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Mobile Augmented Reality: User Interface Design for Spatial Presence

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Abstract

It is said that augmented reality (AR) is expected to become a \$72.7 billion dollar market in 2024 [1]. As augmented reality has become more advanced, companies have been continuously obsessing over using this technology to grab the attention of consumers with methods from face filters to billboard pieces that break reality. AR has only become more popular as mobile phones have progressed to be able to handle the technology, and companies have made it their goal to engage consumers with this new attention-grabbing toy. Immersion and sense of presence is constantly mentioned in regards to virtual reality (VR), but how does one determine a user's sense of presence when dealing with AR? With a focus on user interface (UI) design in mobile AR applications, this paper will look into the question "Can a user interface design have a significant impact on a user's sense of presence in an AR handheld application?".

Looking at user movement while using these handheld AR applications, the aim is to lay out the groundwork for a study testing different interaction methods (or UI) as well as collect data regarding the user's sense of presence throughout. Will these small changes in interaction encourage the user to be more engaged in the experience? Will these changes make the virtual objects in the scene more believable to the user?

Keywords: augmented reality, user interface, design, interaction, presence

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1 Introduction

Immersive technology has revolutionized how individuals can interact with the media around them. Virtual reality (VR), in particular, has garnered a lot of attention in recent years as audiences clammer to be immersed in various video games and unreachable locations. Another recent development has been a surge of interest in augmented reality (AR) since Pokémon GO was released in 2016 [2]. It brought AR to the public's attention and showed companies that AR was viable in a mobile and/or handheld format. Plenty of industries since have begun to pour money into the continued research of this new technology [3]. It is even suggested that technology like Pokémon GO [Fig. 4] “point[s] to a future in which AR is a potentially commonplace technology worn or carried on (or in) the person” [2].

Another thing to note, as augmented and virtual reality slowly becomes more ingrained in the everyday lives of consumers, is that the novelty that once made these emerging technologies memorable is slowly wearing off. Companies can no longer expect anything labelled with AR/VR to have a large impact on its own since consumers are now likely to have prior experience with the technology. These experiences are now held to a higher standard: expected to be reliable, interactive, and immersive.

Improved AR technology has largely impacted company marketing both physically and digitally from billboards that break reality to virtual clothing try-ons. Augmented reality face filters, sign translations/wayfinding, and mobile gaming are just examples of some uses that have started to invade the modern consumer's everyday life. On the other hand, there're still plenty of individuals who aren't as familiar with this new technology and need their AR applications to be easy to use with an intuitive design.

1.1 Motivation

In the past few years, augmented reality has become more reliable with less bugs. Though constantly used in filters and body-tracking, there is a shortage of fully interactive mobile AR experiences [2]. There are a few such as the mobile AR Star Wars Holochess game [Fig. 1] or The Walking Dead AR campaign, but games such as these rely more on the intellectual property (IP) grabbing attention than the game itself; this is leveraging the brand's image and can lead to a lot



Figure 1. Star Wars Holochess

of fanfare [4]. The main marketing point was Star Wars, and the AR technology behind the game was not as important. High quality AR is now accessible to anyone with a compatible phone, so why is there a lack of quality AR games in the app store? How can developers create replayable AR experiences where the novelty doesn't wear off?

Augmented reality can have an extremely positive impact on a user when done correctly, but how do we design an experience that immerses the user using a handheld device? Comparing

different AR application designs will aid developers in selecting the best method for their project, whether it is a game, art piece, or something more educational. Currently, there isn't much of a precedent, or basis, for developers to know how user's prefer to interact with mobile virtual objects for the most comfortable and immersive experience. Given the large scope of various AR projects with different industries, devices, and spatial limitations, it is quite impossible to have a set of basic guidelines that covers every possibility. As such, more research needed to be done to determine the scope of this project.

When looking into recent AR research as a whole, I began to narrow down the project to focus on two main questions. Firstly, what determines immersion or 'sense of presence' in regards to augmented reality? Secondly, will manipulating the user interface (UI) have a significant impact on this 'sense of presence'?

The aim of this dissertation, more simply, is to explore AR user interface design with a highly-interactive mobile AR experience and determine how each design impacts the user's sense of presence and opinions regarding mobile AR. In order to achieve this, a mobile AR experience will have to first be developed with multiple UI designs to allow for comparison, and a method for recording testing data will have to be decided upon. Overall, the outcome of this project is meant to aid developers with their future UI design decisions in AR and encourage more researchers to delve further into handheld AR immersion. Hopefully, this will lead to more immersive AR content in the hands of everyday consumers via their mobile and/or handheld devices.

2 Augmented Reality

To fully understand the definition of augmented reality, one must first understand the Reality Virtuality (RV) continuum which was originally created by Milgram [Fig. 2] [5]. With our real reality at one end of the spectrum and a full virtual environment on the other representing virtual reality (VR), augmented reality is one of the points in the middle, representing a form of mixed reality (MR).

In this case, AR allows for virtual objects to be placed in the surrounding physical environment as opposed to augmented virtuality (AV) where a virtual environment still allow for some physical elements to remain [5]. An example of AV would be allowing the user to still view another person in the room with them while the rest of their environment has been replaced by a virtual environment of some sort. Both AR and AV are forms of mixed reality, and recently, a new term coined extended reality (XR) has been used as an umbrella term to cover everything on the spectrum that extends beyond real reality [5]. Thus, it includes the entire spectrum except for real reality.

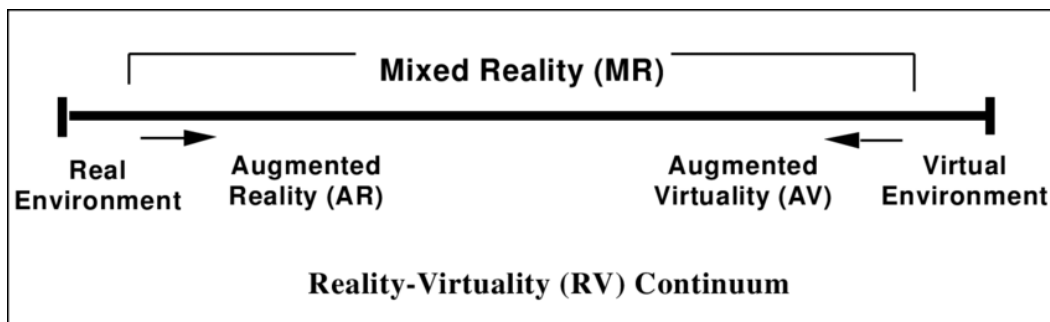


Figure 2. Reality-Virtuality Continuum

Specifically, augmented reality is often defined as 3D virtual elements projected onto the physical world via the use of a device [6]. It can also be defined as “displaying digital information over people’s real-time view of object, people, or spaces in the physical world” [4]. The idea is to make virtual objects (VOs) appear as if they have actually been placed in the physical world around the user(s). Virtual, or digital, objects are completely computerized element without any physical presence. The idea of placing them in the physical world as part of an AR experience is to suggest to the user that these objects have a simulated ‘presence’. Many scholars often look to Azuma’s work when describing the main characteristics of AR [7]. Though AR didn’t take off until the 2010s, many still stick to the basic principles of needing an AR experience to combine real-world elements with virtual images, be spatially convergent, and have real-time interaction available [1].

This project will follow these rules closely as the resulting AR experience should require a single individual to consistently interact with the virtual objects overlaid onto the handheld device’s AR camera in real-time. An AR device, in general, can be many things from a smartphone or tablet, to a headset with AR capabilities such as a HoloLens [Fig. 3].

2.1 Devices

Head-mounted displays (HMDs) are quite advantageous for these interactive experiences; however, they are quite expensive and not as widely used as smartphones or tablet devices [1]. As handheld augmented reality utilizes this



Figure 3. Microsoft HoloLens

everyday equipment, mobile AR reaches more potential consumers [Fig. 4].

Wearable AR has the advantage of being hands-free, allowing users to move about freely and interact in a more intuitive way [Fig. 3]. Information is shown directly across the user's field of view without a small screen to separate the user from their perceived reality [1]. The head mounted displays that are most well-known include Microsoft's HoloLens Two and the Magic Leap Two [2].

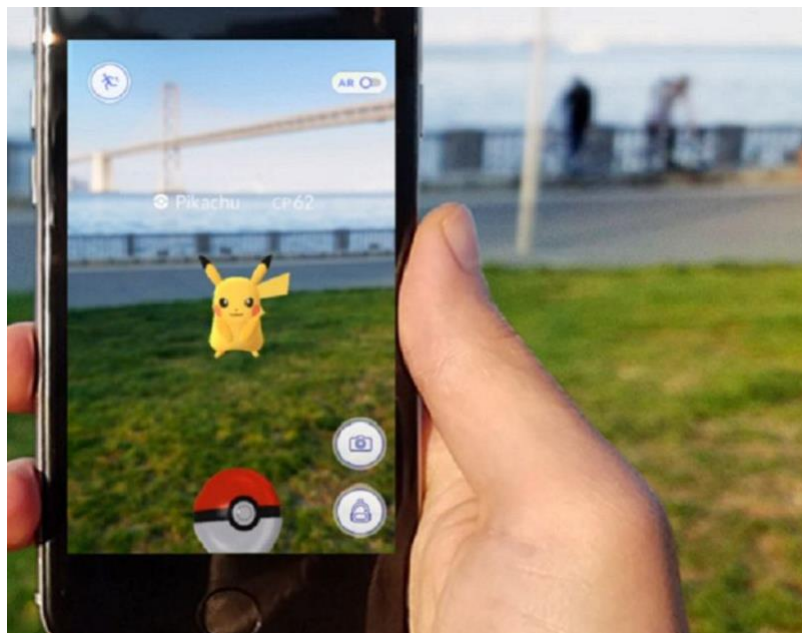


Figure 4. AR Pokémon GO!

Various smart glasses are also starting to pop up such as Google Glass and Snapchat Spectacles. These are somewhere in between full HMDs and handheld AR devices. They can be broadly described as wearable glasses that are both computer-capable and can overlay digital elements onto the real-world by projecting onto the lenses or something similar [2].

Though not mentioned often, other forms of AR include spatial AR projection onto surfaces as well as larger scale 2D screen AR such as overlaying digital elements onto a live video on a baseball stadium screen or campaigns such as The Walking Dead AR fake window [4].

Each device has its own limitations. For example, HMDs can use hand tracking (hand gestures) or even motion controllers, but there are less visual aids in the control method. Gestures have to be memorable, and a lot of headsets have various flaws such as tethers or the fact that they are too heavy to wear for long periods of time. There are also headsets that do not require a tether to run, though many of these have less storage space and tend to have limits in their graphics capabilities without the added processing power of a desktop computer to back it up [5].

Gamers tend to be used to extended periods with screens and headsets, though the average consumer has to be considered as well. Children, in particular, would have issues with the weight of a headset as well. Overall, both the lack of visual reminders via a head-up display (HUD) and the issues with use over a long duration of time can cause issues for individuals unfamiliar with, or less adept with, technology. Typically, larger learning curves hinder the user's ability to have a fully immersive experience [8].

Traditional 2 dimensional UI on a touch screen is more familiar to the average consumer due to the popularity of smartphones, and familiar symbols allow for more intuitive designs that people can pick up easily between different applications. It is easier for the consumer to use and gain familiarity with AR, but the smaller field of view can be annoying to some consumers. Plus, having visual controls that take up the limited screen space (2D or spatially) can clutter the screen, making the experience less appealing to consumers [4].

As many of these devices can have multiple pros and cons in regards to AR usage, it is important to consider the audience of the specific application. As this project focuses on the average consumer as opposed to a company or institution, the user may not necessarily be familiar with AR and/or they may not have a reason to invest in any sort of AR specific hardware at the moment. Thus, this project is focusing on the most AR-capable device for the average consumer

to own: a mobile phone [3]. Though this application will be usable on other handheld devices, a smartphone will be used for all test subjects in order to limit variability between tests.

3 Spatial Considerations

Augmented reality, unlike virtual reality which completely blocks off the real world, involves real world space in its development. Real-world tracking is used to attach the virtual objects (VOs) to the user's surroundings. Thus, considering the spatial limitations of the user in certain situations is imperative for the developer. For clarity's sake, these spatial limitations can be broken down into four categories: intimate, personal, social, and public space [Fig. 5] [9]. Intimate space tends to involve virtual objects within a foot or two of the user, while personal space reaches beyond that similar to the idea of a 'personal bubble' or the space just beyond the person's reach. Social space, can be define as reaching outside of that bubble until around 12 feet, or around the size of a medium room. Public space is most self-explanatory, extending to any large (typically public) space beyond the social zone [9]. This breakdown is taken from Edward Hall's idea of proxemics: "taking into account the interpersonal relationship between people depending on their proximity to each other" [9]. This proximity sectioning is a great way to categorize AR experiences, describing the user's proximity to the VOs present in the environment.

Currently, the most widely used/developed category is intimate space AR applications. Examples of this include facial filters, clothing try-ons, and other body tracking applications like tattoo visualization [10]. The virtual elements in these applications manipulate or add to physical features within a foot or two of the user, typically using a phone camera or even a magic mirror. The limited scope of these applications allow for mobile users to interact with these AR features no matter their location [10]. Thus, there is much more research as well as applications dedicated to intimate space AR.

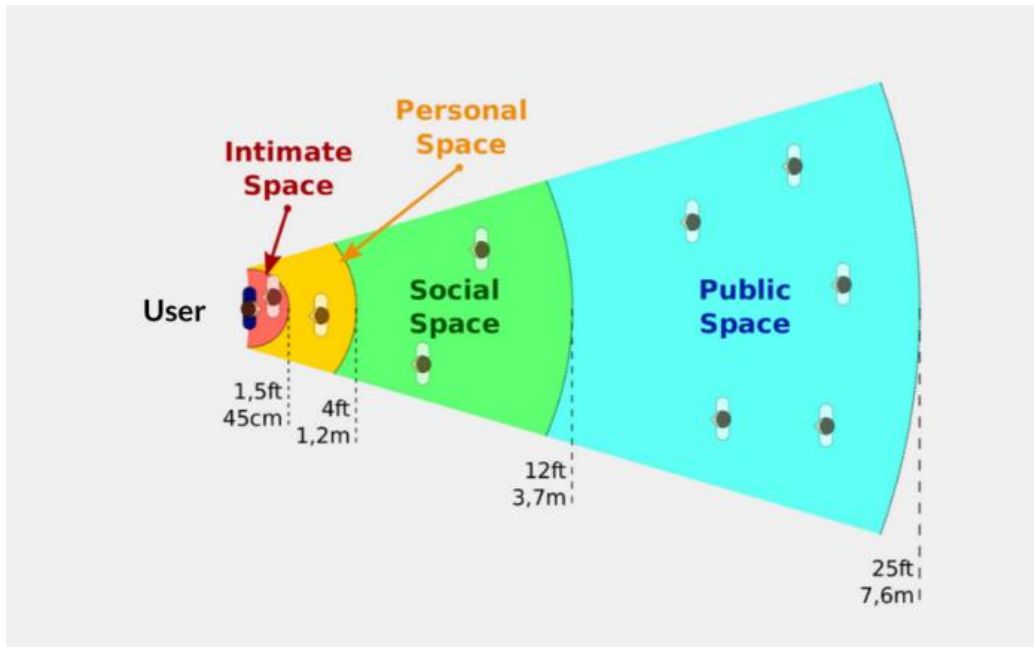


Figure 5. Edward Hall's interpersonal distances of man

Social space AR has mostly been seen in multiplayer AR games as well as applications for buying/testing out furniture [10]. Larger scale public space experiences tend to be more location-based, anchoring virtual elements to billboards or buildings. This 'anchor' in most cases involves image recognition and cannot be utilized away from the object designed to trigger the experience. Due to the size, many people are able to run the experience/application at the same time without interference. Though this is a good marketing strategy to bring in attention through novel experiences, it is not necessarily a situation where developers are considering the user's immersion in the space. The distance from the augmented element(s) works to their advantage in that way.

The fourth category, and the main focus of this dissertation, is personal space applications [2]. Aside from intimate space, most mobile users will have access to a decent amount of floor or table space whether it is at their home or work. Personal space reaches about four feet from the

user, so if the user was central to the application, surrounding the user with VOs would cover close to an 8' by 8' area [9].

Also, as the focus will be on the individual and not user to user interaction, limiting the project to personal space is a good size for the individual human-computer interaction without extending beyond a regular person's available space. The average apartment will have that amount of space in a living or dining room.

3.1 Design for Walking

Lages has a set of wearable AR interaction techniques for walk-centric UI which all fall into one of three categories: walking-based, walking-friendly, and walking-aware [11]. While walking-based interfaces require walking and walking-friendly interfaces exploit the user's cognitive and motor limits, he describes walking-aware techniques as adapting or conforming to a new environment or orientation [11]. As the goal for this project is to encourage movement as opposed to requiring it, the walking-aware technique seems to be the option most suited for testing this hypothesis.

Though aware of the spatial limits, it is important to consider how the interface and overall spatial design can encourage users to walk or move around the limited space allotted for the application to utilize.

In such a limited space, orienting the UI controls towards a central point as the user moves around a space encourages movement while keeping the individual anchored to a central point. Thus, there is freedom to move without limiting any interactions while the user does feel the need to stray too far from the selected anchor.

4 Sense of Presence

The term ‘sense of presence’ typically pops up in discussions in relation to virtual reality. Very similar to immersion, sense of presence tends to describe the user’s subjective experience [10]. As the user becomes more immersed, they become less aware of the physical world around them and feel as if their new virtual environment has become their reality. A user’s sense of presence in regards to virtual reality is exactly that. How present does the user feel in the environment they are placed in?

A high sense of presence is imperative in keeping the user engaged. The more engaged they are in the experience, the more they will care about the outcome of that experience (i.e. score, plot, etc.) [3, p.]. Though it is defined as a subjective experience, most research on the subject of presence in VR deals with attempting to find the commonalities between these well-made experiences and determine the best method(s) to objectively build a better environment for any potential user. Similarly, the goal is to make AR users feel more engrossed and present in the space. However, as it is not a virtual space, but virtual objects the user is interacting with, the idea is slightly different.

Due to the fact that an AR user is already immersed in their real world environment, augmented reality has a slightly different definition of presence. In this case, a ‘sense of presence’ is referring to the digital elements feeling real and a part of the physical environment. As one paper expressed it, “AR elicits a different sense of presence: ‘it is here’ presence” [8]. Does the AR user feel as though the digital is part of the physical?

This goes back to the definition of a VO; the goal is to trick the human brain into thinking that this computerized element has taken up a physical position in space, so when the user interacts with it in real-time, the interaction feels completely natural and to the user [10]. Limiting this to a

handheld device gives a greater challenge as even though people are comfortable in using their phones, it erects a wall (the screen) between the physical space the object is supposed to fill and the interaction controls. Where it is easy to build immersion and a physical presence when haptic technology and other AR capable devices cover more of the users field of view, this project is focusing on more rudimentary interactions that can still feel natural to a user without the large price tag.

A break in immersion is another term that is mentioned in abundance when it comes to VR yet is almost never considered when it comes to AR. When a user fully feels present in a virtual environment, these 'breaks' can be anything that disrupts the belief the player has in the experience or distracts from the experience's intended focus [2]. For example, a user physically running into a piece of furniture or a wall while playing a game can completely break the player's focus as they are reminded of the space they are in physically, even though there is nothing positioned there virtually.

A break in immersion that happens quite often in both AR and VR is when the clipping planes aren't functioning properly. As all virtual object need to be drawn, with larger projects, objects are only drawn if they are in the user's field of view and within both the near and far clipping planes. The near clipping plane is near the user's eyes and cuts off the computer from drawing behind the camera. If it is too far away, getting within a foot or two of a virtual object

Many smaller breaks in immersion happen fairly frequently. Different forms of locomotion that cause cybersickness, hearing spatial audio from the wrong location, feeling the HMD's tether while in VR, and even visual lag that doesn't quite match the user's movements can all cause the user to question their belief in their surroundings.

Scholz talks about how VR researchers look at perception, manipulation, and interaction to determine how immersive an experience is [4]. This can translate into the realm of AR fairly easily, except Scholz uses the term ‘affordance’ to describe the types of actions available to the AR user [4]. More specifically, this project will be looking at the user’s sense of presence in AR in terms of their perception of the VOs in space and the affordance (possible interactions) offered to the user as they play.

Virtual objects need to have a constant perceived position in space to feel realistic. Perception of these VOs can also be impacted by the lighting or shadows in the room as some users will notice when those details fail to align with the surround reality. Does the human eye notice that these elements do not belong or are they perceived to belong in the space?

As for user interactions, it is said that true ‘interaction’ requires the VOs and the user to mutually impact each other [4]. This project will be allowing the user to interact and move objects to try to score the highest they can in a game/experience. As the user progresses, the game is supposed to encourage the player to move around the space in order to gain different perspectives. In this sense, the user’s movement in the space will be just as important as their perception of the VOs in gauging the user’s sense of presence [2]. Thus, the user’s location data will be gathered along with the sense of presence surveys in order to determine the impact each user interface design has overall. A correlation between higher survey scores and a higher amount of movement data would then suggest that our theory regarding the UI’s impact on an AR experience is probable.

4.1 Designing the Environment

The combination of limiting the user’s movement and keeping the user immersed gives us a few different possibilities for designing the limited environment. The goal is to keep the user

from having a reason, or wanting, to leave the designated game space and allowing free movement without making the user feel claustrophobic or overly controlled. Originally, there was a lack of direction when deciding whether a game or another type of AR experience would best embody this project.

The first possibility was to create a user-centred experience where the user is surrounded by the AR elements, allowing them to turn towards each object to interact with it. This is often the layout for shooter games as enemies spawn a set distance from the player and approach the player to attack. This was deemed to be constraining to a user's movement and focused too much on player rotation rather than physical movement/walking. Even if the VOs did not move in this scenario, there would probably have to be a clear border of some sort to communicate the spatial limit to the user. Thus, this environmental design was deemed too constricting.

Boxing AR elements into an invisible 'interaction zone', subtly suggesting the spatial limits to the user, also appeared to be an option for a while. For example, implementing animated objects, such as wandering animals, for the user to interact with. Physically having the user move to VOs was another option like picking up and moving 3D puzzle pieces around. This would indicate the limitation to the user based on the VO locations without fully boxing them in. An exploratory experience would, while lacking in data such as a game score, allow for more freedom of movement around the AR objects. An experience that was considered was exploratory butterfly application where different types of AR butterflies flew around the set spatial limits, and the user would move around to click on the different butterflies, gaining species information on them. Though this was deemed an option for raising engagement with students, this specific experience was not guaranteed to garner equal interest from everyone as it was a niche topic. Also, there was

both a lack replayability and no motive for spending an extended time walking around the space such as a score or time variable.

Finally, an AR object-centred experience seemed the easiest to contain to our smaller spatial requirements while encouraging walking around the perimeter of the space. This also seemed the most compatible option for the use of a game. The application would only need to track one position on the floor for the entire game. Though there would have to be specific requirements for the selected game in order to require movement and have a purpose for its use in AR beyond the basic novelty factor, the use of a game in this environment is more likely to keep the individual interested and make them interested in playing again [4]. As multiple play attempts will be required of the same game with different UI designs, replayability is imperative so the player does not exhaust the experience on the first run-through. Encouraging this engagement will aid in suspending the user's belief of the VO's existence [4].

That being said, having a 2D screen between the user and the virtual objects creates a clear separation between the real reality and the augmented one. This is a huge barrier to building the immersion between the user and their perceived reality with VOs. Thus, it made sense to consider whether the 2D controls would translate well to the 3D environment of the game. As discussed previously (pg. 18), a walking-aware interface would work well with the current spatial limitation so long as there's an anchor for the interface to use for orientation [11]. An object-centred experience is perfect in this case as the object itself can be the anchor, allowing the user to orbit the object as they interact with it.

5 Development Decisions

Starting out, it was fairly simple to implement the AR tracking in Unity Game Engine and overlay a VO onto the phone's screen, though it took a few attempts to get the scale right. As the user is not centralized in this specific application, the digital element (game grid) in the application was restrained to a 4' by 4' area so as to allow space for the user to move around the elements as well as to stay within our rough definition of personal space [9]. From here, decisions had to be made about which game to implement as well as what various UI designs (two or more) would work best alongside the selected game and its mechanics.

5.1 3D Tetris

When deciding on which game to use for this project, a few different factors had to be considered. Firstly, the game had to be fairly recognizable and/or intuitive so new players would be able to pick up the rules quite quickly. Being unfamiliar with the chosen game could have led

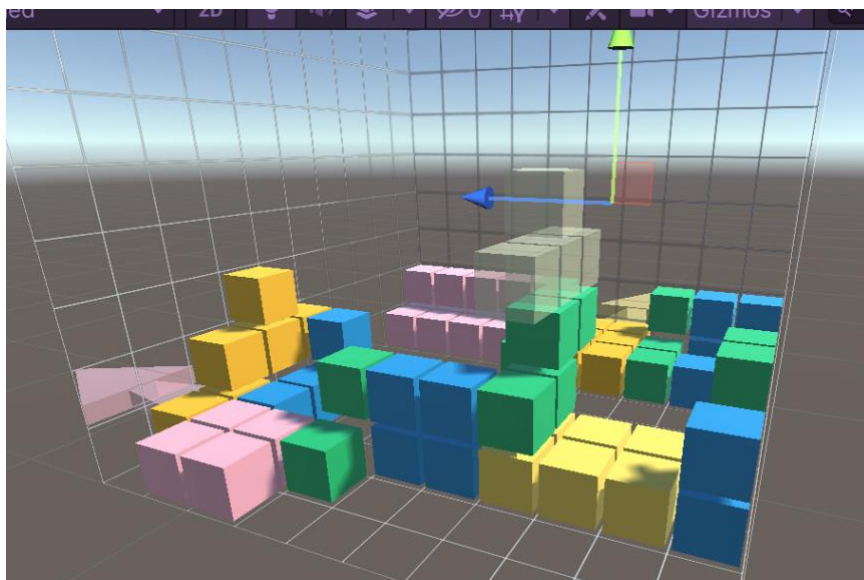


Figure 6. Tetris gameplay within Unity

to users scoring better on latter tests as the player's familiarity with the game grew. Secondly, the game had to require the user to view the game board/space from different angles or sides. Since player movement was included in the gathered data, the player had to benefit from moving around in some way. Third, the game would have to be limited to the user's personal space as explained above [9]. Finally, the selected game had to be unplayable in a regular tabletop scenario. If the augmented reality feature of the game was pointless and could be replaced by a physical board, there would be no point to using AR other than the novelty factor.

As Tetris is a well-known tile-matching puzzle game and has been considered a classic single-player game since its release in 1984, it was an obvious contender due to the familiarity criterion [12]. Basically, the game consists of different block shapes falling from the top of a screen. Controlling one block at a time, the goal is to place each block so as to create full rows at the bottom of the screen. As a row is completed, the row will vanish, allowing more space for the user to work with and buying more time for the player. The game ends once a block reaches the top of the screen. The concept actually translated quite well into 3 dimensional space as well [Fig. 6]. Unsurprisingly, further research shows the game has been adapted to 3 dimensions before. In this case, a 10 x 10 x 10 layout was used for the playable area, or grid, and five different block types were used. Also, the traditional 2 x 2 block was converted into a cube so there was at least one 3D block shape would have a larger depth than a single block.

As for encouraging the player to utilize different viewpoints, using the 3D grid for block placement appeared to achieve this. Depending on the user's playing method, as the blocks start to stack up, empty sections of the board could be covered. Players would then have to manoeuvre around their already placed blocks to view the rest of the board and place more tiles. Of course, this also meant that the Tetris grid had to be at a large enough scale and high enough height to

keep the players from having a top-down view. As a game constrained to a neat grid, Tetris could also be scaled to suit the area constraints while allowing the user to circle the entire game zone.

Some important digital elements of Tetris include the timed drop of each block as well as block randomization. As these elements are not possible in a physical setting, Tetris also matched the last criterion set. Tetris is not playable in-person as a tabletop game, so the game is not relying solely on AR bringing novelty to the experience [4]. Thus, it was selected for this project.

5.2 Application Organisation

In Unity Game Engine, the first step was to create three scenes: a main menu, an AR setup/play scene, and a game over screen [Fig. 7]. A game manager script was then created to easily swap between them using Unity's scene management library. From there, the plan was to

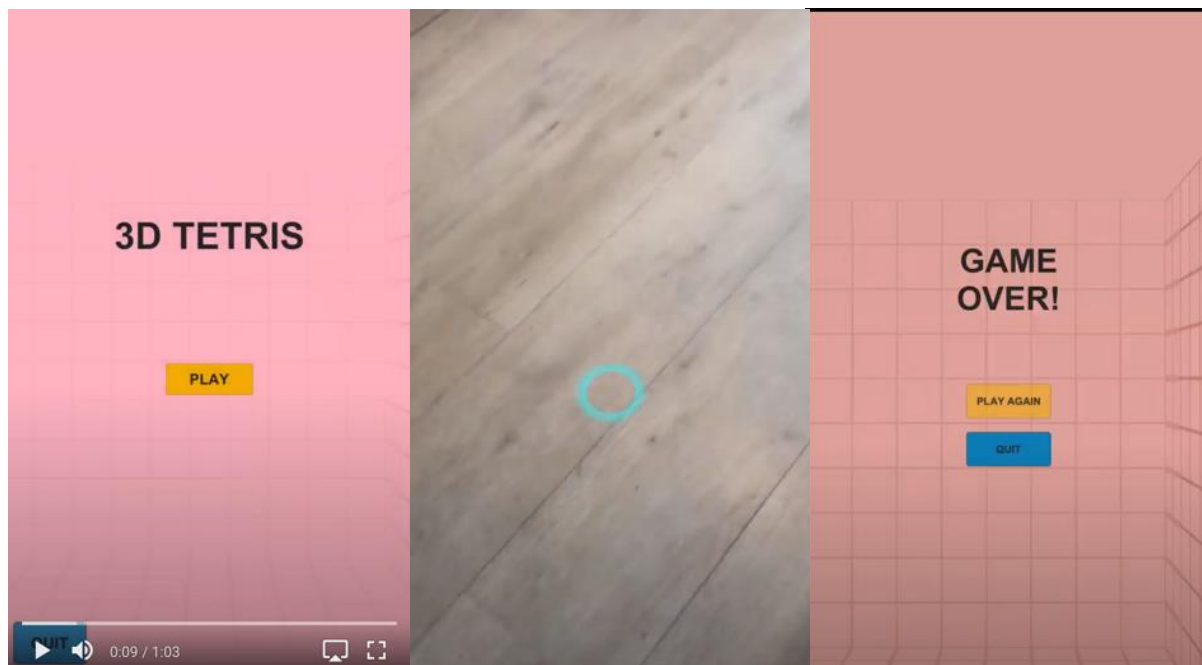


Figure 7. Three main scenes for AR functionality

use ARFoundation (the cross-platform framework) to make sure the game would be able to function on both IOS and Android mobile devices [13].

Once the basic scene functionality and Tetris game grid was laid out, a script was created to randomly spawn one block type at a time at the top of the grid via an empty game object used as a spawn point. A shadow of the block is then made to show where the block would land; this is meant to aid the player's perception of the 3D playing field. Each spawned block also made use of a script to control the falling timing, block tags, and booleans were used in this script to update the movement and rotations of the blocks as well. This script would then be deactivated on each block

as they hit the bottom of the game grid. The blocks script also became the main script for determining valid moves, tracking full rows, and checking for a 'game over'.

A separate script was used in the scene to connect the UI buttons to the current (falling) block. This script finds the current block by searching for its tag and references the attached block script's variables, so that the controls could only impact one block's movement at a time.

With a fully functional 3D Tetris game scene, it was time to attach it to the AR scene [Fig. 8]. In the AR setup scene, the main game objects included the AR session Origin with the AR camera as its child, the AR session with the input manager, and the placement

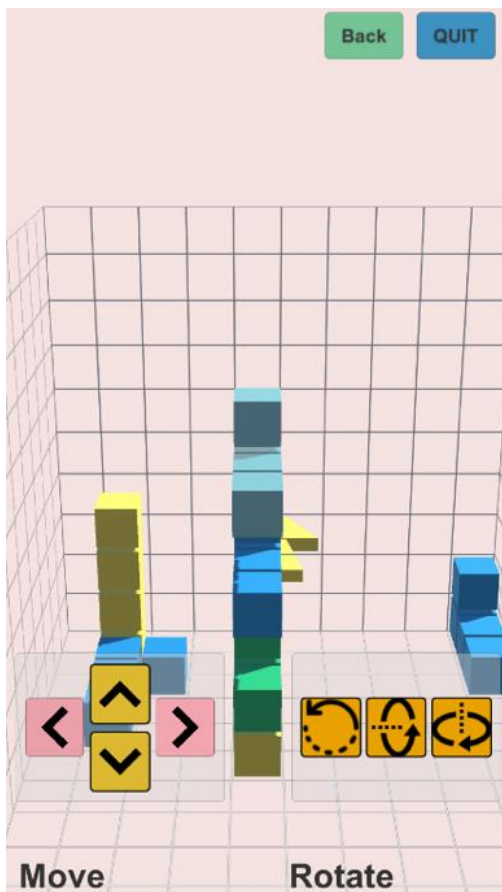


Figure 8. 2D phone gameplay without AR

indicator. When the user hits play, this scene will open the user's camera and use a raycast to place



Figure 9. AR Tetris mobile gameplay: old 2D UI

the indicator on the plane found across from the centre of the screen. A raycast is when a vector is sent in a direction until it hits something. In this case, the phone's raycast hits a trackable plane in AR. The user is then able to move the

phone around and tap the screen when the indicator is in the desired location [14]. As the entire Tetris game had been attached to an empty parent object, a script connected to the AR session origin is then able to replace the indicator by instantiating the entire game as a prefab in AR space. At that point, the game would have started dropping Tetris blocks [Fig. 9].

The largest development issues came from trying to use a newer version of Unity. With Unity 2019 and an old iPhone 7 plus using IOS 15.4, it was necessary to use a newer version of AR Foundation than was originally planned. Both Unity 2018 and 2020 caused issues with either the package manager or the AR camera settings [15]. A raycast manager was needed in the AR session origin since the 2018 version, and it somehow caused problems with the AR camera when it was active. The placement indicator needed a raycast from the centre of the screen so the player could place the game grid.

The first few builds of the game played in AR space without showing the camera even though permission was granted. Once everything functioned together, it was time to focus on the various user interface designs that allowed the users to interact with the game most effectively.

There were three different interaction methods considered: 2D screen-space buttons, gesture controls, and 3D controls as a VO. In the end 3D/spatially placed controls were vetoed from the experiment due to the small screen size of the handheld testing device. It was determined that the VO controlling the Tetris blocks would have to be fairly close to the user at all times and would either take up too much screen real estate or require the user to move the camera too often between the game grid and the control object. The other two options wouldn't require the user to face the camera in a certain direction.

When finally viewing the size of the Tetris game grid, it also became apparent that the game would have to be raised from the ground to roughly eye height. If the game was placed any lower than the player's waist, there was the temptation to lean over the top of the game and play with an almost top-down view instead of physically moving around the grid to play. Raising the game grid prevented this.

5.3 2D User Interface

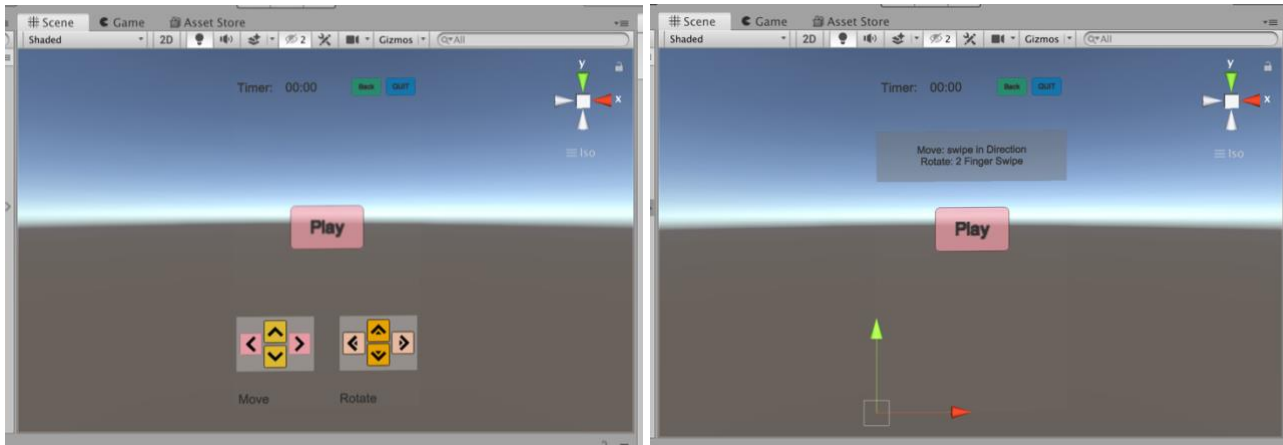


Figure 10. Final UI canvases in Unity scene

A 2 dimensional user interface was the first design to test, where a basic button system was implemented [Fig. 10]. A four button panel of arrows was used alongside a rotation panel for X, Y, and Z axis rotations for the blocks. As the current falling block was already tagged during gameplay, the same tag could be used to find the right block that needed to be moved/rotated.

5.4 Touch Gesture Manipulation

Gesture controls or swiping motions is a fairly intuitive method for movement and wouldn't take up any screen space. A script was implemented specifically to register both single-finger and two-finger swipes as well as recording the rough direction and distance of the swipe (i.e. up, down, left, right).



Figure 11. 2D UI designs: side by side

The single-finger swipes were used for block movement and the two-finger swipes were used for rotating the blocks. As this was a less visual type of controlling the VOs, an extra panel was added to the play scene in order to describe the controls before the play button was pressed [Fig. 12].

5.5 Comparable Controls

In preparing for testing, it was important to make sure the two user interfaces were as similar as possible in both usability and intuitiveness. As both the block rotations and translations had four directions for the user to swipe in with the gesture controls, it was deemed necessary to change the X, Y, and Z axis rotations in the 2D UI version to match the four directions as well [Fig. 11].

Since a portion of the data collected during this experiment would be movement related, the player's movement around the game grid had to be considered. As such, a script was created

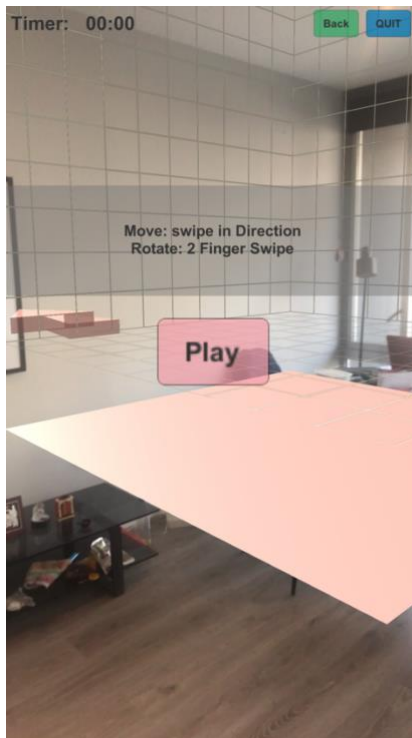


Figure 12. Gesture interface play screen

to track the player's movement in relation to the centre of the game grid. This was then used to decipher which of the four sides the user was standing on and re-orient the controls accordingly. This re-orientation is what classifies these two interfaces as walking-aware [11].

With the 2D controls, this meant rotating the two arrow pads at 90 degree intervals so that, for example, the left arrow key would always move the block to the player's local 'left' no matter which direction the original left of the grid was. As standing on the 45 degree angle was also made an option to the user, the original up/down arrows were colour-coded yellow as opposed to the left/right arrow keys which

were made pink. This, in addition to the two transparent coloured arrows, helps the user recognize the current orientation of the arrows.

In the case of the gesture controls, the swipe directions also adjust based on the user's position, keeping to the same four directions: up, down, left, and right. Since the gesture controls do not have a visual component to its method of interaction, there are, unfortunately, no visible cues for this orientation switch [Fig. 13]. The testing phase will have to determine whether this is an issue for the user or not. Though, this form of interaction does seem to have the advantage of not distracting the user's eyesight from the game grid to another component, both controls are as similar as they can be, keeping to for movement controls in four directions as well as four rotation controls in four directions.



Figure 13. Three different viewpoints as player moves

6 Testing Structure

When collecting data for this experiment, it was decided early-on that the participants would alternate between testing out one of the Tetris versions followed by its corresponding survey. As the Tetris game grid is slightly smaller than 4' by 4' in size, the testing space was decided to be around 6' by 6', if not slightly larger, to allow for movement around the exterior of the VO [9].

The main menu was updated for testing to allow both game versions to be played using separate play button. The game over screen was also updated to hold the recorded player positions, the position of the game grid, and the time score they received [Fig. 14]. This allowed for the researcher running the tests to have easy access to all of the round information on one page. The main screen also allowed for the user to go back to the last game over screen with the 'last data' button in case one of the test subjects closed it out accidentally.

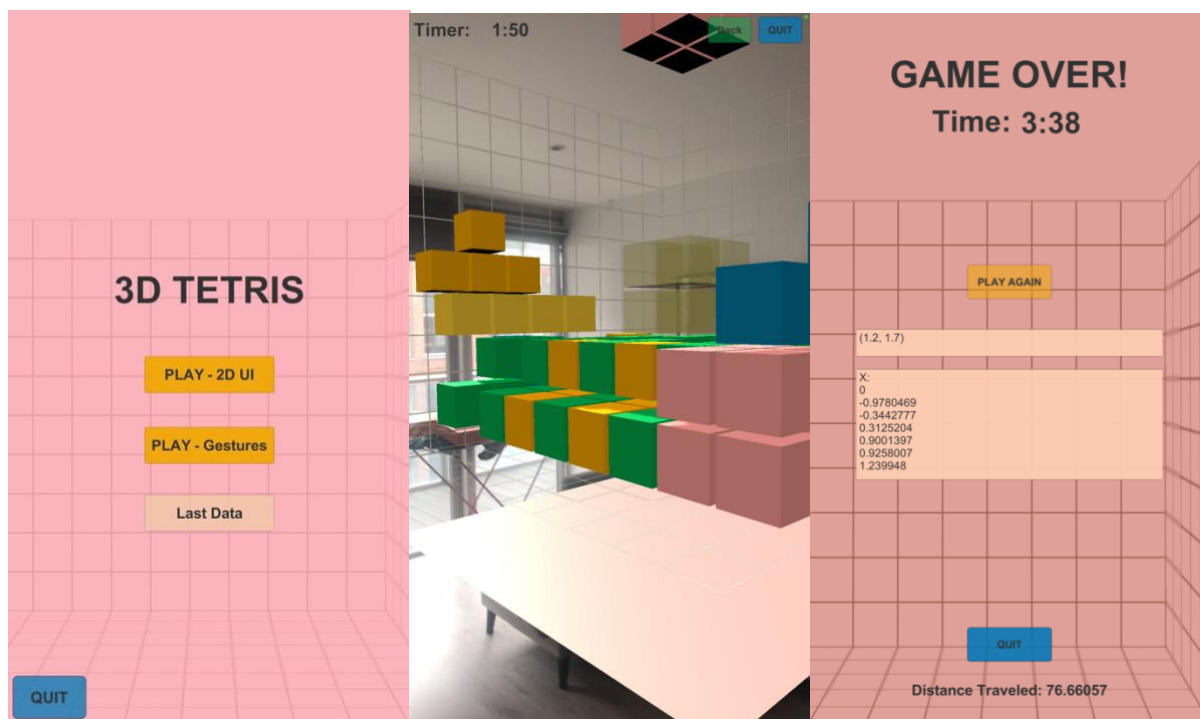


Figure 14. New layout of AR main scenes

6.1 Subjects

For test subjects, it was decided that the target audience would be individuals, both male and female, that were 18 and up. Beyond this age limit, there was no inclusion or exclusion criteria; however, it was preferred that these individuals were already familiar with Tetris so it would be fairly easy for them to pick up the controls without worrying about another learning curve regarding learning the rules of Tetris. Most of the test subjects ended up being local college students or young professionals residing in the Dublin area.

As Tetris is a very well-known game, even the individuals who hadn't played the game were at least familiar with the rules and seemed to grasp the 3D concept quickly. Many of the test subjects had also experienced some sort of AR before. Of the seven initial subjects, a few of them were familiar with mobile AR, two were familiar with the HoloLens, and two wrote down Oculus devices as they probably were not aware the differences between augmented and virtual reality. The final tester from the initial group had no experience with immersive technology at all.

6.2 Set-Up

At the start of the experiment, after the procedure has been explained to the participant and they have signed their consent form, the participant will be given an AR capable mobile phone and asked to play the 2 dimensional UI version of the 3D augmented reality Tetris game in the empty 6' x 6' walkable space. After the game has been completed, they will then be given a survey regarding their experience with the application. A similar survey will be given to the participants after the second game has been played as well.

Then, two final questions will be at the end of the experience, allowing the participants to select their favourite version and compare the two experiences. At the very end, the participant will be briefed on the purpose of the investigation, and any other questions they have will be answered.

Each version of the game will be placed by the researcher so as to make sure the game is placed in the middle of the space at a similar scale to all of the other participants. This will be to minimise the chances of movement data being skewed due to a lack of space on one side of the game grid. They can ask questions at any point and are told they are able to walk around the space as they play if they wish to. The participants and surveys are only referred to by number in the surveys so as to protect the participant's privacy.

6.3 Surveys

When writing the surveys, the initial questions were introduced in order to gauge the individual's familiarity with augmented reality devices as well as the game they would be testing. It is helpful when judging their performance whether a lack of experience with AR or even Tetris could possibly impact their results. The first few questions also gathered generic information regarding the person's age and gender identity.

Most of the survey questions used were pulled from various 'sense of presence' questionnaires or adapted immersion in VR studies. Of the study surveys found, only one was used for sense of presence in AR [8]. Though extremely helpful in regards to how various VOs are perceived in a real environment, was written and used for experiments with HMDs and not anything handheld. One section of this paper even stated "we know of no previous attempts to develop a scale for this experience", and this appears to still be the case [8].

Thus, these questions were combined with a few others on the Likert scale, and some questions comparing the two experiences were also placed at the end.

A Likert scale is typically a five or seven point scale that treats a person's attitude towards a subject as a linear continuum from strongly disagree to strongly agree [16]. In this particular group of surveys, a five point scale is used with the following scores: 1-strongly disagree, 2-disagree, 3-neutral, 4-agree, 5-strongly agree. Similarities in attitude will then stand out as higher percentages of the testers having a similar experience.

6.4 Movement Data

As the application was already recording the player's position in respect to the game grid in order to determine the control orientation, it was fairly simple to continuously grab the user's X and Z axis data. Various other movement data and collection methods were considered, and this method not only worked well in Unity with the already functioning code, but it also allowed for plots of a top-down visual indicating where each participant was in relation to the game grid during each round of testing. Plus, it would be easier to determine any movement patterns when layering everyone's positions on top of the same graph. Using the timer that was already implemented, we were able to obtain the player's location every five seconds to add the data to a list that became retrievable once the player reaches the game over screen [Fig. 15].

The next step was to take these coordinates and plot them with the game grid blocked off in order to visually see where the user's moved during gameplay and how far

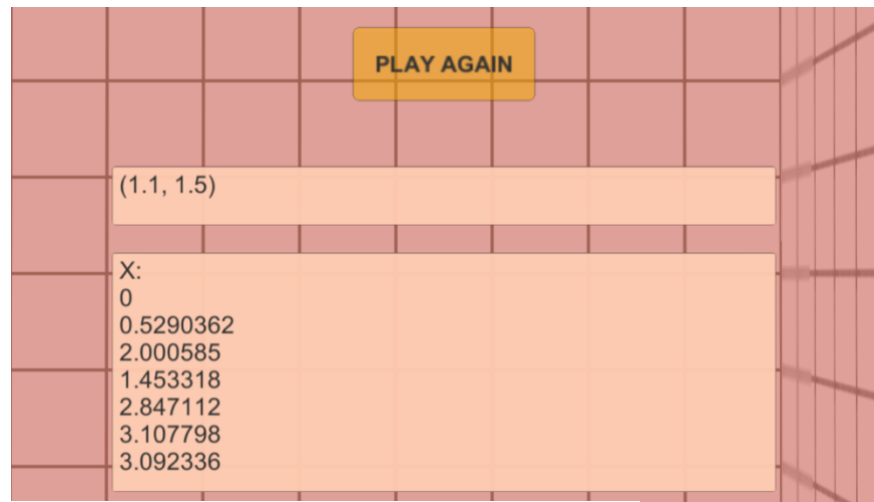


Figure 15. Close-up of movement data input field

they travelled over the duration of the entire game. In theory, the users more comfortable with the controls as well as the game grid's location will be more comfortable moving around the space as they play the game, using their ability to choose their perspective to their advantage [11].

7 Analysis

Dividing the initial results into categories, seven people were tested for some initial results: five men and two women. The youngest individual was 21 years old while the oldest of the group was 35 years old. The majority of the questions were given as statements using the Likert scale of one to five where one was ‘strongly disagree’ and five was ‘strongly agree’. As a score of three is neutral, the first step was to find large groups of 1-2 answers and 4-5 answers.

2D UI Totals:

	1	2	3	4	5
The application was visually pleasing			4	1	1
The application’s controls/icons were easy to understand (perspicuity)		3		1	3
The application controls were efficient to use (practical and well organized)		1	1	4	1
All of the application’s controls worked as expected and were dependable		1	1	1	4
The controls translated well to 3D space		2		3	2
The real environment distracted me from playing the game	2			4	1
The application would have been just as engaging as an application without AR	2	1	1	2	1
The AR feature sparked my interest			1	2	4
This application makes me want to try out other AR applications	1	1			5
The virtual objects felt flat and detached from reality	1	3	2	1	
The virtual objects felt like they belonged among the real objects		4		3	
I was under the impression that I could have touched and grasped the virtual objects	4	2		1	
The virtual objects felt like they had a physical location in space		2	1	4	
I felt constrained and claustrophobic	5	1	1		
Moving around the space felt like a natural part of the experience	1	1	2		3
I felt like this application was frustrating to use		5		2	

Table 1. Total 2D UI Likert responses

Gesture Totals:

	1	2	3	4	5
The application was visually pleasing			2	2	3
The application’s controls/icons were easy to understand (perspicuity)				4	3
The application controls were efficient to use (practical and well organized)		2		2	3
All of the application’s controls worked as expected and were dependable		2	1	3	1
The controls translated well to 3D space			2	1	4
The real environment distracted me from playing the game	3	3		1	
The application would have been just as engaging as an application without AR	3	2	1		
The AR feature sparked my interest				3	4
This application makes me want to try out other AR applications			2	1	3
The virtual objects felt flat and detached from reality	1	5		1	
The virtual objects felt like they belonged among the real objects		3	2	2	
I was under the impression that I could have touched and grasped the virtual objects		1	3	3	
The virtual objects felt like they had a physical location in space		1		6	
I felt constrained and claustrophobic	4	2			
Moving around the space felt like a natural part of the experience		1	1	3	2
I felt like this application was frustrating to use	4	1	1	1	

Table 2. Total gesture control Likert responses

When looking at the Likert responses, there were two statements that stood out as having all seven people on the 4 or 5 mark. Regarding the application with gesture controls, both ‘the application’s controls were easy to understand’ and ‘the AR feature sparked my interest’ had all seven test subjects (100%) either agreeing or strongly agreeing with those statements [Table 2]. The same application as had six people (85.7%) either disagreeing or strongly disagreeing with

‘the virtual objects felt flat and detached from reality’, and six saying they agree with the statement ‘the virtual objects felt like they had a physical location in space.

When looking at the Likert responses to the 2D UI application, though not obviously worse, did seem to have slightly more varying answers [Table 1]. Only four of the seven, or 57.1%, found those controls easy to understand, and six of the seven (85.7%) agreed/strongly agreed with ‘the AR feature sparked my interest’. Both of those statements were the unanimous responses from the gesture application tests.

It was also quite interesting that even though 57.1% of the subjects were initially neutral to ‘the application was visually pleasing’ on the 2D UI survey (and one didn’t answer that question), 71.4% of them either agreed or strongly agreed with that statement when it was asked on the gesture survey. None of the visuals had changed beyond the removal of the arrow pads, yet the majority scored the game higher on visual appeal. The statement ‘I was under the impression that I could have touched and grasped the VOs’ even went from mostly disagreement (85.7%) with the 2D controls to three neutral and three agreement marks in the second survey: only 14.3% disagreed. As the gesture controls appear to be favourite of 85.7% of the subjects, with the last test subject saying they liked both, it might fair to suppose that the bias towards the second set of controls could cause the subjects to feel more immersed in the game overall.

Luckily, none of the participants felt either of the games were constraining or claustrophobic. Thus, the spatial limits of the game did not appear to cause any stress or frustration in the test subjects. Though five individuals (71.4%) said that the real world distracted them from playing the game, it appears they got used to it the second round where 85.7% said they weren’t distracted by their surroundings. Another noticeable feature in the responses was the fact that all seven individuals, when scoring the 2D UI application, had vastly different views on whether the

application would have been just as engaging without AR; it was the only statement that received responses in all five possible options [Table 1].

7.1 Results

The movement data that was gathered was plotted to show each participant's path around the space with the orange square representing the position of the game grid as they played. As data points were only recorded once every five seconds, it is important to note that the lines between dots do not necessarily represent the direct path taken. As such, there are a few lines that cross

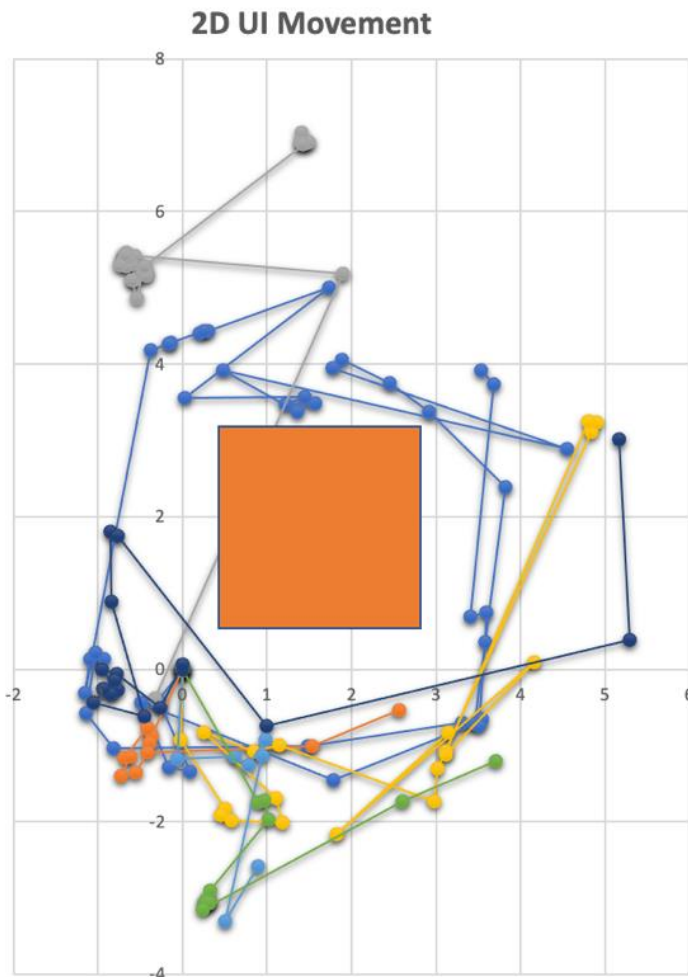


Figure 16. 2D UI movement data graph

through the grid, and we can assume the player just rounded the corner quickly, missing the intermediate point.

Each participant started at the origin of the graph, and the colour of each line responds to a specific participant. In this case, the green points on both graphs represent participant number six [Fig. 16, 17]. The number of points on each graph suggests that most if not all participants lasted for a longer time using the gesture controls. Though some of this could be due to gained familiarity with the game, it is significant enough to suggest that the gesture controls were also more intuitive than the alternative. Most users seemed to prefer moving around the game grid to their right with a few exceptions. It is not surprising that individuals seemed to prefer playing close

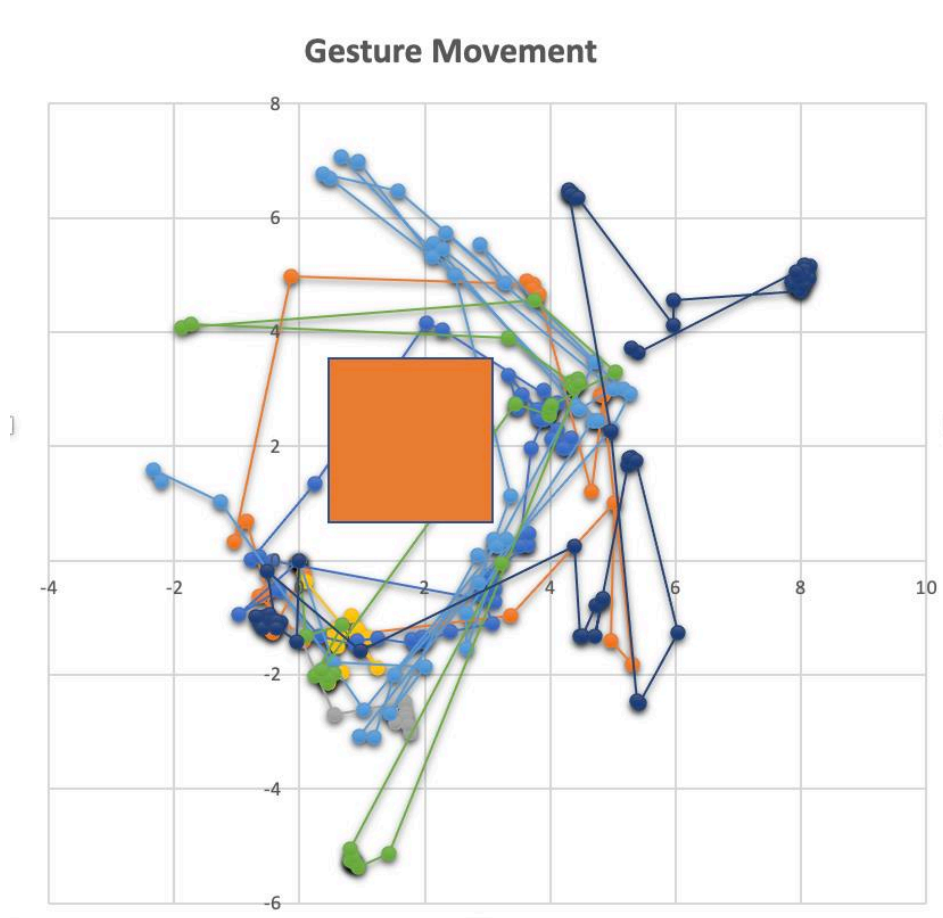


Figure 17. Gesture movement data graph

to the corners, allowing them to have the best view of the X and Z axes while still keeping away from the 45 degree angle where the orientation may shift on them.

The shortest time someone scored was 16 seconds when they had trouble grasping the rotation controls. The longest time a player score was 4 minutes and 4 seconds. The longest time, however, probably shouldn't be taken at face value. Though the players are allowed to move around, this particular tester was able to find a nearby object to climb on, gaining the top-down view the game grid position was supposed to avoid. This participant's round is shown as the Navy plot points on the gesture movement graph. The cluster of points around 8 on the x-axis represent the portion of time the participant was standing on the object. Thus, this subject had an advantage for that round. This behaviour from a test subject was both unexpected and unaccounted for in the rules as described to the participants.

If the maximum time is to be thrown out, the next highest scoring time was 3 minutes and 38 seconds. Both of these high scores were obtained in the gesture control round. Similarly, the two shortest rounds were 16 and 17 seconds, both scored in the 2D UI version. It's also interesting to note that the individual who move around the space the least was an individual who had tried AR twice before. On the other hand, the individual who had never experience AR before (sky blue plot points), though they started out with a shorter run, ended up being one of the most successful in the second round in both time and distance travelled [Fig. 17].

8 Conclusion

Overall, the test was successful and many individuals were interested in playing again to improve their score. It is fairly obvious that gesture controls were the favourite of this testing group. Adjustments will have to be made to the 2D interface before this study is continued at a larger scale.

As both user movement and the survey sense of presence scores improved with the changed UI, it seems fair to say that the user interface design has definitely had a positive impact on the user experience. The Likert scale scores increased quite significantly with the gesture UI version. The length of time each subject lasted playing the game went up as well.

Once adjustments are made to improve the 2D interface and the applications are brought back into testing, it would be interesting to randomize which interface the user starts with, so familiarity becomes less of a variable as the users improve in the latter round. Familiarity was considered when selecting Tetris as a game, but the learning curve of Tetris being in 3 dimensions was not discussed as a possible issue. Though the data is leaning towards suggesting that the UI design impacted the user's sense of presence in the AR environment, it would be best to take this opportunity to use the feedback to build upon this concept. The percentages of each Likert statement is shown in the table below [Table 3].

Results in Percentages:

	2D UI			Gestures		
	Disagree	Neutral	Agree	Disagree	Neutral	Agree
The application was visually pleasing	0%	57.1%	28.6%	0%	28.6%	71.4%
The application’s controls/icons were easy to understand (perspicuity)	42.9%	0%	57.1%	0%	0%	100%
The application controls were efficient to use (practical and well organized)	14.3%	14.3%	71.4%	28.6%	0%	71.4%
All of the application’s controls worked as expected and were dependable	14.3%	14.3%	71.4%	28.6%	14.3%	57.1%
The controls translated well to 3D space	28.6%	0%	71.4%	0%	28.6%	71.4%
The real environment distracted me from playing the game	28.6%	0%	71.4%	85.7%	0%	14.3%
The application would have been just as engaging as an application without AR	42.9%	14.3%	42.9%	71.4%	14.3%	0%
The AR feature sparked my interest	0%	14.3%	85.7%	0%	0%	100%
This application makes me want to try out other AR applications	28.6%	0%	71.4%	0%	28.6%	57.1%
The virtual objects felt flat and detached from reality	57.1%	28.6%	14.3%	85.7%	0%	14.3%
The virtual objects felt like they belonged among the real objects	57.1%	0%	42.9%	42.9%	28.6%	28.6%
I was under the impression that I could have touched and grasped the virtual	85.7%	0%	14.3%	14.3%	42.9%	42.9%
The virtual objects felt like they had a physical location in space	28.6%	14.3%	57.1%	14.3%	0%	85.7%
I felt constrained and claustrophobic	85.7%	14.3%	0%	85.7%	0%	0%
Moving around the space felt like a natural part of the experience	28.6%	28.6%	42.9%	14.3%	14.3%	71.4%
I felt like this application was frustrating to use	71.4%	0%	28.6%	71.4%	14.3%	14.3%

Table 3. Resulting percentages from Likert responses

8.1 Future Development & Testing

To continue this line of research, the next step would be to make some adjustments to the two Tetris versions before testing the applications on a larger group of individuals. Multiple test subjects suggested that the 2D user interface design could be improved by making the input buttons larger or at least adjustable based on the screen and/or hand size. This would be beneficial to

consider as it would bring up an interesting discussion on how much screen real estate a UI should be able to take up before it begins to visually impede on viewing the AR aspects.

Another modification to consider regarding the 2D UI application is swapping the side the move and rotate buttons are on. As the movement buttons were listed on the left, many players seemed to adjust the rotation before the location of the blocks. This may be due to these subjects being right-handed. As development and testing was done mostly by a left-handed individual, this may be a factor to consider changing or making alterable in a settings menu.

As for the feedback on the gesture controls, there were only two passing comments as the feedback for that one was mostly positive. Firstly, the orientation change at the corners of the game grid seemed to be a minor annoyance, though the user's got around this by avoiding standing there. Secondly, there was a comment or two about wanting more responsiveness from the swipe controls, and that it would be better if it wasn't necessary to lift the finger from the screen in between each swipe.

The next iteration of the AR 3D Tetris game will be much more polished with the necessary changes. In addition, having a tutorial or instructions for each interface design directly on the application would streamline the process, allowing users a better idea of what to expect without being thrown into the first round confused.

As the results between the two version tests were so different, the data softly suggests that a user interface design could actually impact the user's spatial awareness and sense of presence in an augmented reality 3D mobile game. Further development and testing is the next step to exploring this theory, but the initial results are in our hypothesis's favour overall.

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Appendix 1 – YouTube Video

YouTube link to the AR 3D Tetris playthrough: <https://youtu.be/U4tIyS6nbBk>

Appendix 2 – Participant Surveys

User Interface Design in Mobile Augmented Reality

Participant Survey: Participant # L test # 1

1. Have you ever experienced/interacted with augmented reality before? (yes/ no)
 - a. If so, how many times? 4
 - b. What device(s) or headset(s) have you used? mobile Devices
2. How old are you? 24
3. Gender Identity? male
4. Are you familiar with Tetris? yes

On a scale of 1 to 5, how much do you agree with the following statements (check box)
 1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

	1	2	3	4	5
The application was visually pleasing			<input checked="" type="checkbox"/>		
The application's controls/icons were easy to understand (perspicuity)				<input checked="" type="checkbox"/>	
The application controls were efficient to use (practical and well organized)			<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	
All of the application's controls worked as expected and were dependable			<input checked="" type="checkbox"/>		
The controls translated well to 3D space		<input checked="" type="checkbox"/>			
The real environment distracted me from playing the game	<input checked="" type="checkbox"/>				
The application would have been just as engaging as an application without AR	<input checked="" type="checkbox"/>				
The AR feature sparked my interest					<input checked="" type="checkbox"/>
This application makes me want to try out other AR applications	<input checked="" type="checkbox"/>				
The virtual objects felt flat and detached from reality			<input checked="" type="checkbox"/>		
The virtual objects felt like they belonged among the real objects		<input checked="" type="checkbox"/>			

I was under the impression that I could have touched and grasped the virtual objects	<input checked="" type="checkbox"/>				
The virtual objects felt like they had a physical location in space				<input checked="" type="checkbox"/>	
I felt constrained and claustrophobic	<input checked="" type="checkbox"/>				
Moving around the space felt like a natural part of the experience					<input checked="" type="checkbox"/>
I felt like this application was frustrating to use		<input checked="" type="checkbox"/>			

1. What did you think about this game overall? Any comments?
 - a. Overall Good experience, Issue with orientation at the start but this was quickly overcome.

User Interface Design in Mobile Augmented Reality

Participant Survey: Participant # L test # 2

On a scale of 1 to 5, how much do you agree with the following statements (check box)
 1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

	1	2	3	4	5
The application was visually pleasing			<input checked="" type="checkbox"/>		
The application's controls/icons were easy to understand (perspicuity)				<input checked="" type="checkbox"/>	
The application controls were efficient to use (practical and well organized)		<input checked="" type="checkbox"/>			
All of the application's controls worked as expected and were dependable		<input checked="" type="checkbox"/>			
The controls translated well to 3D space				<input checked="" type="checkbox"/>	
The real environment distracted me from playing the game	<input checked="" type="checkbox"/>				
The application would have been just as engaging as an application without AR		<input checked="" type="checkbox"/>			
The AR feature sparked my interest					<input checked="" type="checkbox"/>
This application makes me want to try out other AR applications					<input checked="" type="checkbox"/>
The virtual objects felt flat and detached from reality		<input checked="" type="checkbox"/>			
The virtual objects felt like they belonged among the real objects			<input checked="" type="checkbox"/>		
I was under the impression that I could have touched and grasped the virtual objects			<input checked="" type="checkbox"/>		
The virtual objects felt like they had a physical location in space				<input checked="" type="checkbox"/>	
I felt constrained and claustrophobic	<input checked="" type="checkbox"/>				
Moving around the space felt like a natural part of the experience					<input checked="" type="checkbox"/>
I felt like this application was frustrating to use				<input checked="" type="checkbox"/>	

1. What did you think about this game overall? Any comments?
 - a. Great Gesture Controls Felt more natural But slightly unresponsive especially the "Double swipe"

User Interface Design in Mobile Augmented Reality

Participant Survey: Participant # _____ Final Questionnaire

1. Which test did you prefer? What did you like about it?

2. What didn't you like about the other test?

User Interface Design in Mobile Augmented Reality

Participant Survey: Participant # 2, test # 1

1. Have you ever experienced/interacted with augmented reality before? (yes / no)
 - a. If so, how many times? 00
 - b. What device(s) or headset(s) have you used? HoloLens
2. How old are you? 26
3. Gender Identity? Male
4. Are you familiar with Tetris? Yes

On a scale of 1 to 5, how much do you agree with the following statements (check box)?
 1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

	1	2	3	4	5
The application was visually pleasing					✓
The application's controls/icons were easy to understand (perspicuity)					✓
The application controls were efficient to use (practical and well organized)			✓		
All of the application's controls worked as expected and were dependable			✓		✓
The controls translated well to 3D space					✓
The real environment distracted me from playing the game	✓				
The application would have been just as engaging as an application without AR					✓
The AR feature sparked my interest					✓
This application makes me want to try out other AR applications					✓
The virtual objects felt flat and detached from reality				✓	
The virtual objects felt like they belonged among the real objects				✓	

I was under the impression that I could have touched and grasped the virtual objects		✓			
The virtual objects felt like they had a physical location in space			✓		
I felt constrained and claustrophobic	✓				
Moving around the space felt like a natural part of the experience					✓
I felt like this application was frustrating to use		✓			

1. What did you think about this game overall? Any comments?
 - a. Control could have been bigger or adjustable.

User Interface Design in Mobile Augmented Reality

Participant Survey: Participant # 2, test # 2

On a scale of 1 to 5, how much do you agree with the following statements (check box)?
 1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

	1	2	3	4	5
The application was visually pleasing					✓
The application's controls/icons were easy to understand (perspicuity)					✓
The application controls were efficient to use (practical and well organized)				✓	
All of the application's controls worked as expected and were dependable			✓		
The controls translated well to 3D space			✓		
The real environment distracted me from playing the game	✓				
The application would have been just as engaging as an application without AR	✓				
The AR feature sparked my interest					✓
This application makes me want to try out other AR applications					✓
The virtual objects felt flat and detached from reality		✓			
The virtual objects felt like they belonged among the real objects				✓	
I was under the impression that I could have touched and grasped the virtual objects				✓	
The virtual objects felt like they had a physical location in space				✓	
I felt constrained and claustrophobic	✓				
Moving around the space felt like a natural part of the experience					✓
I felt like this application was frustrating to use	✓				

1. What did you think about this game overall? Any comments?
 - a. Player Orientation for the 3D UI game and controls sometimes are unsynchronized

User Interface Design in Mobile Augmented Reality

Participant Survey: Participant # , Final Questionnaire

1. Which test did you prefer? What did you like about it?

3D UI I was familiar to with the game
2. What didn't you like about the other test?

The on screen controls limit the user and sometimes distract from the experience.

User Interface Design in Mobile Augmented Reality

Participant Survey: Participant # 3, test # 1

1. Have you ever experienced/interacted with augmented reality before? (yes) no)
 - a. If so, how many times? 2
 - b. What device(s) or headset(s) have you used? _____
2. How old are you? 32
3. Gender Identity? male
4. Are you familiar with Tetris? used very

On a scale of 1 to 5, how much do you agree with the following statements (check box)?
 1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

	1	2	3	4	5
The application was visually pleasing					
The application's controls/icons were easy to understand (perspicuity)					✓
The application controls were efficient to use (practical and well organized)					✓
All of the application's controls worked as expected and were dependable					✓
The controls translated well to 3D space				✓	
The real environment distracted me from playing the game				✓	
The application would have been just as engaging as an application without AR			✓		
The AR feature sparked my interest					✓
This application makes me want to try out other AR applications					✓
The virtual objects felt flat and detached from reality		✓			
The virtual objects felt like they belonged among the real objects		✓			

I was under the impression that I could have touched and grasped the virtual objects	✓				
The virtual objects felt like they had a physical location in space				✓	
I felt constrained and claustrophobic	✓				✓
Moving around the space felt like a natural part of the experience					✓
I felt like this application was frustrating to use		✓			

1. What did you think about this game overall? Any comments?
 - a. Bestest way to play a old game fresh cont of play

User Interface Design in Mobile Augmented Reality

Participant Survey: Participant # 3, test # 2

On a scale of 1 to 5, how much do you agree with the following statements (check box)?
 1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

	1	2	3	4	5
The application was visually pleasing					✓
The application's controls/icons were easy to understand (perspicuity)					✓
The application controls were efficient to use (practical and well organized)					✓
All of the application's controls worked as expected and were dependable					✓
The controls translated well to 3D space				✓	
The real environment distracted me from playing the game	✓				
The application would have been just as engaging as an application without AR					✓
The AR feature sparked my interest					✓
This application makes me want to try out other AR applications			✓		
The virtual objects felt flat and detached from reality	✓				
The virtual objects felt like they belonged among the real objects			✓		
I was under the impression that I could have touched and grasped the virtual objects		✓			
The virtual objects felt like they had a physical location in space				✓	
I felt constrained and claustrophobic		✓			
Moving around the space felt like a natural part of the experience			✓		
I felt like this application was frustrating to use	✓				

1. What did you think about this game overall? Any comments?
 - a. Good take on an old

User Interface Design in Mobile Augmented Reality

Participant Survey: Participant # _____, Final Questionnaire

1. Which test did you prefer? What did you like about it?

Both were good. Second more VR Related. would try on AR.
2. What didn't you like about the other test?

They were too fast for me.

User Interface Design in Mobile Augmented Reality

Participant Survey: Participant # 4, test # 1

- Have you ever experienced/interacted with augmented reality before? (yes) no)
 - If so, how many times? 2
 - What device(s) or headset(s) have you used? Oculus
- How old are you? 33
- Gender Identity? Female
- Are you familiar with Tetris? Yes

On a scale of 1 to 5, how much do you agree with the following statements (check box)?
 1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

	1	2	3	4	5
The application was visually pleasing				<input checked="" type="checkbox"/>	
The application's controls/icons were easy to understand (perspicuity)		<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>		
The application controls were efficient to use (practical and well organized)				<input checked="" type="checkbox"/>	
All of the application's controls worked as expected and were dependable		<input checked="" type="checkbox"/>			
The controls translated well to 3D space				<input checked="" type="checkbox"/>	
The real environment distracted me from playing the game				<input checked="" type="checkbox"/>	
The application would have been just as engaging as an application without AR	<input checked="" type="checkbox"/>				
The AR feature sparked my interest					<input checked="" type="checkbox"/>
This application makes me want to try out other AR applications					<input checked="" type="checkbox"/>
The virtual objects felt flat and detached from reality		<input checked="" type="checkbox"/>			
The virtual objects felt like they belonged among the real objects		<input checked="" type="checkbox"/>			

I was under the impression that I could have touched and grasped the virtual objects	<input checked="" type="checkbox"/>				
The virtual objects felt like they had a physical location in space		<input checked="" type="checkbox"/>			
I felt constrained and claustrophobic		<input checked="" type="checkbox"/>			
Moving around the space felt like a natural part of the experience	<input checked="" type="checkbox"/>				
I felt like this application was frustrating to use					<input checked="" type="checkbox"/>

- What did you think about this game overall? Any comments?
 - It felt rigid and that the buttons were too small. However, I was terrible so I would have liked to play a few more times to get the hang of it.

User Interface Design in Mobile Augmented Reality

Participant Survey: Participant # 4, test # 2

On a scale of 1 to 5, how much do you agree with the following statements (check box)?
 1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

	1	2	3	4	5
The application was visually pleasing					<input checked="" type="checkbox"/>
The application's controls/icons were easy to understand (perspicuity)				<input checked="" type="checkbox"/>	
The application controls were efficient to use (practical and well organized)		<input checked="" type="checkbox"/>			
All of the application's controls worked as expected and were dependable		<input checked="" type="checkbox"/>			
The controls translated well to 3D space					<input checked="" type="checkbox"/>
The real environment distracted me from playing the game		<input checked="" type="checkbox"/>			
The application would have been just as engaging as an application without AR	<input checked="" type="checkbox"/>				
The AR feature sparked my interest					<input checked="" type="checkbox"/>
This application makes me want to try out other AR applications					
The virtual objects felt flat and detached from reality		<input checked="" type="checkbox"/>			
The virtual objects felt like they belonged among the real objects				<input checked="" type="checkbox"/>	
I was under the impression that I could have touched and grasped the virtual objects				<input checked="" type="checkbox"/>	
The virtual objects felt like they had a physical location in space				<input checked="" type="checkbox"/>	
I felt constrained and claustrophobic					
Moving around the space felt like a natural part of the experience		<input checked="" type="checkbox"/>			
I felt like this application was frustrating to use		<input checked="" type="checkbox"/>			

- What did you think about this game overall? Any comments?
 - Much more fun. I would like to play again to get the hang of walking around. I liked the 3D feel of the game.

User Interface Design in Mobile Augmented Reality

Participant Survey: Participant # ____, Final Questionnaire

- Which test did you prefer? What did you like about it?

second test
felt more exciting and 3D.
- What didn't you like about the other test?

It felt Squashed and too small
would be better on a tablet.

User Interface Design in Mobile Augmented Reality

Participant Survey: Participant # 5, test # 1

1. Have you ever experienced/interacted with augmented reality before? (yes /no)
 - a. If so, how many times? _____
 - b. What device(s) or headset(s) have you used? _____
2. How old are you? 35
3. Gender Identity? Male
4. Are you familiar with Tetris? Yes

On a scale of 1 to 5, how much do you agree with the following statements (check box)?
 1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

	1	2	3	4	5
The application was visually pleasing			✓		
The application's controls/icons were easy to understand (perspicuity)					✓
The application controls were efficient to use (practical and well organized)				✓	
All of the application's controls worked as expected and were dependable					✓
The controls translated well to 3D space				✓	
The real environment distracted me from playing the game				✓	
The application would have been just as engaging as an application without AR		✓			
The AR feature sparked my interest				✓	
This application makes me want to try out other AR applications					✓
The virtual objects felt flat and detached from reality		✓			
The virtual objects felt like they belonged among the real objects		✓			

I was under the impression that I could have touched and grasped the virtual objects	✓				
The virtual objects felt like they had a physical location in space		✓			
I felt constrained and claustrophobic	✓				
Moving around the space felt like a natural part of the experience		✓			
I felt like this application was frustrating to use					✓

1. What did you think about this game overall? Any comments?
 - a. Very fun, the Controls were a bit too small so could press wrong direction or position

User Interface Design in Mobile Augmented Reality

Participant Survey: Participant # 5, test # 2

On a scale of 1 to 5, how much do you agree with the following statements (check box)?
 1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

	1	2	3	4	5
The application was visually pleasing			✓		
The application's controls/icons were easy to understand (perspicuity)					✓
The application controls were efficient to use (practical and well organized)					✓
All of the application's controls worked as expected and were dependable					✓
The controls translated well to 3D space					✓
The real environment distracted me from playing the game				✓	
The application would have been just as engaging as an application without AR	✓				
The AR feature sparked my interest					✓
This application makes me want to try out other AR applications				✓	
The virtual objects felt flat and detached from reality		✓			
The virtual objects felt like they belonged among the real objects		✓			
I was under the impression that I could have touched and grasped the virtual objects			✓		
The virtual objects felt like they had a physical location in space		✓			
I felt constrained and claustrophobic		✓			
Moving around the space felt like a natural part of the experience					✓
I felt like this application was frustrating to use	✓				

What did you think about this game overall? Any comments?

- a. Very fun, Second time around I felt the Controls worked better.

User Interface Design in Mobile Augmented Reality

Participant Survey: Participant # _____, Final Questionnaire

1. Which test did you prefer? What did you like about it?

Second test, Controls were better.
2. What didn't you like about the other test?

the Controls were too small.

User Interface Design in Mobile Augmented Reality

Participant Survey: Participant # 6, test # 1

1. Have you ever experienced/interacted with augmented reality before? (yes / no)
 - a. If so, how many times? 2 years
 - b. What device(s) or headset(s) have you used? Galaxy
2. How old are you? 38
3. Gender Identity? Male
4. Are you familiar with Tetris? Yes - Familiar

On a scale of 1 to 5, how much do you agree with the following statements (check box)?
 1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

	1	2	3	4	5
The application was visually pleasing				<input checked="" type="checkbox"/>	
The application's controls/icons were easy to understand (perspicuity)		<input checked="" type="checkbox"/>			
The application controls were efficient to use (practical and well organized)				<input checked="" type="checkbox"/>	
All of the application's controls worked as expected and were dependable					<input checked="" type="checkbox"/>
The controls translated well to 3D space		<input checked="" type="checkbox"/>			
The real environment distracted me from playing the game				<input checked="" type="checkbox"/>	
The application would have been just as engaging as an application without AR				<input checked="" type="checkbox"/>	
The AR feature sparked my interest			<input checked="" type="checkbox"/>		
This application makes me want to try out other AR applications		<input checked="" type="checkbox"/>			
The virtual objects felt flat and detached from reality	<input checked="" type="checkbox"/>				
The virtual objects felt like they belonged among the real objects				<input checked="" type="checkbox"/>	

I was under the impression that I could have touched and grasped the virtual objects				<input checked="" type="checkbox"/>	
The virtual objects felt like they had a physical location in space				<input checked="" type="checkbox"/>	
I felt constrained and claustrophobic	<input checked="" type="checkbox"/>				
Moving around the space felt like a natural part of the experience				<input checked="" type="checkbox"/>	
I felt like this application was frustrating to use	<input checked="" type="checkbox"/>				

1. What did you think about this game overall? Any comments?
 - a. Change the controls to feature large round buttons with clearer axis labels

User Interface Design in Mobile Augmented Reality

Participant Survey: Participant # 6, test # 2

On a scale of 1 to 5, how much do you agree with the following statements (check box)?
 1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

	1	2	3	4	5
The application was visually pleasing				<input checked="" type="checkbox"/>	
The application's controls/icons were easy to understand (perspicuity)				<input checked="" type="checkbox"/>	
The application controls were efficient to use (practical and well organized)				<input checked="" type="checkbox"/>	
All of the application's controls worked as expected and were dependable				<input checked="" type="checkbox"/>	
The controls translated well to 3D space					<input checked="" type="checkbox"/>
The real environment distracted me from playing the game		<input checked="" type="checkbox"/>			
The application would have been just as engaging as an application without AR				<input checked="" type="checkbox"/>	
The AR feature sparked my interest			<input checked="" type="checkbox"/>		
This application makes me want to try out other AR applications		<input checked="" type="checkbox"/>			
The virtual objects felt flat and detached from reality	<input checked="" type="checkbox"/>				
The virtual objects felt like they belonged among the real objects				<input checked="" type="checkbox"/>	
I was under the impression that I could have touched and grasped the virtual objects				<input checked="" type="checkbox"/>	
The virtual objects felt like they had a physical location in space				<input checked="" type="checkbox"/>	
I felt constrained and claustrophobic	<input checked="" type="checkbox"/>				
Moving around the space felt like a natural part of the experience				<input checked="" type="checkbox"/>	
I felt like this application was frustrating to use	<input checked="" type="checkbox"/>				

1. What did you think about this game overall? Any comments?
 - a. Swipe controls more intuitive Tutorial level with direction breakdown

User Interface Design in Mobile Augmented Reality

Participant Survey: Participant # _____, Final Questionnaire

1. Which test did you prefer? What did you like about it?

2 - swipe controls more intuitive
2. What didn't you like about the other test?

Button design

User Interface Design in Mobile Augmented Reality

Participant Survey: Participant # 7, test # 1

- Have you ever experienced/interacted with augmented reality before? (yes / no)
 - If so, how many times? I am familiar
 - What device(s) or headset(s) have you used? HoloLens, mobile
- How old are you? 21
- Gender Identity? Female
- Are you familiar with Tetris? yes

On a scale of 1 to 5, how much do you agree with the following statements (check box)?
 1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

	1	2	3	4	5
The application was visually pleasing			<input checked="" type="checkbox"/>		
The application's controls/icons were easy to understand (perspicuity)		<input checked="" type="checkbox"/>			
The application controls were efficient to use (practical and well organized)		<input checked="" type="checkbox"/>			
All of the application's controls worked as expected and were dependable				<input checked="" type="checkbox"/>	
The controls translated well to 3D space					<input checked="" type="checkbox"/>
The real environment distracted me from playing the game					<input checked="" type="checkbox"/>
The application would have been just as engaging as an application without AR				<input checked="" type="checkbox"/>	
The AR feature sparked my interest				<input checked="" type="checkbox"/>	
This application makes me want to try out other AR applications					<input checked="" type="checkbox"/>
The virtual objects felt flat and detached from reality			<input checked="" type="checkbox"/>		
The virtual objects felt like they belonged among the real objects				<input checked="" type="checkbox"/>	

I was under the impression that I could have touched and grasped the virtual objects		<input checked="" type="checkbox"/>			
The virtual objects felt like they had a physical location in space				<input checked="" type="checkbox"/>	
I felt constrained and claustrophobic			<input checked="" type="checkbox"/>		
Moving around the space felt like a natural part of the experience			<input checked="" type="checkbox"/>		
I felt like this application was frustrating to use		<input checked="" type="checkbox"/>			

- What did you think about this game overall? Any comments?
 - The 3D format of the game, distracted me from understanding the orientation of the blocks, unless I move around the entire space as each block appears.

User Interface Design in Mobile Augmented Reality

Participant Survey: Participant # 7, test # 2

On a scale of 1 to 5, how much do you agree with the following statements (check box)?
 1 = strongly disagree 2 = disagree 3 = neutral 4 = agree 5 = strongly agree

	1	2	3	4	5
The application was visually pleasing					<input checked="" type="checkbox"/>
The application's controls/icons were easy to understand (perspicuity)					<input checked="" type="checkbox"/>
The application controls were efficient to use (practical and well organized)					<input checked="" type="checkbox"/>
All of the application's controls worked as expected and were dependable				<input checked="" type="checkbox"/>	
The controls translated well to 3D space					<input checked="" type="checkbox"/>
The real environment distracted me from playing the game		<input checked="" type="checkbox"/>			
The application would have been just as engaging as an application without AR			<input checked="" type="checkbox"/>		
The AR feature sparked my interest				<input checked="" type="checkbox"/>	
This application makes me want to try out other AR applications					<input checked="" type="checkbox"/>
The virtual objects felt flat and detached from reality				<input checked="" type="checkbox"/>	
The virtual objects felt like they belonged among the real objects		<input checked="" type="checkbox"/>			
I was under the impression that I could have touched and grasped the virtual objects			<input checked="" type="checkbox"/>		
The virtual objects felt like they had a physical location in space				<input checked="" type="checkbox"/>	
I felt constrained and claustrophobic	<input checked="" type="checkbox"/>				
Moving around the space felt like a natural part of the experience				<input checked="" type="checkbox"/>	
I felt like this application was frustrating to use	<input checked="" type="checkbox"/>				

- What did you think about this game overall? Any comments?
 - The game which had touch controls was more pleasing to play.

User Interface Design in Mobile Augmented Reality

Participant Survey: Participant # _____, Final Questionnaire

- Which test did you prefer? What did you like about it?

I would prefer the second game as I am more familiar by playing with touch controls rather than buttons on the corner of the screen
- What didn't you like about the other test?

In other test I had to constantly be aware of which button works for which movement, which also distracted me along with the environment and made me feel like this game would be more fun if it was 2D.