Investigating the Role of Gesture Modalities and Screen Size on Fatigue, Game Competence and Engagement in an AR 3D Maze Game.

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ABSTRACT

In pursuit of immersive AR Games, the interaction via gestures is often considered as an ideal method of interaction. Several studies have explored the impact of various gesture modalities employed in AR games. However, the attention paid to investigate the effect of screen size in conjunction with the gesture mode in AR games is minimal. An experimental study was designed with AR prototypes of 3D game to investigate the effect of gesture modes for varying screen sizes on the game competence, fatigue and user engagement. The test results revealed that the gesture modes affect the game competence and fatigue while they had no impact on user engagement. Further analysis has unraveled that surface gesture outperform for tasks like attacking and motion gesture outperform for turning a character in AR games. The role of screen size was studied and the results suggest that it had no effect on AR game design.

CCS CONCEPTS

• **Human-centered computing** → *Mixed / augmented reality.*

KEYWORDS

Augmented Reality, gestures, screen size

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1 INTRODUCTION

The interaction via gesture is often considered as an ideal method of interaction [11] in an Augmented Reality (AR) game. Gestures are also entitled as a natural user interface as they enable users to interact with the game as if they interact in the real-world scenarios. [2]. Since the advent of touch screen mobile devices, the surface gestures have occupied the prominent place as a primary mode of interaction [5]. On the other hand, the user defined motion gestures [18] for AR games is also gaining momentum recently as an emergent gamification element [22].

Several studies have explored the impact of various interaction methods in AR games [3][9]. However, the attention paid to investigate the effect of screen size in conjunction with the interaction mode in AR games is minimal. The size of the screen does leverage the user engagement in games [10]. Many scientific studies have unraveled potential benefits relevant to the increased screen size such as effectiveness, efficiency and perceived usability [15]. Further, the increased screen size has also improved the competence in games via reducing the time taken to accomplish the game tasks accurately [19]. Further, studies have also confirmed that the increased screen size causes greater visual fatigue [12]. On this ground, the investigation of intertwined effect of screen size on the gesture mode is paramount to overcome design issues in developing a successful AR game.

Figure 1: An experiment with AR puzzle game

On the basis of these premises, this experimental study is designed with AR game prototypes of a 3D game to investigate the effect of varying gesture modalities and screen sizes for game tasks such as jump, turn left/right and attack on the metrics such as fatigue, game competence and engagement of players. The count of the three tasks is considered to be a confounding variable and thus maintained equally throughout the game. The following is the list of hypotheses that this study is built upon.

- **H1:** The mode of interaction has significant interaction effect with the screen size on game competence because control-display relationship is an important factor that affects performance.
- **H2:** Motion Gestures in small screens work better to rotate or turn a character in a 3D environment and it improves the user engagement due to perceived ease of control.
- **H3:** Surface gestures in large screens works better for actions like attack and jumping and improves the game competence as accuracy improves with size.
- **H4:** Fatigue is highly associated with increased screen size, but surface gesture will cause a higher fatigue as surface gesture on large screens cause excessive visual stimulation.

The comparative analysis of the responses from experimental groups collected via a standard questionnaire have found that the interaction mode has significant interaction effect with the screen size. Further, all the metrics under the study such as the fatigue, competence of game and user engagement increased linearly with the increased screen size. In addition, the use of surface gestures on a large screen size increased the game competence mainly due to the fact that surface gestures have been in practice over many years. However, motion gestures led to the improved user engagement as it facilitates perceived ease of control of games [22].

This study contributes to the design of AR game in two important ways. At first, the findings from our study reveals few best practices in design choices of AR games that would leverage the game designers and marketing practitioners to produce user engaging AR games. Secondly, we highlight the importance of the intertwined influence of screen size and gesture modalities along with the underlying psychological mechanism. As gestures still serve as a pertinent mode of mobile interaction not only in gaming but in diverse of application contexts, we believe that this study contributes substantially to the extant literature on interaction effects.

2 RELATED WORK

2.1 Gestures

Different from traditional input with keyboard or mouse, mobile platforms enable various new modalities via sophisticated sensor technologies. One input modality involves surface gestures (e.g. clicking, dragging, and moving objects on the screen of a mobile device). Another input modality involves a set of motion sensors (e.g. accelerometers, gyroscopes, orientation sensors), where users can engage in motion gestures (e.g. shaking, tilting, or rotating a mobile phone) in the 3D environment. Related work in [20] proposed the use of device tilt in conjunction with touch control in mobile games using two virtual analog sticks to independently control player movement and orientation. Robert and Andrew performed experiments using four control modes (touch-touch, touch-tilt, tilt-touch, and tilt-only) [20]. They concluded that participants preferred touch-based control since it is commonly used and easiest [20]. But the tilt-based movement was a close second in subjective preference since it can provide intuitiveness [20]. Participants claimed that 'Tilt-Touch' is the most engaging and fun [20].

Follow-up research on those two gestures is also conducted by Dong and Clark [5]. They allowed participants to define surface and motion gestures from 12 tasks on 6 mobile AR applications [5]. After clustering total gained 504 gestures, the final gesture set of 13 surfaces and 12 motion gestures are gathered [5]. By comparing the sets in terms of goodness, ease of use, and engagement, the survey has shown that surface gestures were familiar legacy gestures that were easy to use but motion gestures were more engaging [5]. Both papers concluded as touch is easier and tilt is more intuitive. Playsketch is a 2D top-down racing game, where players draw racetracks on paper and then play the game using their own drawing as a basis for track design [17]. In Playsketch, five control schemes of four surface gestures (button, wheel, joystick, button, and joystick) and a motion gesture (tilt) are compared [17]. Since the game was developed for children, the participants prefer surface gestures over tilt [17]. In our study, we will investigate user engagement and game competence on the most popular gesture types which are surface gesture (touch-based) and motion gesture (tilt-based).

We can also analyze common issues based on different gesture types. A compact secondary research paper reviewed three different gestures for 3D object manipulation in mobile AR [8]. They investigated surface (touch-based) gestures, mid-air gestures, and motion gestures [8]. They discussed improving the user's AR experiences, including fatigue, and other specific issues [8]. The fatigue may affect the user's AR experience that directly determines the effective interaction time in prolonging the activity period [8]. They concluded that compared with touch-based and mid-air gestures-based, the device-based technique seems more robust in fatigue context because the user can interact using both hands [8]. Fatigue will not be very distinct in our system since participants are restricted to use both hands for both gesture types. However, it will be more interesting to analyze fatigue over the combination of different screen sizes and gestures. In contrast, we will investigate the interaction effects of two gesture types and three screen sizes in our proposed AR application.

2.2 Screen Sizes

Past researches have shown that screen size affects user experience and usability and cognitive load. [15] conducted a study on the effect of screen size over user's perceived usability, efficiency and effectiveness with the information seeking task. The result claimed that screen size matters for the typical everyday mobile users and it is more efficient with a larger screen size. [16]. also claimed that the larger the screen size is, the better the experience users will get when watching contents. Although the large screen promotes better experience, it decreases the portability of the device and reduces the ability to use the device with one hand. The larger screen size also leads to an increase in cognitive load in learning tasks as well [1].

For those who mainly use their device to play games, or watch media, the larger screen size will lead to higher enjoyment and leverage the user engagement [10, 15]. [21] demonstrated the usage of eye tracking to study the effect of screen size on experience of immersion. They found that users get more significant experience of immersion when they play games with bigger screen size than playing with smaller screen size, which align with the result of [10, 15].

However, there is a little volume of research investigating the effect of screen size on users when they perform augmented reality tasks. The recent study of [23] tried to investigate the relevance of screen size on users' choice of VR/AR by allowing the participant to experience both VR and AR scenes. In contrast with the previous research study on the effect of the screen size, [23] found that not many participants thought that the largest screen size (10.8-in.) was the best option to experience AR scenes. The proper screen size to experience AR would be between 5.8-in. to 9.7-in.

[23] conducted the research on this topic with 5 different device screen sizes, but the interaction on AR content is not considered. The participants only watched the content of the AR with no other interactions. Therefore, in this study, we investigate the effects of screen sizes and gesture modalities on game competence and engagement in an AR 3D maze game.

2.3 User Engagement in AR Games

There are numerous factors that might involve and maximize the impact of user engagement in AR mobile games development. Firstly, the goal is the main source of the reward experience in achieving optimal engagement for AR applications. Explained overriding and intermediate goals would require players to continue playing the games to find out the answers. [4]. The Satisfaction is the other factor for engagement in AR games. As suggested by [6] that satisfaction in user engagement as novelty, endurability and felt involvement. The Focused Attention is the next factor and in fact will keep the user's attention in order to engage or immerse them in any activity of AR applications. [4]. The Mixed Fantasy is the next and the synchronization of play between the real-world and virtual environments is a key factor in AR games. [**?**] In the mixed fantasy triad, it is important to balance between both virtual and physical content. According to [4] its suggested three different content to be considered i.e. virtual, real and imagination content. Other factors included the way to locate a precise virtual 3D object in real environment setting. Perceived Usability is another factor and it refers to the how convenience and ease of use to everyday life situations particularly for mobile technology. [4] The Challenge motivates the player to continue play the game by finishing all challenges provide inside game such as surpassing opponents, reaching desired goal, mastering skills and testing skills [4]. The Interaction in AR is slightly different than other technology for the users to interact with real physical world. Good interaction design will create more enjoyable feeling that significant for engagement [4]. Finally, the social factor, that according to [4] the social element in game such as multiplayer function, leader board, and social network links are necessary include in order engaging user in interactive mobile technology.

2.4 Tasks

Designing the tasks of Augmented Reality mobile games with AR interfaces is challenging to provide an interactive and immersive paradigm in which digital information is blended with the physical world. Moreover, virtual controls are also available in mobile phones by simulating joysticks and buttons for the game actions. Recreating the experience of a real game increases external validity by decreasing boredom or distraction and making the games more challenging and engaging. Some AR games applied immersive game tasks like killing the enemies as the goal with different movements. In Angry Bots Arena [20], the player needs to search and destroy a boss robot while avoiding or destroying enemy robots (mines, flyers and walkers). The game trial ends when the boss robot is destroyed. For these tasks, the player movement (left, right, forward and backward), shooting robots and player orientation was controlled by both touching (joystick) and tilting the phone [20]. The limitation in this work is that with tilt and touch control mode, participants often ran sideways, employing tilt-based aiming minimally. Despite the virtual joystick for movement, they tended to slide along walls and collide with the environment more often [20]. In fact, since physical actions happen in the 3D space, while graphics user interface (GUI) is rendered on the 2D screen, it is even more challenging to achieve this goal with physical interfaces [13]. Maze games have been developed using AR interfaces to provide a platform for user studies that further understand player interactions and experiences in mobile AR games. Moreover, maze games let the players move in complex and branched passages to find a particular target or something and different movements can be applied. NerdHerder is a maze-like mobile 3D puzzle game that tries to combine the knowledge from both human-computer interaction and game design to create an engaging game-play experience for players who may not be familiar with AR interfaces. It runs on mobile devices (tablet and phone) and uses marker-based technology [13]. NerdHerder has very simple tasks in which a player can attract nerds towards the donut or repel nerds away from the paperwork in order to guide nerds to their cubicles using virtual fishing rod attached to the mobile phone camera through closed or locked doors, over conveyor belts, and through revolving doors [13]. For these tasks, the lure that the player uses to herd the nerds is attached to a fishing line and moves the lure sways back and forth by twirling and swinging the phone [13]. This game has some limitations. It works best when at least some part of the target is in the camera's view [13]. Another AR mobile game called ARQuest is a very fun game in which a young pirate has to explore the island, find and open a treasure box, avoiding any possible obstacles that may stand in his path. The available commands are: forward, turn left, turn right, pick up and throw [7]. Forward moves the pirate to the next cell in the direction he is facing, turning left and right changes his direction respectively and pick up allows the pirate to take and hold the element found in his current cell [7]. The challenge terminates successfully when the pirate finds himself in the position of the treasure box holding the key [7]. Some students confused with the difference between pick and throw command as pick up allows the character to hold the element found in the current cell, while the throw command makes the character throw the item player is holding to the next cell forward [7]. To address the limitations of previous works, we applied jump, turn and attack the enemies with both tilt and touch control modes in our 3D mobile AR maze game and we expect that the game is more challenging and engaging.

3 METHODOLOGY

3.1 Participants

Twelve participants (9 male and 3 female) took part in the study between the ages of twenty-four and thirty-four (M = 25.91, SD = 2.07). The familiarity towards playing AR in mobile game platforms were recorded where 7/12 participants have experience with AR. Participants were not paid for involvement in the study and prior permission was obtained for recording.

3.2 Apparatus

The experiment used iPhone7, iPad Mini, iPad Pro 2020 for varying screen sizes. The display sizes measured diagonally were 4.7", 7.9" and 11" respectively. The Application was implemented using Unity 3D and Vuforia for target-based AR. The game was implemented and tested to run in an iOS platform across the devices concerned.

3.3 Task

This game involves controlling a player to navigate a scene while avoiding traps and killing the monsters. The scene has a single, flat, and clearly delineated path to its terminus where upon the player encounters monsters as he navigate. A game trial ends in 45 seconds which is the time limit of each trial. Within 45 seconds, the player is able to kill as many monsters as possible. The number of monsters attacked will be accounted for game competence. The number of monsters in the scene will be spawn maximum at 20. When the monster is attacked, it will disappear and the new monster will be spawned. The game uses either motion or surface for controlling.

The three game tasks included in the game were "jump" to avoid the traps, "attack" to kill monsters, and "turn" to change the direction that is controlled either by tilting the phone or touching the phone display. With surface gesture, the player needs to tap the display for attacking, swipe up for jumping and swipe left and right for turning left and right. On the other hand, for motion gesture, the player needs to tilt up the phone to jump, tilt down to attack and tilt left and right to turn left and right respectively.

3.4 Experimental Design

The experiment employed a 2 x 3 factorial within-subjects design for gestures and screen size variables. The independent variables and levels were as follows:

(1) Gestures (Surface mode and Motion mode)
(2) Tasks (Jump, Turn, and Attack)
(3) Screen size (4.7", 7.9", and 11")

The metrics of the study were game competence, user engagement, and fatigue. The age and educational background of participants are assumed as random variables. Participants were asked to use both hands to hold the device in landscape orientation throughout the game play and move around in order to play the game. Implementation of AR game with surface gesture and motion gesture is considered a confounding variable for this study.

Condition	Screen Size	Gesture Mode
C0	4.7"	Motion
C1	7.9"	Motion
C2	11"	Motion
C3	4.7"	Surface
C4	7.9"	Surface
C5	11"	Surface

Table 1: Test Conditions

The experiment is ordered using the balanced Latin square for gestures and screen size variables while three levels of the task are randomized in the game. Participants have a minute break between each trial. They have to fill a questionnaire with responses on a 5-point Likert scale during break time. Since the time limit to play a trial is 45 seconds, the total time for the whole experiment is 9.5 minutes. The test condions are listed in Table 1

3.5 Procedure

Participants were greeted upon arrival and clear instruction on playing the game and the purpose was provided. The practice time was provided to reduce the shock effect caused by playing an entirely new game which could impact the results of our study. At first, the questionnaire to collect the demographic information was provided before the experiment. Participants were told to jump over the traps and attack as many monsters as possible along the way. The experiment involved playing through the same map for each of the test conditions in a random order. The player started by navigating through the scene to kill the monsters. The whole experiment was recorded for future implications. Upon completing a trial, a short break was given for players before the next trial began. A post questionnaire was provided to measure the user engagement and the fatigue caused by playing each of the game mode for varying screen sizes. Participants were allowed to revise their responses after the completion of the entire experiment.

3.6 Questionnaire

The questionnaire on User Engagement followed a standard questionnaire of UES-SF [14]. There were 12 questions focusing on Focused Attention, Perceived Usability, Aesthetic Appeal and Reward. The average of the responses were considered as user engagement level of each participant. The questionnaire had also included questions measuring the fatigue and the preference of a specific task across test conditions. The responses were recorded for analysis.

4 RESULTS

4.1 Experimental Results

The statistical analysis on collected measures were performed to investigate the main effect and interaction effects of screen sizes (three levels) and gesture modalities (two levels) on game competence. The assumption check of normality on the data using Shapiro-Wilk test was significant, suggesting that the data is not normally distributed. Non-parametric Durbin Test revealed that the Gesture Modes have a significant main effect (Durbin's χ^2 (1)=15.066, p<0.001) on Competence of AR games between Motion

Gesture (*Md*=2.5) and Surface Gesture (*Md*=6.5). However, the test failed to find any statistically significant main effect of Screen Sizes (Durbin's$\chi^2(2)$ = 2.285, n.s.) on the Game Competence. Further tests also failed to identify any interaction effect between the two factors on the metric competence.

4.2 Questionnaire Results

Although the assumption checks of normality and homogeneity have not been violated, non-parametric Durbin test was conducted since the responses obtained via questionnaire on fatigue and user engagement are ordinal. Tests showed that the Gesture Modes have significant main effect (Durbin's $\chi^2(1)$ = 3.890, $p<0.05$) on Fatigue associated with playing AR games between Motion Gesture (*Md*=7.500) and Surface Gesture (*Md*=8.375). However, the test failed to find any significant main effect of Screen Sizes (Durbin's $\chi^2(2)$ = 2.777, n.s) on the fatigue caused by playing AR Games. Further tests also failed to identify interaction effect between the screen sizes and the gesture modes on the fatigue.

The study was not able to find a significant effect of gesture on how users are engaged while playing the AR game (Durbin's$\chi^2(1)$ = 0.916, n.s). In addition, the test was unable to find the main effect of screen size (Durbin's $\chi^2(2)$ = 0.710, n.s) as well as the interaction effect between gesture modes and screen sizes on user engagement.

The study also found the significant differences in how the users preferred the different tasks within a game for gesture modes (H(2)= 16.409,$p<0.01$), however the difference in screen sizes are not significant on the task preference of users (H(1)= 1.042,*n.s*). Pairwise comparisons across test conditions revealed that the surface gestures are preferred for tasks such as attacking enemies while motion gestures were preferred for turning despite the screen sizes used as shown in Figure 2.

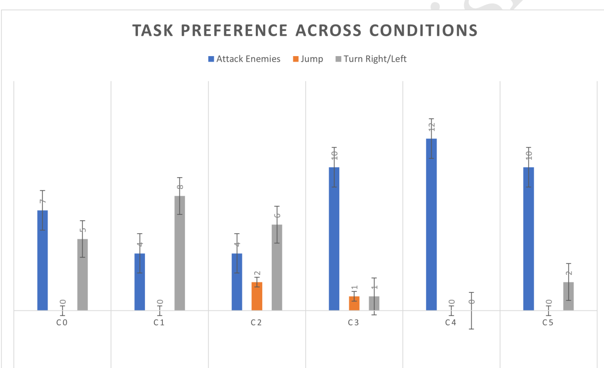

Figure 2: Pairwise comparison of task preference across test conditions

5 DISCUSSION

The results of the experiment suggest that there is a benefit of choosing the specific gesture mode for varying game tasks to improve the competence while reducing the fatigue caused while playing. The results have confirmed that the Surface gestures works better for actions like attack and improves the game competence. This could be due to the perceived ease of use of the surface gesture. Whereas motion gestures work better to rotate or turn a character in a 3D environment in any screen size due to perceived ease of control. Thus, the study has been able to statistically prove the hypotheses H2 and H3 focusing on the gesture modalities with less importance to the screen size. However, the tests were not able to prove H1 leaving out an insight that the screen size does not play a significant role in an AR game while accounting the competence, fatigue and user engagement of games. Further, the results have confirmed that the fatigue is proportional to the increased screen size. However, the statistical tests have failed to validate H4 which suggest that the screen size do not affect the fatigue caused during games.

During the experiment, the participants were queried about their preference toward the game tasks as well. This was mainly done to derive design implications for game development. The positive attitude towards a game task is highly associated with the engagement in game, less fatigue and higher competence. Thus, this question has been vital in obtaining design choices for AR games that would leverage the game designers and marketing practitioners to produce user engaging AR games.

Although the experiment failed to find the effect of the factors concerned on the user engagement, we understand that this metric is hard to be measured in a game that is only 45 seconds longer. Therefore, the effect on the game competence is highly crucial in such contexts since learnability is not anticipated. Thus, in such games we propose that the use of surface gesture would be more appropriate in developing games that demands an attack on enemies and are relatively shorter. However, in contrary, we suggest that the motion gestures would be appropriate for games that are longer and continuous as motion gestures often provides perceived ease of control while improving the engagement towards the game as well. These design choices would be beneficial in developing games irrespective of the screen sizes that the game is played on. We also propose the hybrid approach of using surface gesture for tasks like attacking while using motion gesture for turning in a single game to be a subtle approach in achieving the engagement and competence in shorter games as well.

Although there has been no significant effect of the screen sizes on any metrics of our study, we believe that the limited trials in playing a brand new game after a short practice was not able to clearly distinguish the difference in the display sizes. Thus, the experiment can be extended to multiple blocks and trials which could provide potential insights on the main effect of screen size and its interaction effect between the gesture modes.

6 CONCLUSION

This study has evaluated the effects of gesture modalities and screen sizes on the game competence, fatigue and user engagement for an augmented reality puzzle game. Our results demonstrate that there is a significant effect of gesture modes with respect to game competence and fatigue caused by playing AR games. This suggests that the use of specific gesture modes for specific task of game improves the game play. It has been evident that the surface gesture is more appropriate for attack like tasks and motion gesture is appropriate for turning an AR game character. The perceived ease of use of the surface gesture and perceived ease of control of the motion gesture is believed to be the cause of the above result. The effect of screen size on any metrics under this particular study has not been proved while there have been potential limitations in evaluating the user engagement in the our experiment.

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