice users. This paper presented a user study with 44 participants, 35 using the outdoor AR configuration and nine using the indoor configuration of the game.

We measured the enjoyment of the game through the use of an exit survey after the participants either: 1) became proficient in the operation of the game by attaining a perfect score or 2) by playing the three minute game four times. The survey results demonstrated a statistically significant preference of enjoyment of the outdoor AR version of Sky Invaders 3D compared to the desktop version. The Sky Invaders game was intrinsically the same for the PC and AR versions – the simplest explanation is that the outdoor AR factor was responsible for the improved enjoyment.

The low complexity of learning to operate the outdoor AR gaming system and game was demonstrated by the low level of intervention by the researcher during the participants' game-play and the rapid improvement of the participants' score over multiple sessions of playing the game.

The participants clearly enjoyed our AR Sky Invaders 3D game. A number of improvements will be investigated in the future to provide the users of the game a better understanding of the location-based nature of the game. The placement of markers on the ground and a better calibration phase will be examined. Furthermore, the development of more challenging and higher levels will be developed to build a more complete game.

9. References

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