Augmented reality to improve surrounding awareness of mobile phone users

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ABSTRACT
Nowadays, people use mobile phones frequently for different purposes such as searching the web, checking the weather, reading, listening to music, playing games and many other tasks. This frequent use of mobile phones draws users' attention and sometimes prevents them from paying enough attention to the surrounding environment, objects, obstacles, and dangers that might threaten them, so many dangerous things can happen to them. In this paper, we have proposed an android application to measure users awareness when walking while using a mobile phone. We changed the screen background of a game to the real-time camera image, to enable users to see ahead through the phone, which is typically blocked by the contents of the screen. We asked users to play with this game, and observed them and recorded the accuracy of their attention to surroundings. Our results show that the use of mobile phones affects a user's attention to the surroundings. However, we could not find a significant difference in attention when having the camera image on the background of the app.

Author Keywords
augmented reality; mobile phone; awareness.

INTRODUCTION
With several functions accumulated in today's mobile phone, it is common to see people walking around focused on different tasks in their mobile phones, such as texting, checking directions or playing games. Although useful, this act seems to draw almost their entire attention to the screen and making people forget about their surroundings [6]. It could pose dangerous situations such as crossing streets without checking for traffic, tripping in a pothole, or simply hitting some obstacle [1][8]. These situations show a need of improving mobile phone systems in order to help people maintain or even increase their awareness of their surroundings while using the phone.

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Because of that, our research focuses on the usage of mobile phone enhancements that could potentially increase users' awareness of their surroundings. Enhancements such as a combination of input sensors, tactile response and augmented reality [3] could leverage user awareness and help decision-making to avoid dangerous situations. Like other enhanced systems such as HUD[15] (Head-up Display System), warnings or alerts could guide the user away from avoidance items and towards predefined goals.

We started our study by evaluating the effects of the mobile phone's camera in a pseudo augmented reality environment on user awareness. We augmented an existing mobile game, Frozen Bubble (see Figure 1), with the real-time camera image that enables users to see ahead through the phone. Enhanced systems such as HUD combine information on the screen with the augmented reality environment to enable users to focus on both [10]. However, in the case of a user texting on the phone, information on the screen cannot be combined with the camera background creating an augmented reality environment [9]. Therefore, by putting the live camera on the background screen of any unrelated task on the phone, we investigate how it affects the user's awareness when attention is entirely focused on the task instead of the camera.

Our contributions include developing the mobile application (making changes to an existing application), running an experiment and reporting its results. Results from this study provide a better understanding of the effect of the background camera on the user's awareness of its surroundings.

Our initial thought suggested that some improvement should be noticed, even in a pseudo augmented reality. However, data from our experiment could not point any significant difference in participants' attention with the use of the camera image on the background, as shown further ahead in our results section. Nevertheless, we expect to lay some foundation on solid experimental data that could help improve mobile phone systems on user's awareness of the surroundings.

RELATED WORK

Mobile Phone Distraction
Many research works have investigated the influences of mobile phones distraction on users and dangers which might threaten them. Nasar and Troyer have studied injuries related to mobile phone use among pedestrians [8]. Jiang et al. have investigated how different mobile phone distractions, such as

music, conversation, or messaging distraction affect the behavior of pedestrians while they are crossing the street [6]. Using an interactive and immersive virtual environment, Jacobson [4] have examined the behavior of college pedestrians when distracted by a cell phone conversation. She also investigates the impact of different distractions conditions on pedestrians safety [13].

Finally, Sobhani et al. [12] presented a similar experiment with virtual reality to study the impact of mobile phone distraction in crossing roads. They also propose a safety measure with color changing flashing LEDs on the crosswalk. Their results show a significant negative impact of the mobile phone usage on the performance of crossing roads, as well as a significant improvement of the pedestrian awareness when the safety measure is in place.

Mobile applications and safety

Many efforts have been devoted to developing mobile applications that preserve users safety when working with the mobile phone and walking. Wang et al. have proposed WalkSafe, an Android smartphone application, that helps pedestrian mobile phone users that walk and talk to improve their safety. This application uses the back camera of the phone along with machine learning techniques to detect approaching vehicles and alerts the user of unsafe conditions using sound and vibration from the phone [14].

Liu et al. have proposed InfraSee, a system that is able to detect a sudden change of ground using a small infrared sensor. It helps users to be aware of dangers like trips, falling from stairs, or falling into an open hole [7]. Jain et al. have created LookUp that uses shoe-mounted inertial sensors which are able to extract the user step pattern and the inclination of the ground and send the data to a smartphone application. It helps users to be aware of stepping over a curb or walking down sidewalk ramps[5]. Zhou has developed HeadsUp, a walk pattern recognition system that uses mobile phone sensors such as accelerometer and gyroscope to compute movement pattern of mobile phone users and warns the user and locks the screen when the user looks at the mobile phone while walking [16].

Augmented reality and awareness

There are several pieces of work conducted on awareness improvement with the use of augmented reality. A few of them are briefly discussed here, which all describe the use of overlaid information into real-time images of the environment. This kind of composition brings users to the full attention of both the task being performed and their surroundings.

Grubert et al. [3] describe the concept of "Pervasive Augmented Reality" where the interface is totally context-aware of the user's surroundings, and extra information overlays with images seen through the screen. In this kind of systems, the user is in total control of the interaction between the environment and the information seen, thus totally focused on both with increased awareness.

Rehman [9] explored the use of augmented reality to assist users on performing specific tasks. Although pointing that

(a) (b)

Figure 1: (a) original game (b) modified game

augmented reality did not affect the learning effect on the performed tasks significantly, results show that it improved the situation awareness of the task being performed in the defined workspace. Again, this study considered overlaying of information and image, with the user fully focused on both.

Ruano et al. [10] discusses an augmented reality tool that overlays information to a video stream screen for UAV (Unmanned Aerial Vehicle) operators. Results show a significant improvement on the situation awareness of operators while performing their missions, again focusing totally both on information and image.

Rusch et al. [11] explored the use of augmented reality to increase driver's attention to roadside hazards. Information related to obstacles or intersections were displayed overlaid to the real-time video exhibition of the driveway. Results show benefits in response time and response rates for displayed hazards, and false alarms did not affect the driver's response.

To the best of our knowledge, no previous research work was performed with full attention given only to one of them, either the task being performed or the environment shown by augmented reality techniques. However, Ayers et al. [1] present an assessment of accidents potentially caused by the game Pokémon Go. This game presents an augmented reality mode, where the player is fully focused on the task of catching a pokémon. While this mode overlays information to the real-time image of the environment, they are completely independent. Their findings would suggest that this mode does not improve the awareness of the player to the surroundings.

IMPLEMENTATION

The main idea of this study is to understand the effect of one specific enhancement of augmented reality on the user's awareness of the surroundings. Therefore, we perform an experiment where the participant is focused on a specific task on the mobile phone while it is possible to visualize the cur-

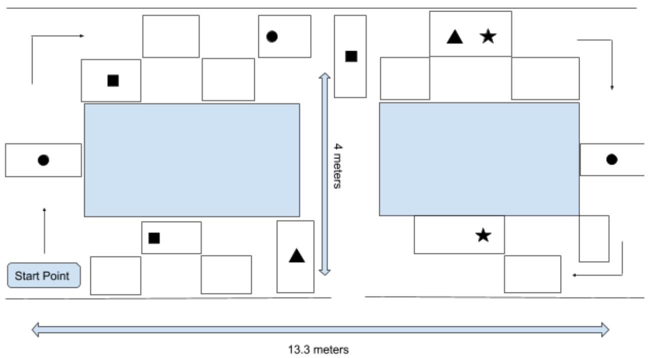

Figure 2: experiment circuit map

rent environment (surroundings) through the real-time camera image on the screen background.

To perform this kind of experiment, we used a mobile app where the user is fully focused while performing a specific task. In our case, we decided for implementing the game "Frozen Bubble" [2] (see Figure 1a) for Android devices. The characteristics of this game retain the entire attention of the user, as not taking action for too long might cause the user to lose the game. In addition, the game layout on the screen allows a significant amount of free space to visualize the real-time background camera while still playing the game. Therefore, to fit our experiment, we adapted the game to display the real-time camera image on the background (see Figure 1b) while logging the participant's actions during the game.

With the custom implementation of the game, the participant should walk around a predefined path while playing the game. This predefined path contains obstacles such that the participant is forced to bear right or left to avoid them. Some situations also require the participant to step over an obstacle. To create obstacles, we simply laid out pieces of paper on the walkway, requesting users not to step on them.

Also, we wanted to measure the accuracy of a participants' attention to their environment. For this purpose, we printed a set of different shapes on each paper that we placed on the ground and asked participants about the shapes they have observed. For this experiment, we used squares, triangles, circles, and stars. The shapes were printed in the size of a Letter-sized paper, all in black. Figure 2 shows the circuit and obstacles layout, and distribution of shapes on obstacles. After each run with the shapes laid down, we asked the participants the following questions:

- Did you notice any shapes laid down on top of the obstacles?
- If yes, what kind of shapes did you notice?
- How many of each shape could you notice?

During each run of the experiment, we observed how many times the participant steps on an obstacle. It is considered an "error". By calculating errors in addition to the shapes observed, we can measure how accurately participants pay attention to their environment when working with their mobile phone.

EXPERIMENT

Pilot Study

We first conducted a pilot study in order to find the problems and limitations of our experiment and try to improve it. Four people from our lab (2 males and 2 females) participated in the pilot experiment. First, we asked each participant to play with the game for a while to become familiar. Then we asked them to walk through the circuit one lap and try their best not to step on papers, and we measured the time and the number of errors. After that, we asked them to walk and play the game. This pilot study revealed some important points. First, we realized that the number of obstacles was not enough and it was easy for participants to avoid obstacles and finish with no errors. Hence, we decided to increase the number of obstacles.

Another finding was that one lap was not enough and the participants were able to finish that quickly, so in order to get more reliable results, we decided to increase the number of laps to two. Also, we wanted to make sure that the size of shapes was large enough for participants to see through the screen, and all the participants mentioned that the size of shapes is appropriate.

Full Study

For our study, our hypotheses are stated as follows:

- Null hypothesis 1: Usage of a mobile phone while walking does not decrease environment awareness.
- Alternate hypothesis 1: Usage of a mobile phone while walking decreases environment awareness significantly.

If alternate hypothesis 1 is confirmed:

- Null hypothesis 2: This kind of visual aid (augmented reality) does not change awareness significantly (i.e., if the user is fully focused on the task, the user will not perceive the background).
- Alternate hypothesis 2: This kind of visual aid (augmented reality) improves awareness significantly (i.e., the user can better avoid obstacles and other dangers in the walkway).

To run the experiment, the following protocol was performed with each participant. After setting up the walking path and the app, we conducted the following experiment block with each of the participants:

1. Block 0: playing the game for a while (learning), ideally for a longer time than it took to complete the walking course. We measured game score in 1 minute, as the mean time to complete the circuit with the mobile phone was around 1 minute. In case the participant lost the game before 1 minute, we asked to start over, and scores from multiple plays were added up to 1 minute.
2. Block 1: walking with no mobile phone. It is the baseline for performance fully focused on walking. We measured time and errors.

3. Block 2: walking and playing the original game. It is the baseline for performance focused on the game and can be compared with the baseline entirely focused on walking. We measured game score, time walking, errors and attention accuracy (with shapes survey).

4. Block 3: walking and playing the modified game (with the camera on the background). It is the performance comparison with previous baselines. We again measured game score, time walking, errors and attention accuracy (with shapes survey).

We conducted the experiment in our office, which is the Software Analytics Group (SWAG) Lab in the University of Waterloo. We gathered 13 participants for the experiment. Except for one participant who was the HCI course instructor, all of the other participants were HCI course students including 10 males and 2 females.

The length and the width of the space used for the experiment were 13.3 and 4 meters respectively. Figure 2 shows the map of the space used for the experiment and the position of obstacles. Obstacles were created by attaching 6 letter-sized sheets of paper. We decided to use papers as obstacles and ask participants try not to step on the papers due to safety reasons, as real obstacles could be dangerous for the participants and hurt them.

Ten large black shapes were laid down on some of the obstacles. We used 3 squares, 3 circles, 2 stars, and 2 triangles for block 2, and 4 squares, 2 circles, 3 stars, and 1 triangle for block 3. Figure 3 shows an example of a triangle and a star on obstacles. During block 1, where participants had to walk two laps without using the mobile phone, we flipped the shapes over so that participants could not see them. After that, we asked participants to step into a spare room in our office in order not to see the changes we applied to the shapes. We flipped the shapes over after block 1 so that participants could see them, and we replaced one circle with one square and one triangle with one star after block 2, to change the number of shapes. After finishing blocks 2 and 3, we asked each participant whether they could observe any shapes on the ground or not. Then we asked about the type of shapes they could see and the number of each shape. At the end of the experiment, we explained the purpose of our research to the participants and captured any comments they had.

In order to find any potential learning effect we balanced game types for block 2 and block 3. In other words, for half of the participants we asked them to play with the regular game first (block 2) and with the modified game second (block 3), and for the other half of the participants, we changed this order. So for some users block 2 includes the regular game and block 3 includes the modified game and for others, it is reversed.

RESULTS

Hypothesis 1

First, we want to reject null hypothesis 1. In this null hypothesis, we define awareness in terms of three dependent variables, time to complete the circuit, game scores, and the number of errors (obstacles that participants stepped on) which are dependent variables. Our independent variables for this hypothesis are block and game type.

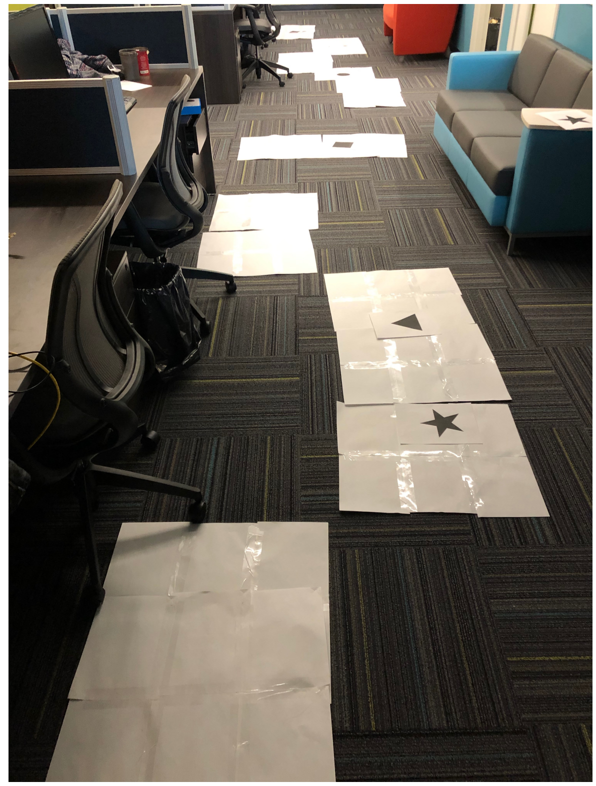

Figure 3: An example of obstacles and shapes

Time

The mean time for block 1, in which the user had to walk around the circuit for two laps without using the mobile phone, is 48.14s and the values for block 2 and block 3 are 60.6 and 60.93 respectively (Figure 4a). Since we have a within-group design and we have three levels for block variable, we did an ANOVA test that revealed a significant effect of block ($F(1,12) = 26.98$, $p < .001$, petsasq = .69) on time. Then we did a pairwise comparison to find where the significant effect comes from. The results revealed that there is a significant increase ($p < 0.001$) in time between block 1 and two other blocks which means the experiment takes less time when the participant is walking without using the mobile phone.

Regarding the game type, we have three game types. We call the game type of block 1 "None" and denote it with a dash. So we have None, regular, and camera game types. The mean times for None, regular and camera game types are 48.14s, 62.02s, and 60.52s respectively (Figure 4d). ANOVA test revealed that there is a significant effect of game type ($F(2, 24)=33.88$, $p < 0.001$, petasq = .74) on time. Again we did a pairwise comparison to find where the significant effect comes from. The results revealed that there is a significant increase ($p < 0.01$) in time between None game type and two other game types. It means the experiment takes less time when the participant is walking without playing any type of game.

Game scores

Here we investigate the effect of block and game type on game scores. In the first part of the experiment (block 0), participants played the game without walking for 1 minute. The mean scores for blocks 0, 2, 3 are 33.46, 30.54, and 33.85 respectively (Figure 4b). ANOVA test showed no significant effect (F(2, 24) = 0.85, p = .441, petasq = .07) of block on score.

We call the game type of block 0 (when the users plays the game for a while to get familiar) "initial" type which is denoted with a dash in figures. So we have initial, regular, and camera game types and the mean scores for these three types are 33.46, 32.46, and 31.92 respectively (Figure 4e). ANOVA test showed no significant effect (F(2, 24) = 0.15, p = .862, petasq = .01) of game type on score.

Errors

Here we investigate the effect of block and game type on the number of errors. We have errors for blocks 1, 2, 3 (no error for block 0) were the user had to walk. The mean error values for blocks 1, 2, 3 are 0.38, 0.66, 0.69 respectively (Figure 4c). After running Shapiro normality test on error data, we realized that it does not follow normal distribution. So we decided to use Friedman non-parametric test. Friedman test showed no significant effect (chi-squared = 1.0667, df = 2, p-value = 0.5866) of block on the number of errors.

The mean error values for game types None, regular, and camera are 0.38, 0.54, 0.77 respectively (Figure 4f). Friedman test showed no significant effect (chi-squared = 3.2, df = 2, p-value = 0.2019) of game type on the number of errors.

In conclusion, we can not reject null hypothesis 1 completely. We can reject it from the viewpoint of time. In other words, we found that using the mobile phone has increased the time variable significantly, but it has not had a significant effect on scores and errors.

Hypothesis 2

In hypothesis 2, we define three levels of awareness. The first level of awareness is merely noticing any shapes while walking and playing. The second level of awareness would be identifying what kind of shapes were present on the obstacles correctly. The third level of awareness is counting the numbers of each shape laid on the obstacles correctly. We had shapes only for blocks 2 and 3 and as a result only for regular and camera game types.

First level of awareness

All of the users were able to notice shapes in both blocks except one user who could not notice any shape in any of the blocks 2 and 3. Since the result has not changed between blocks for all users, there is no significant effect of block or game type on first level awareness. It was confirmed with a Wilcoxon signed-rank test (V=0, p=value = NA).

Second level of awareness

There were four types of shapes (squares, circles, triangles, stars) in both block 2 and 3. The second question that we asked from participants after blocks 2 and 3, was about the type of shapes they could observe. We calculated the number of shape types identified for each participant. The minimum for this value is zero (when the participant did not mention any of the mentioned four shape types), and the maximum is 4 (when the participant mentioned all types correctly). The mean values of shape types correctly identified for block 2 and block 3 are 1.62 and 2.85 respectively (Figure 5a). Wilcoxon test revealed a significant effect (V = 3, p-value = 0.01288) of block on shape types identified.

It indicates that users were more aware of shapes on the second time they were running the experiment (block 3) which means there was a learning effect between block 2 and block 3. However, Wilcoxon test showed no significant effect (V = 24.5, p-value = 0.7956) of game type on shape types identified. The mean values of shape types correctly identified for regular and camera game types are 2.31 and 2.15 respectively (Figure 5c).

Third level of awareness

There were 3 squares, 3 circles, 2 triangles and 2 stars for block 2, and 4 squares, 2 circles, 1 triangle and 3 stars for block 3. The third question that we asked from participants after blocks 2 and 3, was about the number of each shape they could observe. We calculated how far off the estimated value is from the correct value. For example, for block 2 the formula is described by equation 1.

$$\begin{aligned} errors = & abs(3 - squares)) + \\ & abs(3 - circles)) + \\ & abs(2 - triangles)) + \\ & abs(2 - stars)) \end{aligned} \tag{1}$$

Likewise, errors in identification of shapes in block 3 are described by equation 2.

$$\begin{aligned} errors = & abs(4 - squares)) + \\ & abs(2 - circles)) + \\ & abs(1 - triangles)) + \\ & abs(3 - stars)) \end{aligned} \tag{2}$$

The mean count errors for block 2 and block 3 are 7.31 and 4.69 respectively (Figure 5b). Wilcoxon test showed significant effect (V = 60.5, p-value = 0.01569) of block on the number of shapes identified. Again, it confirms the learning effect between blocks 2 and 3 because the error is less for block 3. Nevertheless, Wilcoxon test showed no significant effect (V = 35, p-value = 0.8932) of game type on number of shapes identified. The mean count errors for regular and camera game types are 5.92 and 6.08 respectively (Figure 5d).

In conclusion, we can neither reject nor accept null hypothesis 2. The results did not show any significant effect of using the

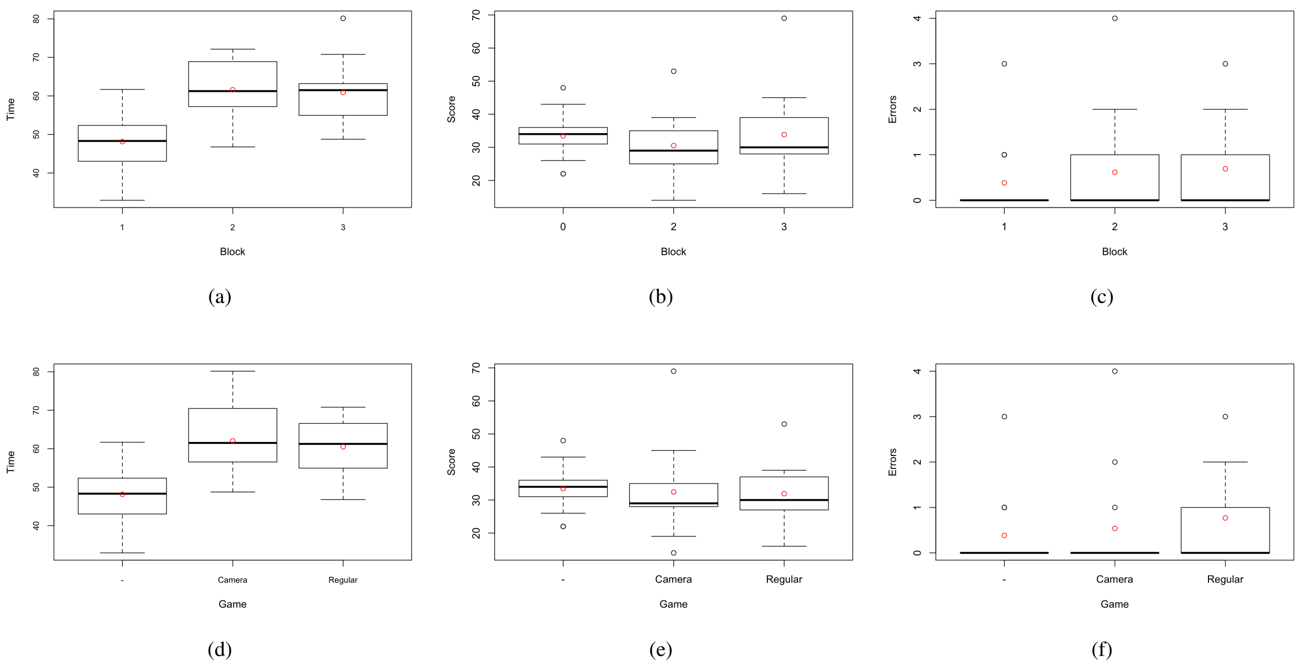

Figure 4: Time (a), scores (b) and errors (c) aggregated by blocks. Time (d), scores (e) and errors (f) aggregated by games. Mean values are represented as red dots within boxplots.

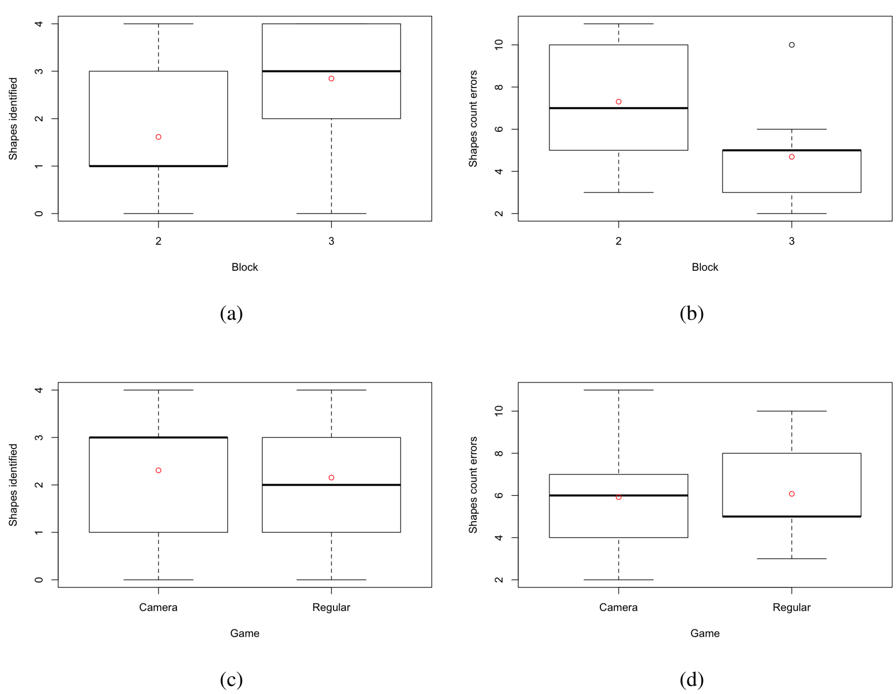

Figure 5: Shapes identification (a) and count errors (b) aggregated by blocks. Shapes identification (c) and count errors (d) aggregated by games. Mean values are represented as red dots within boxplots.

modified version of the game on noticing, identifying or counting shapes. There was only a learning effect for identifying shape types and counting shapes between block 2 and block 3.

DISCUSSION

We received some interesting comments from the participants during the experiment. After the first run working with the modified version of the game, one participant mentioned that the camera did not help that much. However, after the second run working with the regular version, it was mentioned that the camera actually helped. It was interesting for us that, after comparing the two versions, the participant preferred the modified version.

Another participant stated that, after working with the augmented version of the game for a while and getting used to the camera, it might help to see the surroundings better. These two comments show that, in the beginning, it might not be that easy for users to use the camera to see the obstacles. However, after a while, participants get used to the camera and observing the surroundings through the camera might become easier for them.

One participant mentioned that rarely looked at the camera because it was pointing down, so it was difficult to see further ahead through the camera. We believe that it highly depends on the angle that the users hold the mobile phone and how much they bend their neck to look at the phone. Since other participants did not have this problem, we think that this specific participant was bending his neck too much and was looking at the area near his steps through the camera.

In addition, two participants told that it was difficult to see peripheral objects through the camera since it presented a noticeable time delay to refresh the image. It is an important point that we should consider for further studies and future approaches.

LIMITATIONS

There are some limitation aspects in our work that could be improved. First, we had a limited number of participants. In the cases which we could not find a significant effect, more participants might help us to find significant correlations between awareness and applied approaches (e.g., significant effect of camera game type on time or score).

Another limitation is that we only used a game mobile application for this study. Other types of applications might generate different results, especially because of some specific characteristics of games that other applications do not bear. For example, messaging apps do not require constant interaction from the user, meaning that the user can stop the messaging task at any moment and pick it up later on at the same point. This might require less attention from the user to the app, hence providing different results in an experiment like ours.

Finally, a threat to internal validity might be present due to the fact that we did not run any blocks with the modified camera game while the participant was not walking. Although we believe that this might not affect results (since the participant would not be vulnerable to obstacles in this situation), we do not have supporting data to confirm this.

CONCLUSION

In conclusion, we conducted an experiment to measure how participants' awareness changes when they use our proposed modified game that enables them to see ahead through the mobile camera. Our findings reveal that using mobile phone increases the time to walk through a specific path. We found no significant effect of block on game score and the number of errors which indicates that there was no learning effect for these two variables.

On the other hand, we observed a learning effect in terms of noticing, identifying and counting shapes between blocks 2 and 3 which means the participants focused more accurately on the shapes the second time (block 3) that they were exposed to shapes. However, we did not see any significant difference on awareness between game types, which means that with the current number of participants we can not strongly state whether the camera improves the surrounding awareness or not. We need more participants to be able to make firm conclusions.

FUTURE WORK

There are many possible improvements and extensions to our work. The first idea is to run the experiment with more participants. For any situations that we could not find a significant effect, more number of participants might reveal a significant effect of using the modified version of the game on awareness. Another possible extension is to run the experiment using other kinds of mobile applications (e.g., texting, searching or shopping apps). Also, we can enhance the application to be able to identify obstacles and alert the user. Furthermore, We can use different obstacles with different properties (e.g., moving obstacles).

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APPENDIX: DELIVERABLES AND ASSETS

As part of the project deliverables and assets, we provide here the following links:

- Video figure, where we present our technique and experiment tasks: https://www.youtube.com/watch?v=mLMNbknCOt4.
- Modified app source code: https://github.com/cassianomonteiro/cs-889-project.
- Experiment data, R evaluation scripts and this paper can be found in the `experiment` folder within the project's source code: https://github.com/cassianomonteiro/cs-889-project/tree/master/experiment.
- Final presentation slides: https://docs.google.com/presentation/d/1zX1z0NL0qYRoMVOGXmmb7gtw0d6j_gIH9GSon7PzpPs/edit?usp=sharing