Design and Field Implementation of Virtual Buddy-Based Serious Games for Children

by

Catherine Ball

(Under the Direction of Kyle Johnsen)

Abstract

Serious games are games that are intended to serve a purpose other than merely to entertain, such as education or physical fitness. Childhood is a critical time for forming habits that extend into adulthood. Serious games can assist children in forming these habits while still being entertaining games to play. Additionally, virtual buddies can help both to motivate children to engage with the system and as a way to aid in forming these habits. With this in mind, we have designed several virtual buddy-based serious game systems to be used by children. These systems were designed with the ultimate goal of running them at a large-scale, unassisted in the field, where the environments played a pivotal role in the design and implementation of these systems. This article describes our experiences and lessons learned implementing each of these systems in the field. Finally, the goal of this dissertation is to analyze the data from our final study in order to uncover what parts of our latest system may affect participant engagement.

Index words: [Virtual reality, video games, serious games, mixed reality, public display, virtual pet, virtual buddy]

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Dedication

To my family and to Boomer, my not-so-Virtual Buddy, without whom this would not have been possible

Acknowledgments

I would like to acknowledge Dr. Kyle Johnsen for recognizing the potential in me all of those years ago and for being my mentor and research advisor. I would also like to thank Dr. Tim Foutz and Dr. K. Melissa Hallow, my advisory committee, for their ideas and support in my research.

I would also like to thank my family, my mother JoAn Ball, my late father Carl Ball, my brothers Grayson and Joel Ball, and my chosen brother Mark McCoy for all of their love and support. I would not have been able to make it through this journey without them.

Contents

Chapter 1

Introduction

Early childhood is a critical time for establishing habits that may extend into adulthood. Such habits include those that will aid in combating obesity, including physical activity (PA) habits [1] and fruit and vegetable (F&V) consumption [2], [3]. PA habits are an important indicator of overall health [4]. Consuming recommended daily levels of F&V can also aid in combating childhood obesity [2], [3]. About 18% of children from the United States have been classified as obese by 2008 [5], and less than 10% of children consume their recommended amount of F&V each day by 2010 [6]. This means that there is ample opportunity to help both decrease childhood obesity and increase the amount of F&V these children consume each day.

Additionally, childhood is a critical time to foster interest in science, technology, engineering, and math (STEM) areas. Exposure to and interest in STEM during early childhood can be used to gauge interest in STEM areas later in life [7], [8]. One avenue to introduce these concepts to children is through children's museum exhibits, which garner about 30 million visits each year around the world for museums targeting children around 3 to 6 years old [9]. Given the number of visits, children's museums provide ample opportunity to expose children to STEM areas early in life, potentially sparking their interest to work in STEM fields. However, children's museums which target this younger audience are underutilized compared to science museums which target an older audience [10].

For all of these areas, interactive systems could provide an opportunity for establishing these habits and interests in children. For example, digital technology has shown promise in increasing PA behavior of children through an entertaining medium [11]. This medium could take the form of a serious game, which is a game that is designed with a goal other than to merely entertain. This means that the extrinsic motivation of progressing in the game needs to facilitate establishing intrinsic motivations in order for the desired habit to continue beyond the game itself. According to self-determination theory (SDT) [12], meeting the psychological needs of autonomy (making one's own choices), competence (a sense of mastery), and relatedness (connectedness to others) can aid in this conversion. Lastly, these games need to consider not only the intended goal but also both the environment in which they will be deployed and the audience that they will target. Certain interactions simply may not work in a given environment, such as using voice commands in a noisy environment, certain hardware may not be feasible for it, such as requiring a family to make room for a large screen TV kiosk at home, or certain audiences may not be able to interact with it, such as relying solely on text to convey information to 3-6-year-olds.

With all of this in mind, we have designed several systems which target PA [13]–[17], F&V consumption [18], or STEM knowledge [19], integrating these areas as key factors in game progression. We allow children to set their own goals and decide how they want to interact with the game (autonomy). As they play the game, they are rewarded for setting and meeting these goals through increasing points earned and for mastering the game mechanics through beating their old high scores (competence). Each system has its own customizable virtual buddy intended to aid these children in establishing their real-world habits through a bond formed with this buddy (relatedness). Additionally, these children may receive encouragement from their parents through a messaging system where their parents may send messages of encouragement (relatedness).

Several of our systems utilize minigames that incorporate PA and players' body movements into their game mechanics. Similarly, exergames directly utilize a player's PA as the primary input mechanism for gameplay, such as Ring Fit Adventure [20], StepMania [21], and Nintendo Switch Sports [22]. These exergames are intended to make PA itself more entertaining [23]. However, our minigames are not exergames although they utilize participants' real-world movements. Our minigames use these movements without the intention of them exerting a large amount of energy to qualify as exercise. Instead, PA is incorporated into these games through the use of a VB's game statistics, such as using a player's real-world PA to increase their VB's speed or as points to use for customizations. This means our system uses PA not as a direct input but indirectly through a VB's stats or points earned.

As mentioned, VBs are a core component of each of our systems. VBs, often in the form of virtual pets [24], have been utilized for reducing mental stress [25], [26], encourage PA [27], and encouraging other health improvement related behaviors, such as motivating children to undergo cancer treatments [28], [29] or to aid in distracting them from pain [30]. Similarly, as previously mentioned, our systems utilize VBs to encourage healthy PA habits [13]–[17], improve fruit and vegatable consumption [18], and interest in STEM concepts [19] by fostering a relationship with the VB. This dissertation will explore the engineering design process of our past work where we designed and deployed these VB-based systems in the field. Lastly, engagement results from the latest completed Virtual Fitness Buddy (VFB) system will be explored.

Chapter 2

Summer Camp-Based Virtual Buddy Systems

Early pilot studies for the Virtual Fitness Buddy (VFB) system all took place at various weekly summer camps [13]–[15], [18]. They established the overall pattern of design across each of these studies where the team would implement the current version and pilot test it. After the pilot, we would then innovate and iterate on that design based on feedback from that pilot. Upon implementing these new designs, they would then be pilot tested out in the field and so on. While we tested these systems ourselves as we implemented their updates, all of the participant testing was done in the field. This allowed us to see how our participants would behave and how well our system worked "in the real world". We quickly discovered some elements of these systems were not as effective or simply did not work outside of a laboratory setting, where only a few people tested it. The following sections elaborate on two of these systems. One where the goal was to encourage increased fruit and vegetable consumption [18] and another where the goal was to encourage healthier physical activity habits [15]. Both utilized a similar virtual buddy that was placed in a similar virtual world where the participant interactions with these buddies varied given their different goals. They also had similar design constraints, where they needed to have shorter interactions that could be completed by many children promptly, their apps needed to have a focus on health-related concepts, and the children should be able to walk up and play with relative ease.

2.1 Virtual Buddy Fruit and Vegetable System

The Virtual Buddy Fruit and Vegetable (VB-F&V) system was designed to encourage children to consume more F&V by providing them a virtual buddy (VB). It targeted 25 children attending a weekly summer camp, where it was deployed for 3 days during a single summer camp in 2014 [18]. In addition to this treatment group, we included two control groups, where one group used the computer to track their F&V consumption but did not have a virtual pet (22 children) and the other had their F&V consumption tracked by the camp counselors (21 children). This brings the study to a total of 68 children (ages 7 to 13) across all conditions.

Figure 2.1: The range of VB sizes from the least healthy (left) to the most healthy (right).

Prior to this system, the team had developed the original Virtual Fitness Buddy (VFB-O) system, which targeted physical activity (PA) instead of F&V consumption [13], [14] and utilized a motion-based tracking system. The new VB-F&V system was heavily based on this prior system, consisting of a customizable VB, which became slimmer, faster, and able to perform more tricks as their child consumed F&V for lunch in the real world (Figure 2.1). F&V consumption was collected and recorded by camp counselors during lunch and then uploaded into the system. This F&V consumption was then used to unlock more tricks for the VB to perform. In order to perform these tricks, a child needed to spend trick credits. These credits were earned as a child reached their F&V consumption goals, where the number of credits earned scaled with the size of their goal. Instead of using the VFB-O motion-based tracking system, the VB-F&V system used a haptic joystick (Novint Falcon) to interact with the virtual world (see Figure 2.2). Using this new system, children were tasked with checking the health of their VB through three interactions: pumping their VB's heart, checking the major artery, and observing how quickly they completed tricks.

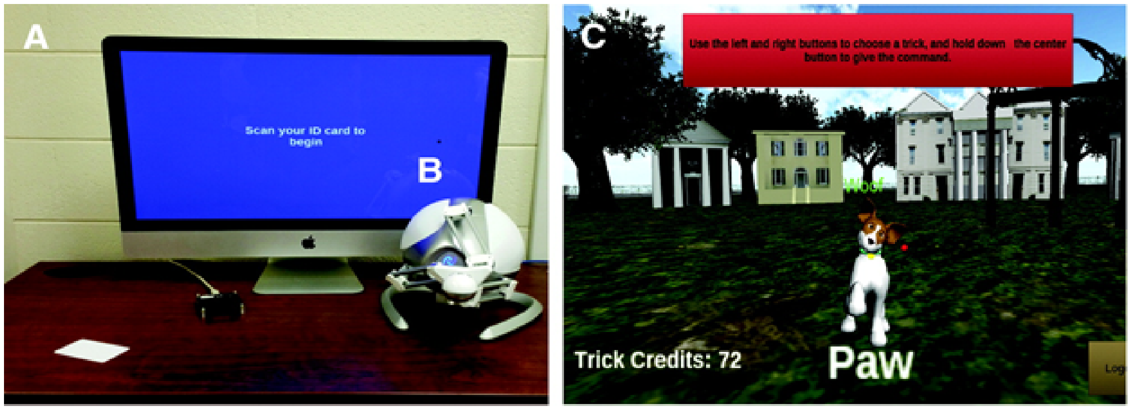


Figure 2.2: A play station for the VB-F&V system (A, left), including the Novint Falcon haptic joystick (B, left). An example of the VB-F&V virtual world, showing a VB and give paw trick (C, right), where the red sphere shown represents the virtual cursor controlled by the haptic joystick (B, left).

Each child needed to pump their VB's virtual heart and feel the elasticity of their major artery (Figure 2.3). As their VB became healthier, it was easier to pump the heart as their VB's artery became more elastic. They could feel the ease of pumping the heart and this elasticity as the amount of resistance provided by the haptic joystick as they pressed into the artery. The harder the heart was to pump and the less elastic the artery was, the more resistance was provided. In order to provide an on-screen representation of the VB's health, a meter was displayed ranging from red to green in color, where red indicating that the VB's health was low (Figure 2.3). This meter was intended to provide a visual reference point for the children to gauge the health level of their VB between interactions with them. Children then had their VB perform tricks, testing their VB's mental health. As their VB became healthier, it was able to complete tricks more quickly. Although we did provide multiple VB-F&V stations, we still designed the interactions to be short as the children only had a limited amount of time to play after lunch. We set these stations up in their own area near the cafeteria, making it easier for children to play with their VB following lunch.

These minigames were designed to demonstrate tangible impacts a child's F&V consumption had on the health of their VB quickly. Due to their bond with their VB and seeing the impacts F&V consumption has on their health, the child would be encouraged to consume more F&V. Lastly, the health of their VB

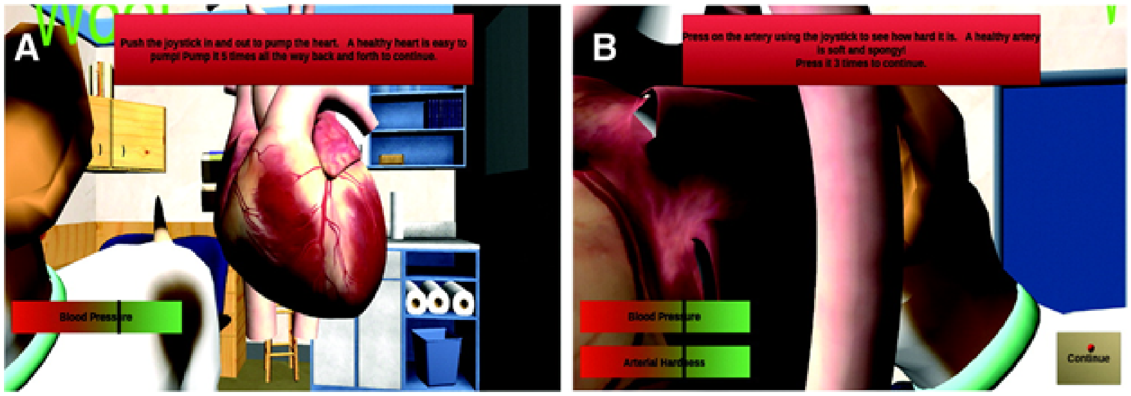


Figure 2.3: The VB-F&V heart pumping (A, left) and artery checking minigames (B, right). The sliders on the bottom left represent the health of the VB, ranging from min health (left/red) and max health (right/green).

was intended to demonstrate those same impacts on their own health, which were on a much slower time scale than the impacts on their VB's health. By making this real-world connection between F&V consumption and health, the child may continue to consume more F&V even beyond the scope of this study.

2.1.1 Results and Observations

We found that the VB-F&V system was successful with treatment participants consuming significantly more F&V than the control (no VB) groups [18]. We found that the children were excited to use the system and, thus, were not very delicate on the haptic joysticks even with supervision. Given the delicate and cumbersome nature of the haptic joysticks, we did not use them in a future system. Additionally, since the amount of F&V consumed during lunch had to be manually calculated, it took a long time to incorporate every child's results into the system. This caused frustration as they could not immediately play with their VB after they finished eating lunch. Lastly, given the success of the VB health check interactions, upcoming systems will use them as the basis for designing minigames for our participants to play with their VBs.

2.2 Virtual Fitness Buddy - Summer Camp System

Based on prior systems [13], [14], the Virtual Fitness Buddy Camp (VFB-C) system was designed to encourage children to engage in healthier physical activity (PA) habits by providing them with a virtual fitness buddy (VFB). Similar to the Virtual Buddy Fruit and Vegetable (VB-F&V) system, this system targeted children who were attending a weekly summer camp. It was deployed for 3 days and consisted of 67 children (ages 9 to 13) at a single summer camp in 2015, where 39 children were in the treatment (received points) condition and 28 children were in the control (received no points) condition [15]. The children were only able to interact with their VFB during the time that they were attending the camp.

Similar to the VB-F&V system, the VFB-C system consisted of a customizable VFB, which became slimmer, faster, and able to perform more tricks as their child engaged in PA in the real-world. The only VFB customization available at this time was changing the VFB's tag color. By tying the VFB's health to the child's PA, they could quickly see tangible benefits of their PA that were intended to reflect their own real-world health benefits, which sometimes can be hard to see overtime. For this new study, we switched to using a new PA tracker (the Fitbit Zip) instead of using the PA tracker from the original VFB (VFB-O) system. The Fitbit Zip also served as the method of logging into the system. By requiring these trackers to login, the child's PA was downloaded prior to playing with their VFB, allowing them to be rewarded in real time rather than needing to wait for it to be manually uploaded as in the VB-F&V study.

Each child played with their VFB using a mobile kiosk system, consisting of a large-screen TV and Microsoft Xbox360 Kinect (Figure 2.4 (left)). The Kinect allowed us to track and to utilize the child's real-world movements in order to interact with their VFB, intending to make them feel as if they were interacting directly with their VFB. These movements were mimicked by their virtual avatar, which was displayed as a collection of spheres on the side of the screen (see Figure 2.5). Our goal with using these real-world movements and moving the player's avatar to be in proximity of the VFB was to help foster a bond between the child and their VFB, helping to satisfy the psychological need of relatedness [12].

Figure 2.4: A child interacting with their VFB. The VFB-C mobile kiosk is shown on the left with the hover selection system shown on the right. The hover select cursor is shown as a pink circle on the right (located on the bottom of the image in the center near the VFB's foot).

Given that a single kiosk would be used for all of the participants, interactions with the VFB were designed to be short and intuitive. These interactions were modeled after behaviors that a real-world dog could perform, which included a throwing gesture used to play fetch and verbal commands in addition to a menu to initiate tricks. Following a command, the child would also need to complete the corresponding gesture to guide their VFB as they completed the trick. The VFB was able to fetch the ball and complete tricks faster as their health improved. These tricks were unlocked as the child earned points by meeting their PA goals. Each child was allowed to set and meet as many of these goals as they desired throughout the day. Lastly, they were not allowed to interact with their VFB again until they met their current PA goal. By allowing them to set their own goals, we gave each child autonomy over their experience, where they could gain a sense of mastery by meeting these goals more quickly. Additionally, we included the opportunity to give voice commands as a way to aid in improving participants' attachment to their VFBs.

In addition to these PA goals, we implemented a messaging system where a child's parent would receive a text message when their child met one of these goals. If the parent responded to this message, their message would be displayed for the child the next time they played with their VFB. This messaging system was intended to serve as additional encouragement for a child to meet their PA goals and as another avenue to foster a sense of connectedness to their parents.

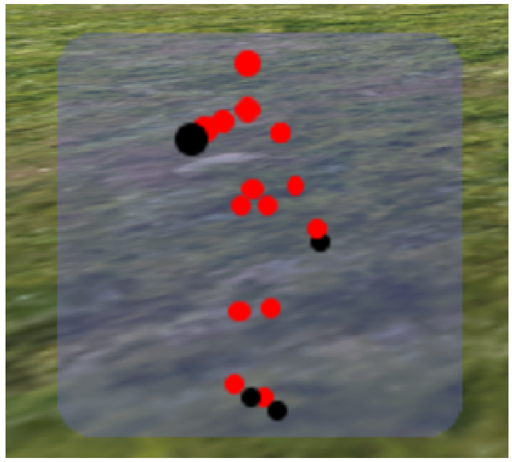


Figure 2.5: An example of the virtual avatar used to represent the player. This avatar was displayed on the side of the screen.

2.2.1 Results and Observations

During the previous study, there was a significant difference in PA outcomes for the treatment group over the control (no VFB) group [13], [14]. However, this new VFB-C system only briefly increased PA. The children set significantly less vigorous PA goals while setting significantly more light intensity PA goals when compared to the control (no point) group. This is likely a result of all goals rewarding the same number of points regardless of PA intensity [15].

From field observations, we found that it was difficult for the system to detect voice commands as the kiosk was placed near the cafeteria, which was a loud area of the camp. Additionally, we had trouble detecting who was trying to log into the VFB-C system using their Fitbit. In our lab tests, we noticed a problem where it was difficult to isolate the single Fitbit that we were using to login. Thus, we implemented an icon-based list for the detected Fitbits to address this problem. However, once the system was deployed in the field, these detection issues arose again. We suspect that the system was overwhelmed with the number of active Fitbits in close proximity. Lastly, we implemented a mid-air, dwell ("hover") selection system (see Figure 4 (right)), where a child would put a hand out in front of them and move it around to hover over the desired selection for a few seconds. This system was used to select the desired child from a list, set PA goals, and select a trick to buy and perform. We found that it was difficult and cumbersome for the children to use.

Given the success of the VFB-C system in encouraging children to engage in PA, we based our subsequent systems on it. These new systems expanded and improved this VFB-C system, adding more minigames for children to play with their VFB and ways to interact with the system itself. These PA-based systems will be explored in more detail in Chapters 4 and 5. The VFB-C system was also used as inspiration for a virtual buddy system designed to aid children in understanding various science, technology, engineering, and math (STEM) concepts. This system will be discussed further in Chapter 4.

Not only was the system a success in encouraging PA, the mobile kiosk was a robust design that was easy to break down for transport and withstood being used by the children at the camp without issue. Additionally, the kiosk was easily setup as it only needed to be plugged into power with a single cable for use everyday at the camp. For these reasons, this kiosk system would also be used in the studies in the upcoming chapters.

2.3 Conclusions and Lessons Learned

Across both of these studies we learned several lessons to apply going forward. First, from the VB-F&V intervention, we realized that children excited to play with their VBs are more likely to be rough on study hardware, meaning we should choose hardware that would be robust enough to sustain interactions across the duration of the desired study. In turn, this also could afford us the ability to leave hardware at a given site to be used without our personal observation, which, in turn, could increase the number of sites that could be using the VB system at a given time. We also realized how frustrating it was for the participants to have to wait for us to upload their data in order to play with their VFB. For future VB systems, autonomous data uploading and downloading was given a much higher priority.

Second, from VFB-C intervention, we discovered how difficult it was for the Kinect to detect participants' voice commands due to the ambient noise level from all of the individuals attending the summer camp. We kept this lesson in mind when planning where future VB stations should be setup and when designing future trick systems, where there should be an alternative way to initiate games or tricks in case the system has difficulties in hearing and understanding participants' verbal commands. Additionally, we realized that having a system function where a participant could simply walk up and play may be more difficult than we previously thought due to hardware limitations. This meant that we should more thoroughly consider the mechanism by which participants would login to play with their VBs rather than simply trying to rely on the strongest signal. We also realized how difficult it was for participants to use the mid-air hover selection system, meaning we should design different input mechanisms for future VB systems.

Lastly, the mobile kiosk, Fitbits, skeletal avatar, parent messaging, and the point-based system were all a success. As previously mentioned, the kiosk was easily assembled and operated without issues across the VFB-C study, meaning it required little from site staff to setup and maintain. Many of the children in the VFB-C study were excited to receive Fitbits despite our struggles with Fitbit detection. All of these features would be reused in the studies discussed in the upcoming chapters.

Chapter 3

Museum-Based Virtual Buddy System

Following our summer camp-based virtual buddy (VB) systems, we departed from a health-centered focus for our next system, focusing instead on sparking interest in science, technology, engineering, and math (STEM) concepts. This new system would also be used inside a children's museum rather than a summer camp. The design challenges were similar to our previous systems, where the system needed to be designed around relatively short interaction times and to accommodate the ability to begin playing quickly and easily. In addition to these design requirements, we also needed to design the interactions and the hardware system such that they would work in a limited space with children playing at nearby stations. We also wanted participants to have more options in customizing both their buddy and their experience interacting with the system. This way participants may become more invested in their buddy and the system itself, which in turn could impact their learning outcomes.

This new Virtual STEM Buddy (VSB-M) system was designed both to engage children with and to attempt to teach children STEM concepts by providing them with a virtual STEM buddy (VSB). It targeted children and parents attending the Children's Museum of Atlanta (CMOA) and was deployed for over 5 years (January 2017 to May 2022) as an exhibit at CMOA. This deployment resulted in 28,122 recorded plays over a 2-year period (January 2017 to January 2019) [19].

3.1 Hardware

Similar to the camp-based Virtual Fitness Buddy (VFB-C) system, the VSB-M system utilized a kiosk consisting of a large-screen TV and Microsoft Kinect for Windows (see Figure 3.1), allowing us to track a child's real-world movements. These movements would then be used to interact with the virtual world. Given our troubles with hover selection from the VFB-C system, we needed to implement a different selection interface for this new system so that our participants could easily customize their VSB and select which minigame to play.

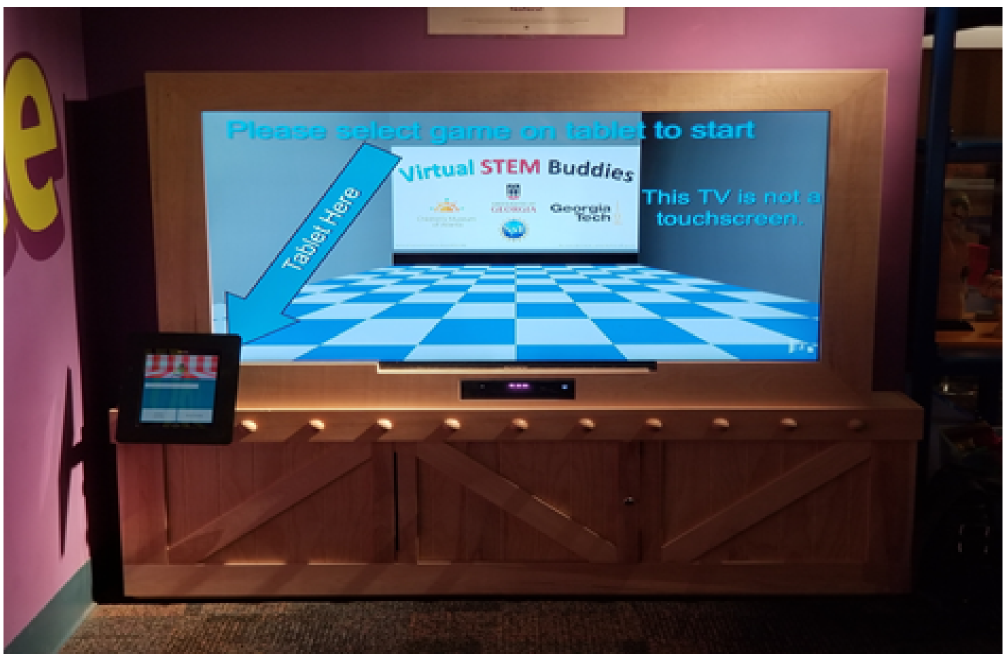


Figure 3.1: The VSB Kiosk at the Children's Museum of Atlanta.

Given the prevalence of smartphones and touchscreens being used for other CMOA exhibits, we opted to include an Android tablet alongside this kiosk as a likely familiar interface. In the field, we found that participants were able to learn and use this new touch interface much more easily than the hover selection interface. However, we did have an issue where the tablet and its encasing were rotated in such a way that snapped the tablet's charging cable. This was quickly addressed by restricting the movement of the tablet and there was no subsequent incident of the charge cable breaking for the duration of the installation of the

VSB-M kiosk. We opted to have the tablet and kiosk computer communicate via bluetooth. Fortunately, we did not experience any issues with this communication stream in the field.

This kiosk was largely self-maintained and seldom needed further assistance from museum staff beyond turning the kiosk on in the morning and off at the end of the day. We had the kiosk set up such that once the pc, locked behind the wooden doors of the kiosk, was turned on, it automatically logged in and launched the VSB-M app. Similarly, the tablet was locked down to only run the VSB-M app, which could be reset by museum staff by pressing an invisible button several times and entering a passcode. Early in the study, we had an issue where the graphics card in the computer failed twice. The first time, we simply installed a new one, suspecting it might be a faulty graphics card. The second time, we realized that maybe the computer was overheating inside the kiosk as its design did not incorporate openings for ventilation. This was then addressed, and we had no further issues with the computer nor with the graphics card.

3.2 Software

In our previous systems, we had not designed games using the Kinect motion-based interaction system. We did have the heart pumping and artery checking minigames in our VB-F&V system, but those had a physical controller, allowing our participants to signal intentionality with a button press. We also knew that the hover-based selection technique we designed for the VFB-C system was challenging for our participants to use. Designing these motion-only interactive games proved to be more of a challenge than we had anticipated. We found that it was very hard to signal intentionality without a physical button or the hover selection. For example, if a player wanted to pick up an object, they could not merely point at it and click a button or hover over it to pick it up. We did know from our previous virtual buddy systems that gestures seemed to translate well using a motion-based system, such as the gestures used to perform tricks with their virtual pet in the VFB-C study.

With all of this in mind, we designed a "grab" mechanic that seemed to work well to indicate a player's intention with the system based on our results. This grab mechanic will be further discussed in the Slingshot section below. Additionally, as mentioned earlier, we included a tablet for interactions which required finer controls, such as menu selection. This allowed us to design games that without needing to consider how they would select the different game options using the motion-based system, reducing the complexity when designing these motion-based games.

3.2.1 STEM Buddy

Figure 3.2: The VSB customization interface (left) along with six customized VSBs showing the various color and shape options (right).

The VSB was designed to be a personalizable buddy which was intended to act both as a motivating buddy and as a teacher. It would help children and their parents understand the underlying STEM concepts of each minigame while encouraging them as they solved each problem, cheering for them from the sidelines. Since part of our intended audience may not be able to read, these VSBs utilized both text and audio to convey both how to play each minigame and facts about the underlying STEM concepts. Each component of the VSB could be customized prior to starting a minigame, allowing children to design their own unique VSB (see Figure 3.2). If a child did not wish to customize the VSB, the system would simply use the previous VSB. Each VSB could be saved using a randomized, unique code which could be texted to a parent. This allowed a child to bring back their personalized VSB during a return visit to the exhibit. An area of interest was also chosen as part of the VSB personalization. This area of interest was used to customize the minigames, where players would complete an image based on the area of interest as they progressed in the minigames. The goal with the personalizable VSB and area of interest was to increase player investment while interacting with the system. It was intended to feel like their own experience and their personal buddy, which in turn was intended to gain their interest while playing the minigames.

We designed an entire system for participants to customize their buddy, where they could choose not only their VSB's name but also the color and shape of each body part. This vastly increased the amount of customization participants could have when compared to our previous virtual buddy systems, where they could only choose the name, collar, and tag of their buddy. This more detailed customization system was possible due to our inclusion of the touchscreen. It allowed participants to use an interaction system they were more likely to have interacted with before as compared to our motion-based, hover selection technique from our previous systems.

The larger vision of the buddy was to design a system where they could take their saved buddy with them once they had finished at the museum. The buddy would be tailored towards their learning needs, adjusting difficulty based on their responses to the system questions. Unfortunately, we were only able to implement the buddy saving system, leaving this "take along" feature for future work.

3.3 Minigames

We designed two motion-based minigames, where the child would use their real-world body to interact with the virtual world. Similar to the VFB-C avatar, this body was displayed as a collection of spheres in the virtual world (see Figure 3.3). Given that we knew the exact amount of space we were able to use at CMOA, we were able to scale the child's movements to ensure they were able to reach the necessary areas of the virtual world safely. Before designing the games, we decided the STEM concepts that we wanted those minigames to convey. These concepts were then integrated into the primary game mechanics of each game. This integration demonstrated the concept while the VSB explained the concept behind it.

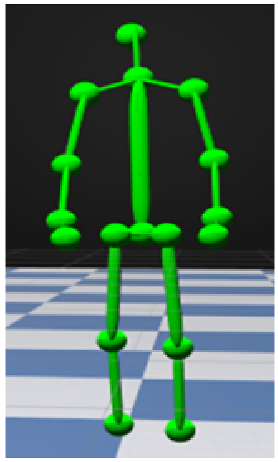


Figure 3.3: The skeleton avatar representing the player from the VSB system.

Additionally, we designed the area of interest system with the goal of the virtual world to showing growth with them as participants became better at playing these minigames. For example, this would have included displaying the images they completed along the virtual wall. The goal of this area of interest was to get participants to become more invested in the system as it was tailored to them and their experiences. It would change based upon their work and progress. This system would have complemented the one where their VSB tailored their experience based upon their interests and game performance. For the purposes of this study, the area of interest only impacted what image participants completed as they played the minigames.

The goal of both of these minigames was to be entertaining while providing information about the underlying STEM concepts of the minigames. Lastly, since the VSB-M system was being used as a museum exhibit, these minigames were designed to have shorter interactions (under 3-5 minutes) that could be played multiple times. They also needed to be playable in the limited amount of space allocated to our exhibit. Both of our minigames will be explained in more detail in the following sections.

Lever Hero

Our first minigame, Lever Hero, was designed around levers and how to balance them (see Figure 3.4 (left)). As it was played, see-saws (a form of lever) approached the player with a weight placed at a randomized location. The child then needed to place a counterweight at the appropriate position to balance the see-saw. When they answered correctly, an image based on their chosen area of interest would be built in the background (see Figure 3.4).

Originally, we had the weight following the player's position as they moved left and right in front of the kiosk, reducing complexity by only allowing their virtual body to move left and right. This way participants did not need to consider forward and back when it came to placing their counterweight. We thought that this would be an easier to use system than our previously used hover technique. However, this mechanic also meant the weight moved along the board, allowing the player to follow the tilt of the lever to adjust their answer accordingly. This means that the lever hero minigame became less about deciding the correct spot to place the counterweight and more about watching the lever balance as they moved, even as the lever approached. Our goal was for them to intentionally set down the weight at the correct spot and not simply move towards the correct answer based on the visualization. We did not change this mechanic in our first major update, but we did change this system to match the "grab" mechanic we designed for our next minigame. This grab technique allowed participants to bring their hands together to snap the weight to their hands. They could then move their bodies in the real world to move the virtual weight to the location they desired to drop it on the lever, which they were able to do by moving their hands apart. This change resulted in increased plays of the lever hero game.

We designed a system that could handle both multiple weights and weights of different sizes. This system would have allowed us to increase the complexity of the lever hero problems without changing how participants interacted with them. However, we opted to leave this feature out of this iteration of the VSB system, teaching the concept of lever balancing on a basic level. This decision was made given that we would largely be targeting likely single session interactions with our participants as opposed to sustained interactions with the same participants over time. In a future iteration, we may revist this idea if we choose to expand upon allowing participants to take their buddies back home with them.

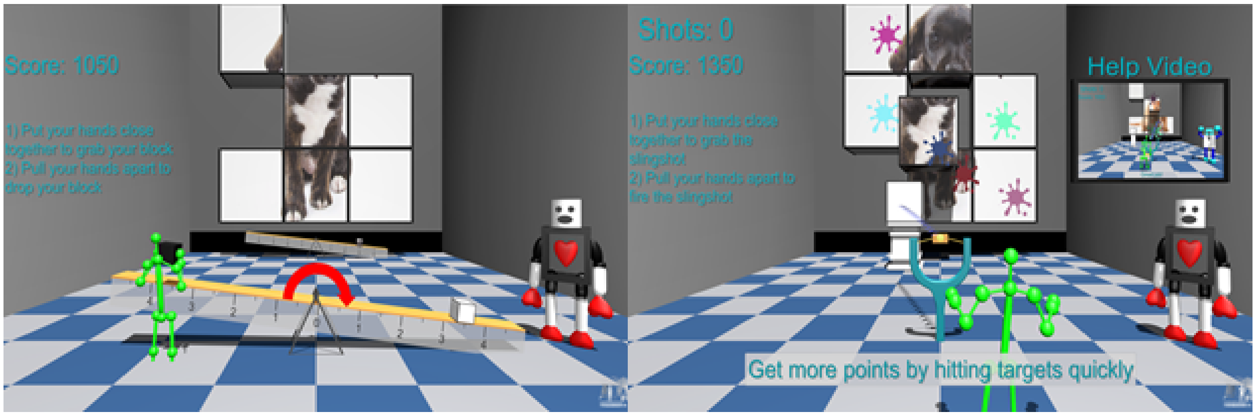


Figure 3.4: Figure 9. The Lever Hero (left) and Slingshot (right) minigames from the VSB-M system. There is an image being built in the background based on the player's area of interest.

Slingshot

Our second game, Slingshot, was designed around trajectories and how to use them to hit a target (see Figure 3.4 (right)). It used a stationary slingshot that children had to aim with the aid of a visible trajectory based on their relative location and distance from the slingshot. As they hit each target, the block then moved to the background, forming an image similar to Lever Hero. The goal of this game was to complete the image without paint splats obscuring it, meaning the child needed to hit the top or sides of the target block. As mentioned in the lever hero section, we designed a grab technique that allowed the slingshot pouch to snap to a participant's virtual hands as they brought their real-world hands close together. When they were ready to fire the slingshot, they pulled their hands apart to let go of the slingshot pouch (see Figure 3.5). Similar to lever hero, we also designed a system to scale difficulty by gradually reducing the length of the trajectory. This would then require participants to rely on their understanding of trajectories more than an on-screen indicator in order to hit the blocks.

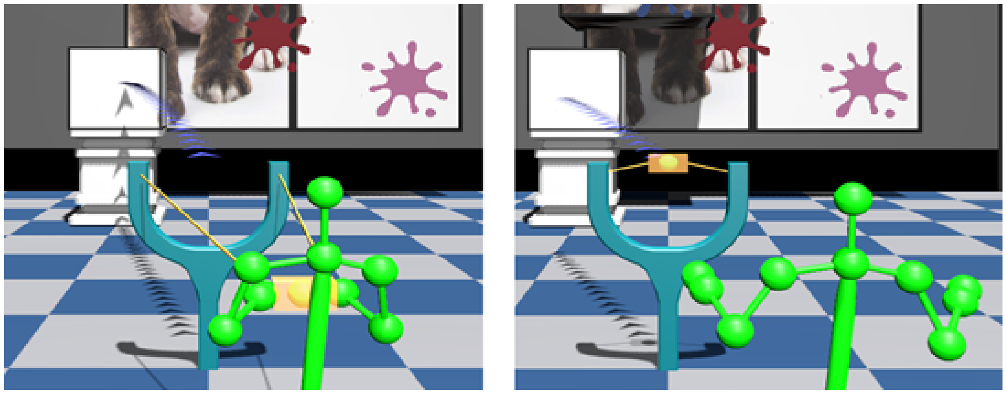


Figure 3.5: A player attempting to shoot a block during the slingshot minigame from the VSB-M system.

3.4 Results and Observations

The VSB-M system was played 28,122 times in about two years from 1/10/2017 to 1/21/2019. We found that early on Slingshot was more popular than Lever Hero, being played about twice as often. We attributed this to a new mechanic we implemented in Slingshot. Upon updating Lever Hero to use this same mechanic, the discrepancy between the game plays was reduced. We also found that the problems solved increased for both games (see Figure 3.6). Unfortunately, we did not record how many times the default VSB was changed and only 176 customized VSBs were saved with a code in about a year and a half (9/6/2017 to 1/21/2019) during which 20,825 total games were played. We attribute this low number of saved VSBs both to a lack of tangible benefit for saving the VSB and to the VSB not being directly engaged with the player. It was not salient that the VSB was encouraging and aiding the child as they play. Lastly, we had some hardware issues early on due to overheating caused by poor ventilation. Once those issues were addressed, the VSB-M system continued to run unassisted without further issue from 8/10/2017 to 1/21/2019 [19].

For future iterations, we conceptualized a tutorial system where a participant's VSB would play the game along with them the first time, showing them how to mechanically play the game. This system would move the VSB from being a stationary figure off to the side to one that would have been actively involved during gameplay. Along with the increased minigame difficulty mentioned earlier, their VSB could also aid them in completing problems. For example, it could be holding an additional counterweight during Lever Hero, giving the opportunity for the VSB to expand participants' understanding on how lever balancing works while further incorporating itself into gameplay.

Upgrade	Duration (days)	Lever Games	Lever Play Time (s)	Lever Problems
BASE	140	4000	75	-
UPGRADE1	61	2162	82.5	3.519
UPGRADE2	10	136	88.32	5.132
UPGRADE3	17	321	139.81	4.913
Upgrade	**Duration (days)**	**Slingshot Games**	**Slingshot Play Time (s)**	**Slingshot Problems**
UPGRADE2	10	237	100	5.16
UPGRADE3	17	441	115.3	5.91

Figure 3.6: Play statistics for the VSB-M minigames after each system upgrade.

3.5 Conclusions and Lessons Learned

From these results, we concluded that our upgrades to the minigames were a success, resulting in more games being played and more problems were solved per play session. This indicated that we succeeded in making these minigames increasingly entertaining. We did not track the long-term educational outcomes of the minigames. As a result, we do not know how well the underlying STEM concepts were conveyed and retained. Given the low number of saved VSBs, making the VSB a focal point of the exhibit was not successful. From this system, we gained more experience both in designing both buddy-based and motion-based games and in implementing such a system unassisted in the field. We learned that the VSB needs to be more directly and saliently involved in the experience. We also learned how to better implement hardware and software in the field so that it can be run unassisted for long periods of time. Other than a couple issues at the beginning of the study, the VSB kiosk operated without further issue during its duration in the museum. Once again, this robust design would continue to be used in future systems.

For our subsequent studies and in terms of hardware, we learned that tablet or touchscreen-based input was a viable possibility to use in conjunction with an otherwise motion-based app. Participants were able to use such an interface rather quickly, which we attributed to familiarity of such systems given that there are many examples of touchscreens that can be used in everyday life. We learned that we could secure additional hardware and be able to keep the cabling safe. That being said, it would be better to hide the cabling where it cannot be accessed easily unless by authorized individuals. Given the robustness and usability of the VSB kiosk, this combination of touchscreen and motion-based kiosk would continue to be used by future systems.

In terms of software, we learned that we should prioritize incorporating the virtual buddy as a core part of the experience, interacting directly with the participant. We also learned that our grab gesture works well as an interaction mechanic and minigames could be designed around this mechanic. We also learned that a system could be deployed in the field for an extended period with minimal input required by site staff and that being able to remotely apply updates or debug problems was very beneficial. Lastly, given the success of the Lever Hero and Slingshot minigames, these minigames would be used as the basis for the designs of the minigames utilized by our upcoming systems.

Chapter 4

Virtual Fitness Buddy - Afterschool Systems

We have explored using both a virtual buddy and motion-based games to encourage children to engage in healthier physical activity (PA) habits with our previous camp-based Virtual Fitness Buddy (VFB-C) projects [13] [14] [15]. The results showed that the VFB-C system did encourage children to engage in more PA during their time at the summer camps. However, these studies were only across the course of a few days, which does not provide sufficient longitudinal data to know how the VFB-C system impacted these PA habits over time. To explore the long-term impacts, we redesigned the VFB-C system into the afterschool-based Virtual Fitness Buddy (VFB-A) system. The design of this system was informed by our experiences and our lessons learned from both the VFB-C and Virtual STEM Buddy (VSB-M) systems, which were virtual agent, motion-based systems for children that were deployed unassisted in public spaces.

Like the VFB-C system, the VFB-A system was designed to encourage children to engage in healthier PA habits. Three cohorts of 223 children across 11 sites used this new system. These cohorts consisted of a 6-week long pilot cohort of 31 children at a single site and two larger, 6-month cohorts of 124 children across 6 sites and 68 children across 4 sites respectively (C1-A and C2-A). We also had control groups at each of these sites, resulting in a total of 42 children across 2 sites for the pilot starting in Spring 2018 and 257 children across 12 sites and 165 children across 7 sites for the two 6-month cohorts starting in Fall 2018

Figure 4.1: (Left) Kiosks used during the VFB-A pilot (left) and C1-A and C2-A (right). The pilot kiosk resembles the original kiosk from the VFB-C study. The C1-A/C2-A kiosk added a touchscreen display for menu selection. (Right) The evolution of the VFB model from the VFB-O system (left) to the VFB-A system (right) with the UGA Arch in the background.

and Fall 2019 respectively. The VFB-A system consisted of an updated kiosk, using a large screen TV and Microsoft Kinect for Windows for motion-tracking (see Figure 4.1 (second from left)). Given the success of the mobile kiosk design during the VFB-C study, we continued to use it for the updated kiosks as it was convenient for the site staff to deploy, power on/off (using a single cable) and store every day. Additionally, we opted to use an avatar similar to the VSB-M skeleton avatar (see Figure 4.2 (left)). This new avatar featured a semi-transparent body (to make it easier to see the virtual world) and opaque, green-colored "hands" (to indicate which sphere could interact with the VFB and other virtual objects). Lastly, unlike the VFB-C study, where the player's avatar was off to the side of the screen, this new avatar existed in the world alongside the VFB.

Figure 4.2: (left) The VFB-A skeleton avatar featured in the VFB-A virtual park. This avatar uses participants' real-world motions to interact with the virtual world (right).

4.1 Interaction Systems

In addition to the new kiosk, we also updated the primary interaction systems, incorporating what we learned both from the VFB-C and VSB-M systems. From the VFB-C studies, we incorporated participant feedback from both mid-air hover selection system and the trick gesture systems. From VSB-M, we incorporated the success of the new avatar system, the new tablet interface, and VFB-C inspired grab gesture interaction technique. Both of these sources of inspiration and their resulting systems will be discussed in further detail across the next few sections.

4.1.1 Pilot: 3D Virtual Keyboard Input System

Given participants' frustration using the mid-air hover selection interface during the VFB-C study, we designed and implemented a new selection interface for the VFB-A pilot study. Although we knew that the addition of the tablet to the VSB-M system was successful, we still wanted to try to find a system that solely relied on the Kinect as the input system because additional devices still meant additional complexity and, potentially, additional development time. Given that this new system would be used across many more sites and participants than we ever had previously, we wanted to minimize hardware complexity in order to reduce the strain on site staff as well as potential points of failure in this new system.

We tried several ideas, including a bin system that would use the grab gesture from the VSB-M system. Participants would bring their hands together to grab a choice block that would then be released when they moved their hands apart over the bin they desired to select. However, we wanted to have this new VFB-C system to incorporate VFB setup into the VFB app itself rather than having participants fill out a paper form that then had to be manually uploaded and verified. This meant that participants needed to be able to name their VFB using the VFB-C app. In turn, this meant we needed to have many bins on screen in order to accommodate a 3D keyboard. We were not satisfied with the screen clutter these bins entailed and, thus, decided to try a different interaction technique.

Figure 4.3: Examples of the "keyboard" keys used for the VFB-A pilot. Similar to a computer keyboard, the red button is pressed in until it "pushes" on the black cylinder.

We opted to build a menu system using virtual "keyboard key" buttons (see Figure 4.3). Similar to how keyboard keys are pressed, participants would "press" these buttons using their virtual hand in order to make a selection. This system worked well during our lab testing as we knew how these keys were intended to work and became more adept throughout testing. Unfortunately, this did not translate to a success in the field. Our pilot participants struggled to use this new system even after using it several times, especially the larger keyboard used during VFB creation, where it was much easier to accidentally press the wrong button. As a result, we ceased our attempts at making a Kinect-only input system and returned to the Kinect and tablet input system from the VSB-M system.

4.1.2 C1 and C2: Touchscreen Based Selection System

Given the success of the VSB-M tablet menu system, we designed and implemented a similar system for the next two cohorts. There were two parts of this system that we wanted to change for the VFB-A kiosk: tablet installation location and bluetooth communication. As previously stated, we had an issue where the tablet and its encasing were rotated in such a way that snapped the tablet's charging cable. Although this was addressed by restricting the movement of the tablet, we sought to design the kiosk in such a way that the needed cabling was self-contained. Additionally, we wanted to reduce system complexity by eliminating the need for bluetooth communication between the tablet and the touchscreen. To address both of these concerns, we opted to use a touchscreen (see Figure 4.1 (second from left)) that was connected directly to the computer, making it an additional display for the computer. By making this switch, we reduced the development complexity of this new menu system as we did not need to develop and test a separate menu application as we did for the VSB-M system. Similar to the VSB-M participants, we found that participants were familiar with how to use touchscreens, learning the new interface much more easily than the previous virtual button interface.

Occasionally, there would be an issue where either the TV or the touchscreen were not turned on prior to the system loading the VFB app. This would cause an issue where the desired component of the app was not displayed properly. Since the problem required an individual to turn on the TV in person, we could not address this problem remotely. We did try to have the TV turn on as the computer booted up, but we were not able to In an attempt to mitigate the impact of this problem prior to the study, we did attempt to have the TV turn on automatically as the computer booted. However, due to hardware limitations, this was not an option. Instead, we added a screen within the VFB-A app that would be displayed on either the TV or the tablet with instructions on how to turn on the respective device and reboot the app. If we saw this issue remotely, we were able to call site staff in order to address it. In the future, if we were return to this kiosk-touchscreen style of interaction, we would ensure that the TV was capable of turning on along with the computer.

4.2 Expanding the VFB Experience

As this system would be used for 6-months as opposed to 3 days, we needed to expand the interactions with the VFB beyond the trick system, which was used for both VFB-C and Virtual Buddy Fruit and Vegetable (VB-F&V) studies. In order to expand these interactions, we introduced the concept of VFB stats (beyond size), a stamina (energy) system, built a new minigame system, and expanded the available VFB customization options. Across the new few sections, we will explore both the inspirations, rationale behind, and implementations of these new systems.

4.2.1 VFB Stats, Stamina, and Leveling

As with the previous VFB studies, a participant's VFB should become fitter as they complete more physical activity (PA) and meet more goals in the real world. Previously, this meant that a VFB would complete tricks more quickly and shrink in size as they became fitter. For this new system, we introduced additional VFB-health related statistics (stats): happiness and stamina. All of the VFB stats were allowed to both increase and decrease in C1 in order to mimic how our fitness fluctuates over time based on our PA. We discovered that all of these stats were rather low overall, indicating that we may have let the stat penalties be higher than intended. As a result, we opted to only let VFB stats increase during C2.

VFB happiness was affected by how often a participant visited their VFB. The more often a participant visited their VFB, the happier they became. We intended to have happiness increase both the VFB's tail wagging speed and its likelihood of successfully performing a given command (trick). Due to limited time constraints and prioritizing other mechanics, we were not able to implement the system where the VFB may not perform the correct trick if they have lower happiness. Thus, across all of these cohorts, VFB happiness only impacted its tail wag speed.

With the addition of stamina, size no longer dictated neither a VFB's max trick nor max run speed. Across all of the VFB-A cohorts, size only affected how small or large the VFB appeared in the app. Stamina controlled how much time participants had to play with their VFB and how quickly their VFB moved.

VFB Stamina System

Part of expanding VFB interactions included extending the duration of play sessions beyond the duration from the previous VFB studies. However, given that there were many kids at each site, and they only had limited time to play afterschool, these interactions still needed to be relatively short. As a result, we limited play time for each participant to 3 to 5 minutes per day depending on the fitness of their VFB, increasing as their VFB became fitter. This time did not roll over to subsequent days so participants could not stack time and play beyond their allocated 3-5 minutes per day. Unlike the VFB-C studies, participants could revisit their VFB multiple times a day as long as they did not exceed their play time.

In this context, the fitness of a VFB refers to their stamina (energy) stat, where play time changed as stamina changed. As a VFB's stamina stat increased, the amount of energy it had to spend also increased, which, in turn, resulted in increased playtime for participants. Initially, the stamina system only acted as a play timer, where play time decreased every second a VFB was running or performing a trick. Starting in C2, minigames and tricks had an associated energy cost in order to play. If a VFB did not meet this energy cost, it did not have enough energy to complete the game or trick and it meant that participants could not play that game or trick until the next day. This system allowed us to increase play time and play variety over our previous studies while restricting how long participants could play so that many participants could interact with their VFBs on any given day.

VFB Level System

Starting in C2, we introduced many more minigames that a participant could play with their VFB. As a result, we wanted to limit access to which games and tricks a participant could perform based on their overall PA. We achieved this by implementing a pet "level" system, where a VFB's stats only increased when their participant had completed sufficient PA in order to increase their VFB's overall level. Each stat, except happiness, had a threshold at which it no longer increased the fitness of the VFB, where it would no longer continue decreasing in size nor continue increasing in speed and play time. As a result, all participants had the potential to reach a max stat pet; it just varied how many VFB levels it took to get there.

Additionally, as we added more minigames beginning in C2, this new level system was used to restrict access to minigames and tricks. Given that the amount of PA required to increase a VFB's level was constant across all participants, it allowed us to uniformly set limits on what a participant could access at certain levels of PA. If a VFB could not play a given game or perform a certain trick, this was conveyed to the participant in the menu system, where they could see all of the upcoming activities they could unlock as their VFB leveled. We opted to show participants the upcoming activities in order to provide a potential additional source of motivation to continue completing more PA over time.

4.2.2 Minigames

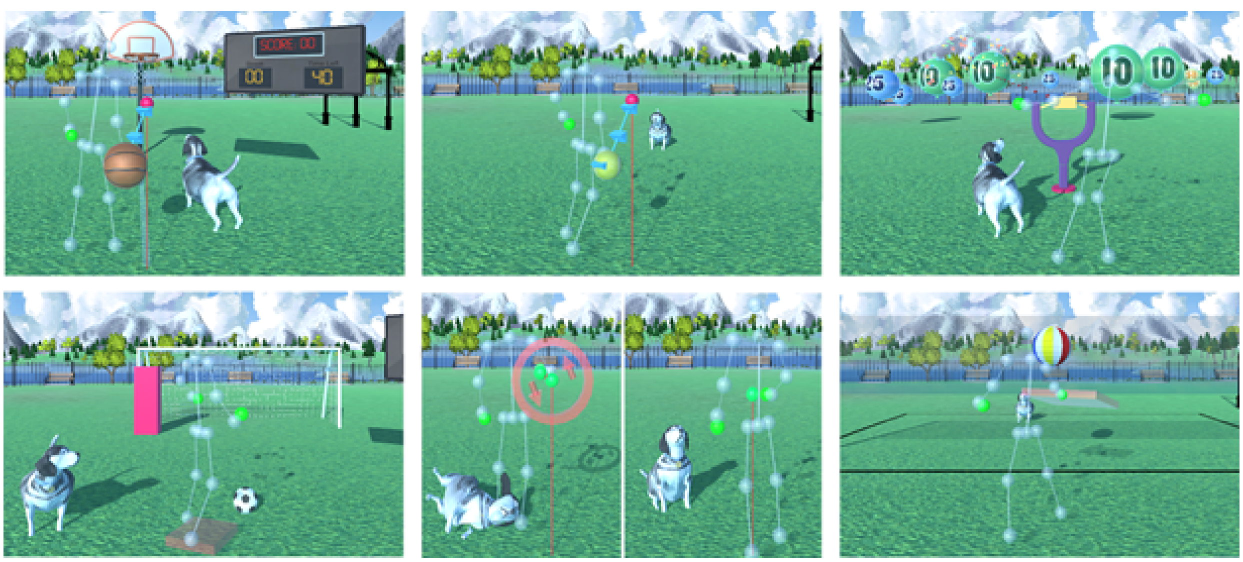


Figure 4.4: The minigames and tricks from the VFB-A study: Basketball (top left), fetch (top middle), Slingshot (top right), Soccer (bottom left), roll over (bottom middle), sit (bottom middle), and Volleyball (bottom right).

As previously mentioned, participants' interactions with the VFB-A system could be longer than those from the previous studies', these interactions would still need to be relatively short as there were many kids at each site and they only had a limited time to play afterschool. With this in mind, we designed minigames (see Figure 4.4) that were limited to 60 seconds each and limited the number of minigames and tricks a VFB could complete each day. This limit increased as the VFB became healthier. Ultimately, we designed 4 new minigames (Basketball, Slingshot, Soccer, and volleyball) in addition to the trick gestures from the VFB-C system. At the beginning of the study, participants only had access to fetch and a few tricks. Access to these minigames and remaining tricks were earned over time as the fitness of the VFB improved and "leveled up" (see Figure 4.5). This way participants had incentive to keep engaging in PA so that they could unlock these minigames. Across the the following sections, an overview of our general minigame design approach will be described along with descriptions of the available minigames and their inspirations from previous studies.

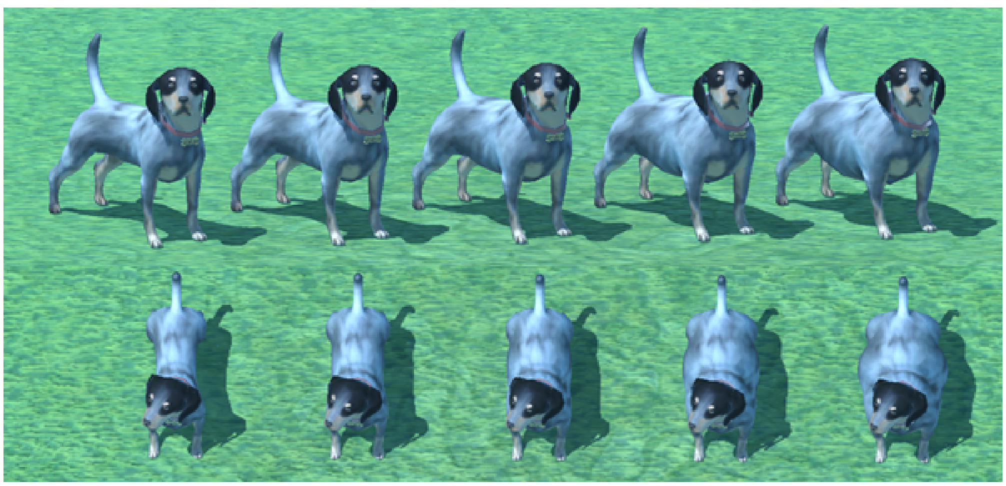


Figure 4.5: A sampling of different body weights of the VFB, starting at maximum health (left) and ending at minimum health (right) both from the side (top row) and above (bottom row).

Design Overview

When designing these new minigames, we had three primary criteria: they should be directly impacted by the health of the VFB (and thus, by the player's PA), should provide a variety of experiences, and should be based on games that can be played with a real-world dog. As in the VFB-C study, a participant's PA impacted their VFB's health, which, in turn, impacted their speed, size, and stamina (number of minigames/tricks available each day). The linkage was intended to quickly show participants the tangible benefits of continuing to engage in PA over time. By making the VFB's health (and, thereby, participant PA) impact the minigames, we reinforce this linkage. The primary way we incorporated the VFB's health was through their speed. We designed minigame mechanics which would increase the highest achievable score as the VFB became faster, providing additional incentive to engage in more PA. For example, with increased speed, a VFB could fetch the toys/treats used for the Basketball, Slingshot, and Soccer minigames much more quickly, resulting in more throws and potential points during their 60 second timer. For volleyball, the increased speed allowed a VFB to reach a return serve more quickly, resulting in a longer chain of serves along with a higher max score.

Our second criterion targeted our requirement to expand this system to provide engagement over the longer 6-month time frame. It stated that these minigames should provide a variety of experiences. This meant that there should be minigames which have different interaction mechanics and/or goals. This criterion was established both to cater to different player preferences and to increase the longevity of the system by adding a variety of different experiences and rewards. Participants were likely to have different preferences on which minigames they would enjoy or even partake in the real-world. Participants could be excited to see their real-world sport of choice represented as a part of the VFB-A system, which may serve to further increase their engagement with the system and bond with their VFB. Additionally, if every minigame provided the same experience with the same mechanics, participants would likely become bored and stop engaging with the system much more quickly. By adding this variety, every day could be a different combination of experiences with the VFB, potentially making interacting with it more exciting day-to-day. This criterion resulted in us designing and implementing different gestures and mechanics around which we could design different minigames.

We drew inspiration from our previous systems for some of these gestures. For example, we used the hand-distance-based gesture from VSB-M Slingshot minigame to implement a new Slingshot minigame and used both the hand-based throw gesture and the hand-based trick gestures from the VFB-C system to implement Basketball and tricks minigames. We designed a new paddle mechanic where a paddle was attached to a specific joint on a participant's avatar, allowing them to hit an incoming toy. This mechanic resulted in Soccer (foot-mounted) and volleyball (hand-mounted) paddle-based minigames. We found that it was hard to aim the Basketball using a throw gesture, replacing it with a new mechanic called the "shot zone" (see Figure 4.4). Participants would touch the "shot zone" (a sphere) to initiate the throw, use the angle between their hand and the sphere (represented by a series of arrows) to aim it, and touch the sphere from this desired angle to complete the throw.

Finally, our third criterion states that these minigames should be based on games that can be played with a real-world dog. We designed many of these minigames to have the VFB's primary role as fetching a toy or performing a trick, which, obviously, are actions that a real-world dog can do. This criterion was important because it grounded the VFB-A system in real-world actions. This grounding was intended to reinforce the connection between a participant's PA and their real-world health benefits by watching their VFB become healthier and capable of engaging in more "PA" themselves. The intended result of this reinforcement was our primary goal with the VFB-A system: to generate a sense of autonomy and mastery which would motivate participants to continue to engage in more PA after they were no longer able to interact with their VFB.

4.2.3 VFB Customizations, Toys, and the Points System

Figure 4.6: Several VSBs using the upgraded customization options, which included collars, hats, tags, and VFB color skins.

In addition to these minigames, we added many more customization options for the VFB (see Figure 4.6) as another way to potentially extend engagement with the VFB-A system. We expanded the collar and VFB skin color options, added new collar tags and hat accessories, and added more toy options (see

Figure 4.7). Given that the VFB-A system was intended to be grounded in reality, the VFB's skin color could not be changed once the VFB had been made. However, implemented an inventory system where the remaining customizations were stored once they had been purchased, giving participants the ability to update their VFB's collar, tag, and toy designs. Additionally, the new toy designs were not merely cosmetic as their bounciness and drag when thrown varied.

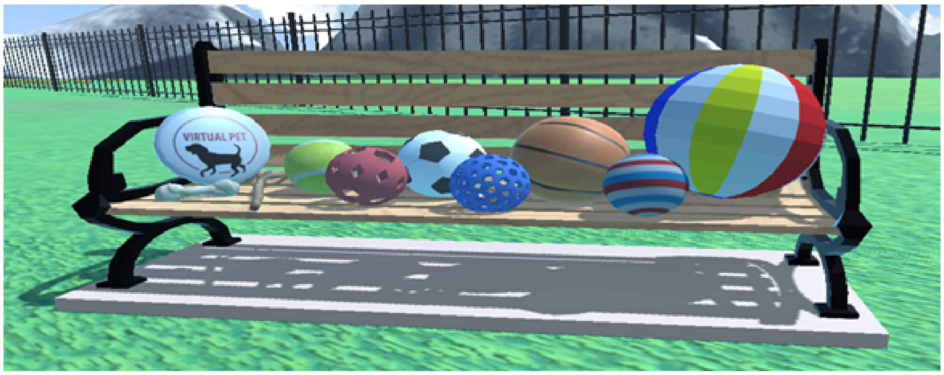


Figure 4.7: The expanded VFB toy options for VFB-A, which include a frisbee, bone treat, stick, tennis ball, red wiffle ball, Soccer ball, blue wiffle ball, Basketball, striped ball, and beach ball.

Participants earned points to purchase these customizations by meeting their PA goals. Unlike the VFB-C study, where participants could set and meet multiple goals a day, VFB-A participants could only meet one goal per day given the increased longevity of the study. Additionally, the number of points earned scaled with the PA goal selected, where higher goals gave proportionally more points than lower goals. This was done to address the issue where participants would set and meet multiple less vigorously active goals to earn points more quickly during the VFB-C study. As with the new minigames, these new customizations were intended to provide an incentive to engage in more PA and to extend engagement with the VFB-A system. Lastly, these customizations were added to aid in forming the bond between a participant and their VFB by providing the autonomy to customize their VFB as they desired.

Social Elements

In addition to these minigames and customizations, we further improved and increased the number of social elements for the VFB-A system. We implemented a new messaging system which allowed messages

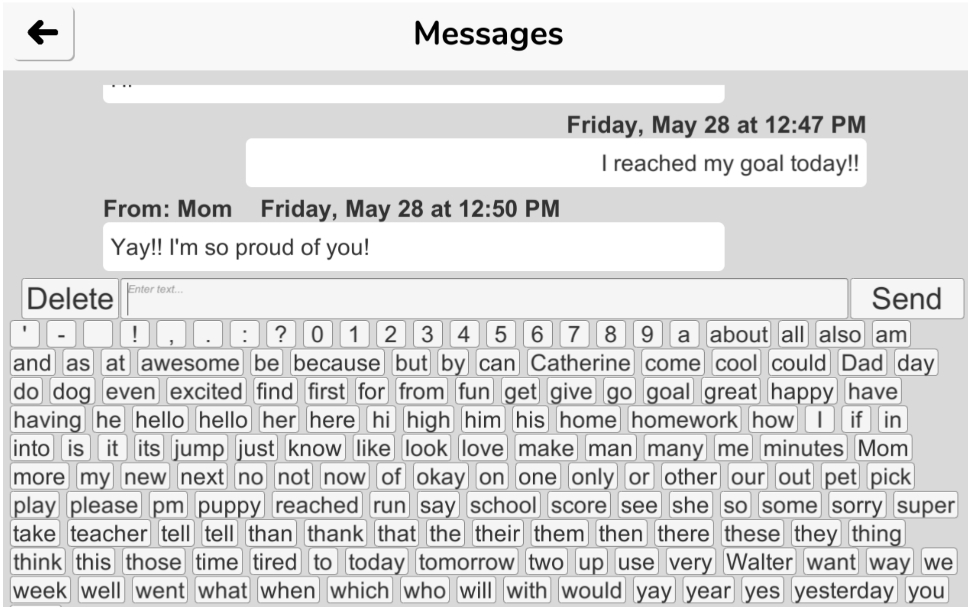


Figure 4.8: The messaging interface from the VFB-A system. Certain phrases were customized based on the participant's name, their VFB's name, and who was listed as the primary guardian.

to be sent between children and their parents rather than solely allowing parents to text their child as in the VFB-C study. This system consisted of a newly implemented scrollable chat history and a virtual keyboard (see Figure 4.8). In order to prevent inappropriate messages from being written and sent, we opted to preload this keyboard with various phrases. Once sent, the participant's message would be added to the displayed chat history and be sent to their parent as a text message.

In order to engage participants with their peers, we implemented a personal top 3 high score leaderboard for each minigame along with weekly and overall PA and VFB interaction leaderboards for each site. The weekly leaderboards were added so that participants would have a new chance every week to reach the top of the leaderboards. They were designed to provide incentive to continue to complete PA throughout the course of the study beyond unlocking all of the customizations, minigames, and tricks. Additionally, for more competitive participants, these leaderboards could provide additional motivation to engage in more and more PA over time. All of these new social systems were designed to facilitate a sense of relatedness between participants and both their parents and their peers. The goal of fostering this sense of relatedness was to motivate participants to continue to engage in PA even after they were no longer participating in this study.

All of these games were intended to provide entertainment, facilitate a bond between a child and their VFB, and demonstrate how PA can improve one's overall health. We added the scoring systems for three reasons: to provide incentive to beat the high score, to foster competition between players, and to provide a metric which improved as the VFB became healthier. The first two help facilitate a sense of relatedness and mastery and the last one provides another salient benefit of completing PA (in addition to the speed and size of the VFB). By allowing players to set their own goals and select which games to play, players should feel a sense of autonomy over their experience. The result is that these minigames are intended to facilitate all the psychological needs enumerated in previously mentioned self-determination theory [12].

4.3 Results and Observations

These results and analyses are focused on VFB-A cohort 2 (C2-A) as many of the minigames covered in the previous sections were introduced at that time. Specifically, we will only be covering the Fall 2019 data as schools were closed during Spring 2020, concluding this study earlier than intended as our participants could no longer access their VFB kiosk. This analysis will include all participants across all four of the treatment sites. Additionally, until an update in mid-October 2019, participants could only play the Slingshot minigame. After this update, they were able to play all of the remaining minigames (Basketball, Soccer, and Volleyball) once their VFB reached the requisite level shown in Table 4.1.

Table 4.1: The VFB-A levels needed to unlock each minigame.

Game	Level Unlocked
Basketball	4
Slingshot	2
Soccer	10
Volleyball	8

We did not begin recording VFB level increases until November 2019. Thus, we used this level increase log along with an event log to approximate the number of days each participant had each minigame unlocked. Prior to November 2019, the first day a minigame was played or a trick was performed, that date would be considered the unlock date for a minigame at or below the required VFB level for that minigame or trick. After November 2019, any minigame that had not already been unlocked for a given participant would be considered unlocked when their VFB reached the requisite level. Lastly, the number of days unlocked were only those days in which participants had access to their VFB. This means that weekends and school breaks did not contribute to the total available play days.

4.3.1 Game Play Metrics

As shown in Figures 4.9 and 4.10, Slingshot was the most played minigame in terms of number of games played overall. However, it is also the first minigame to unlock at VFB level 2 and the only minigame accessible until approximately a month into the study. Volleyball has the greatest overall duration played, which is interesting given that it is the second to last minigame to unlock. However, the overall number of plays and play time varies for each game based upon when participants unlocked them. Thus, we need to account for these discrepancies regarding the number of days each minigame was available for each participant. As shown in Figures 4.11 and 4.12, there is a similar trend even controlling for the number of days each game was available to play.

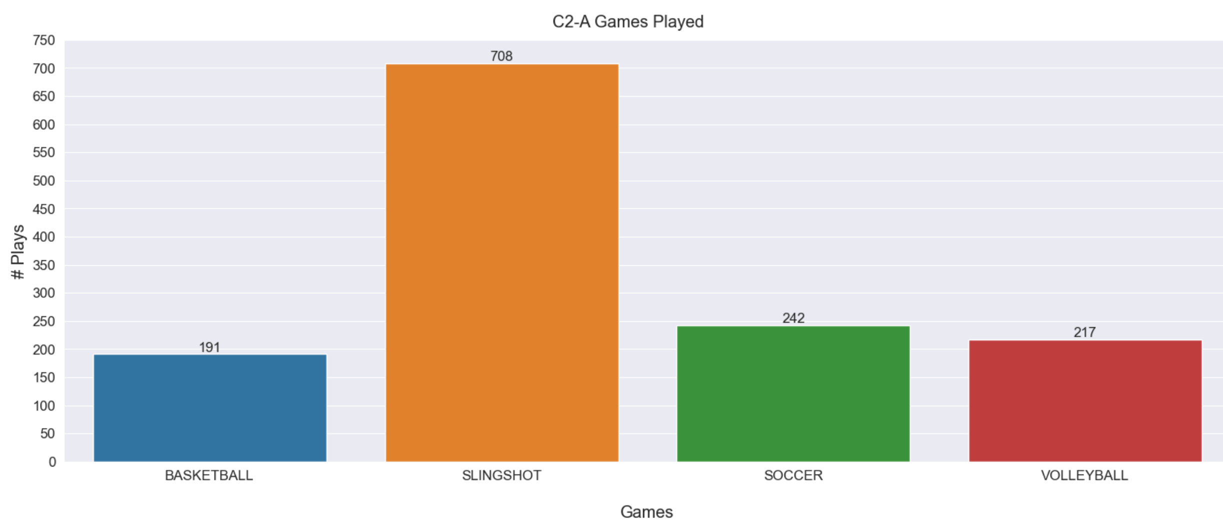


Figure 4.9: Graph depicting the number of plays for each game played during C2-A.

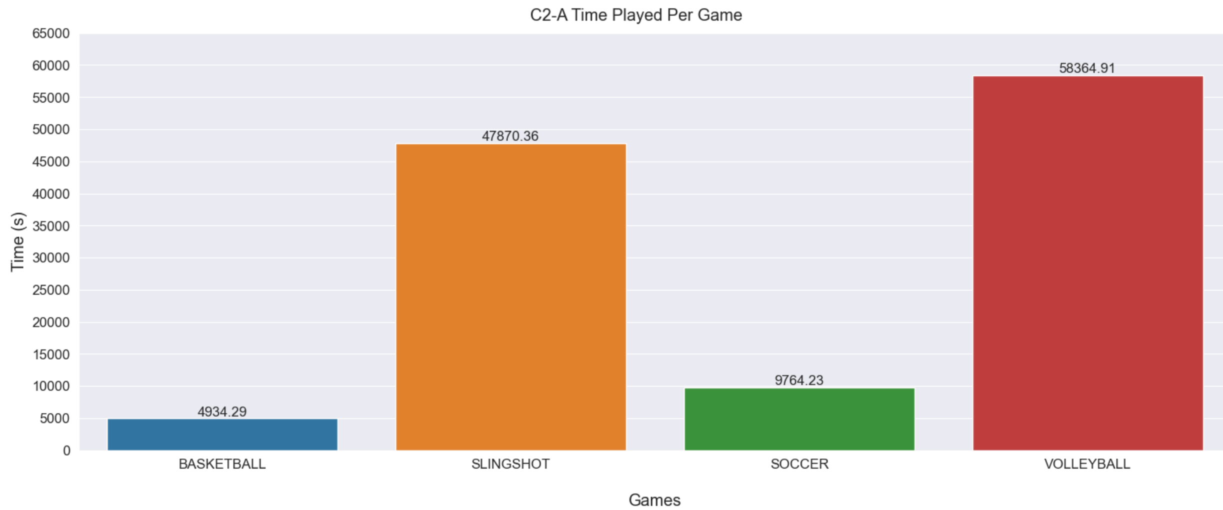


Figure 4.10: Graph depicting the amount of time played for each game played during C2-A.

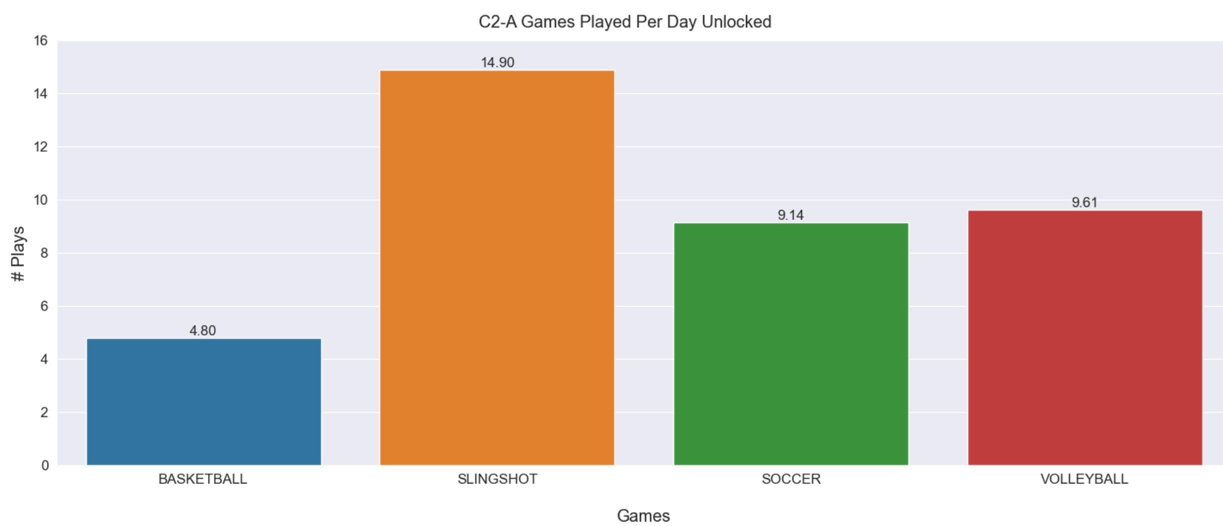


Figure 4.11: Graphs depicting the number of plays controlled for number of days unlocked for each game played during C2-A.

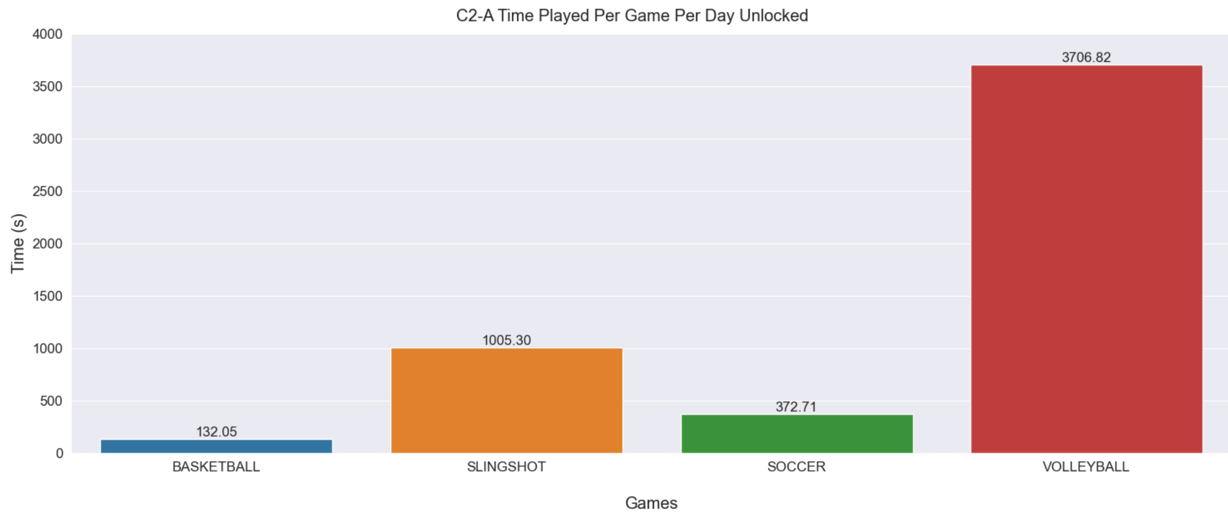


Figure 4.12: Graphs depicting the amount of time played controlled for number of days unlocked for each game played during C2-A.

It is plausible that Volleyball was played for approximately an hour each day given that there were 4 sites and 124 participants. However, both Volleyball and Slingshot did not have a time limit on how long they could be played for a single game, and we did not implement a force logout feature. This means that if a participant walked away from the kiosk during either of these minigames and no other participant logged in, these games would run until the kiosk was shutdown for the day as our intended exit for these games was for a participants' VFB to run out of energy. However, the VFB only used energy while it was running, which it would not do if no one threw a toy for it to fetch. This combination of factors could account for the play differences between these two minigames and Basketball and Soccer, which had time limits of 60 real-world seconds. As shown in Table 4.2, about two-thirds of game plays ended in 60 seconds or less and around 99% of game plays ended in 300 seconds (5 minutes) or less. However, there are 13 plays which exceeded 17 minutes (1000 seconds).

Table 4.2: Number of all minigames played at different play times.

Play Duration (s)	# Game Plays	% of Total Plays
No Limit	1461	100%
<= 60s	893	61.12%
<= 180s	893	94.73%
<= 300s	893	98.63%
<= 1000s	1448	99.11%
> 1000s	13	0.89%

Given this information, we implemented time limits for the max amount of time played for further analysis. Each play was still counted, but if the play time exceeded the limit, the time for that play would be capped at the time limit. Figure 4.13 shows the amount of time played with a 5 minute time limit and Figure 4.14 shows the amount of time played with a 1 minute time limit. With both limits, Slingshot at least 3 times as much play time as the rest of the minigames. Limiting plays to the max time allowed for Basketball and Soccer (60 seconds), Soccer and Volleyball have similar play times with Basketball at around half of their play time.

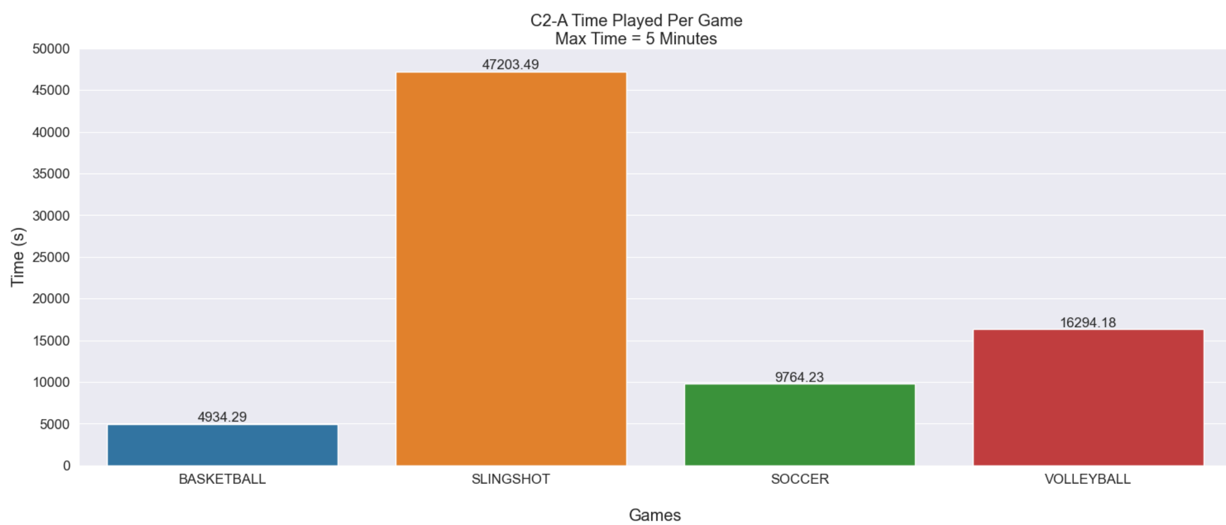


Figure 4.13: Graph depicting the amount of time played limited to 5 minutes per play for each game during C2-A.

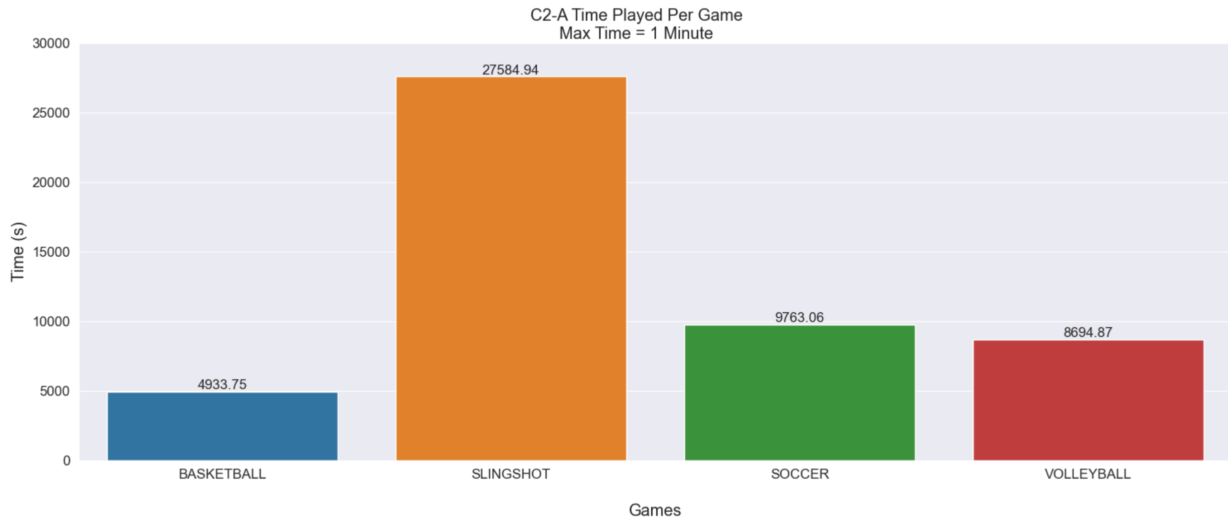


Figure 4.14: Graph depicting the amount of time played limited to 1 minute per play for each game during C2-A.

Figures 4.15 and 4.16 depict the amount of time played controlling for the number of days each participant had each minigame unlocked limited to 5 minutes and 1 minute of play, respectively. The overall trend is similar to the overall play time data. With a 5-minute max time limit, Slingshot has the most play time followed by Volleyball then Soccer and finally Basketball. With a 1-minute max time limit, Slingshot still has the most play time followed by Soccer and Volleyball with Basketball having the least play time. Thus, even accounting for the number of days unlocked, Slingshot still has the most amount of play time and Basketball has the least. All of this seemingly indicates that participants preferred Slingshot the most, Volleyball and Soccer approximately the same, and Basketball the least.

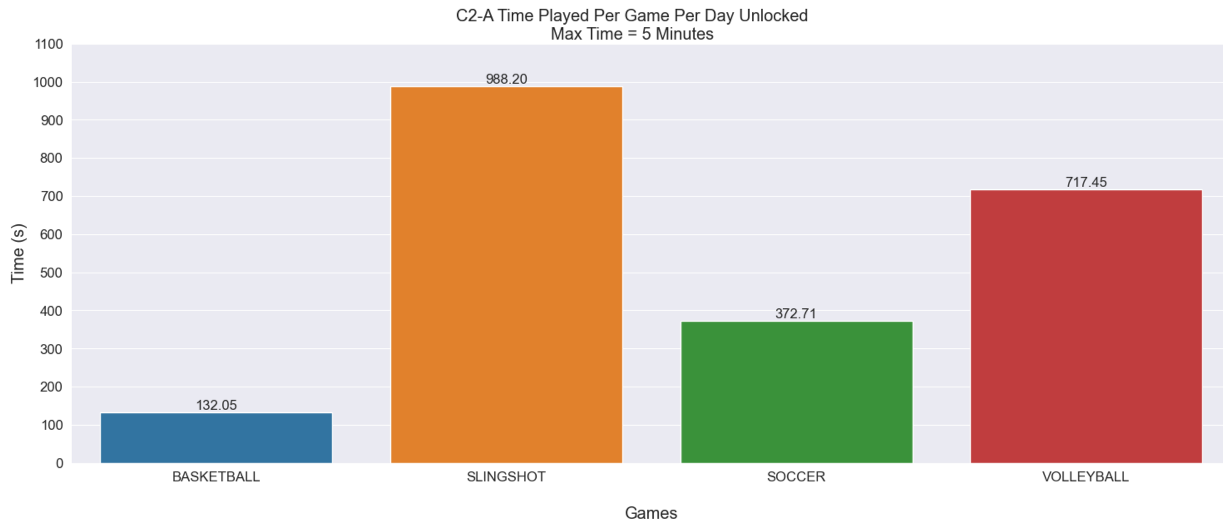


Figure 4.15: Graph depicting the amount of time played controlled for number of days unlocked and limited to 5 minutes per play for each game during C2-A.

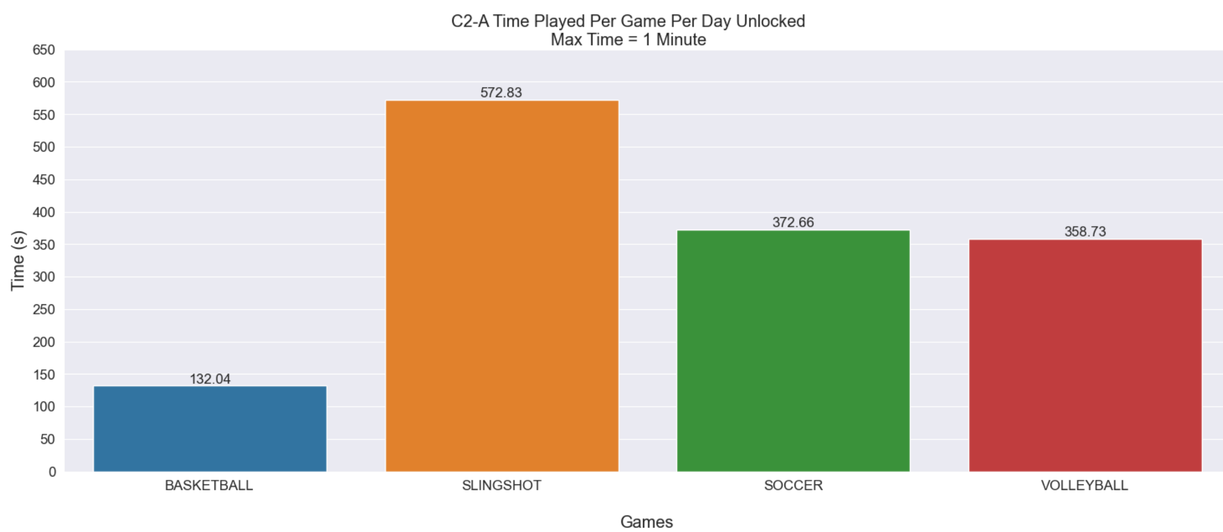


Figure 4.16: Graph depicting the amount of time played controlled for number of days unlocked and limited to 1 minute per play for each game during C2-A.

However, as mentioned earlier, Slingshot was the only game available to play for around the first month of the study with Soccer and Volleyball being the last two games to unlock. As shown in Figure 4.17, Slingshot has many more plays in roughly the first two-thirds of the study compared to the other games. The update unlocking the ability to play Basketball, Soccer, and Volleyball occurred between weeks 4 and 5 of the study. However, this does not mean that every participant was able to play these games immediately as they still needed to meet the requisite VFB level in order to unlock them. There is an overall trend of less games played over time. However, this is a small spike of plays the week following Thanksgiving break on week 11. Potentially, this could mean that participants were excited to play with their VFB again after a week without access.

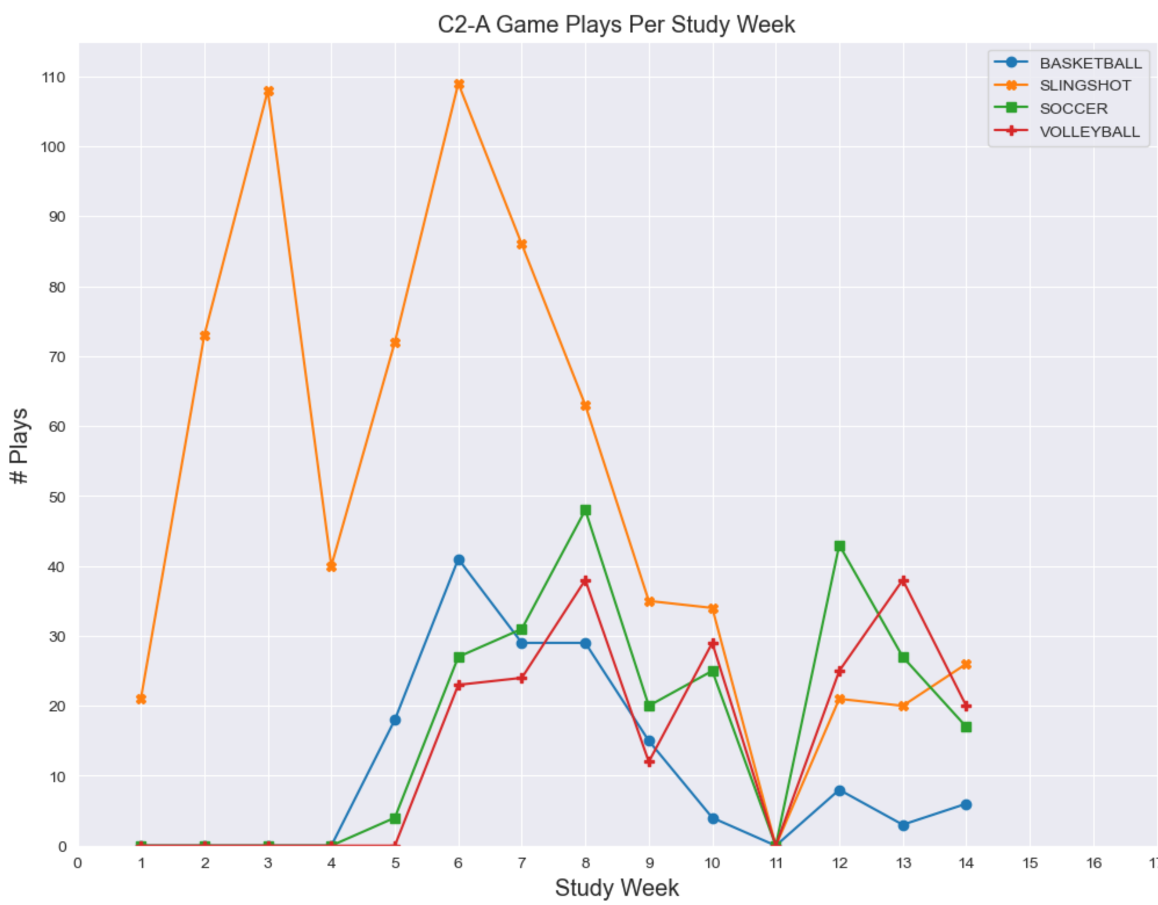


Figure 4.17: Graph depicting minigame plays per week during C2-A.

Figure 4.18 depicts the number of games played per week controlling for the number of days each minigame was available to play for each participant. After roughly week 8, Soccer and Volleyball both have more plays per day unlocked than Slingshot with Basketball plays decreasing over time as these two games were unlocked. Additionally, the discrepancy between Slingshot and the other minigames is reduced once the number of days unlocked is considered. This means that Slingshot was still played more during the first half of the study but the other games were played proportionally more once days unlocked are considered.

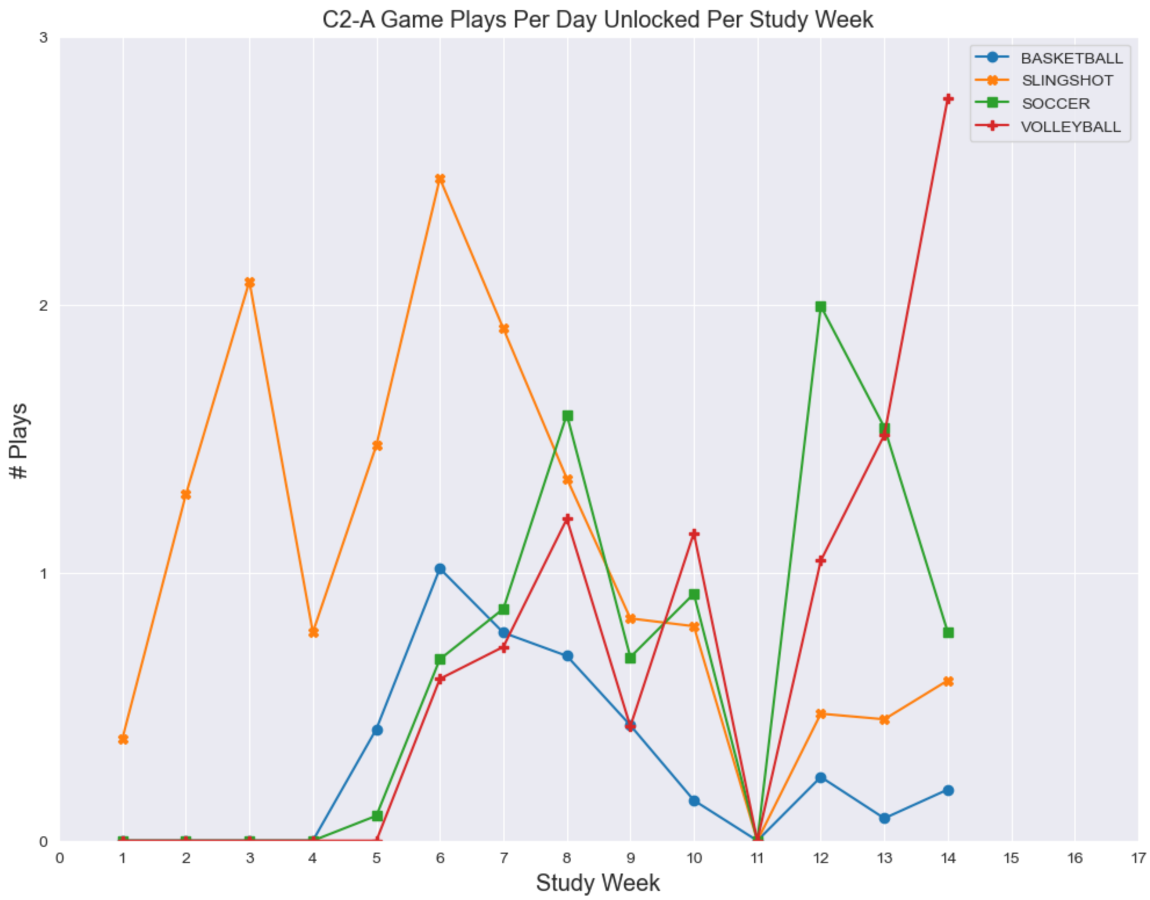


Figure 4.18: Graphs depicting minigame plays controlled for number of days unlocked per week during C2-A.

Finally, all of this data seems to indicate that Basketball is the least preferred minigame as it never had the most plays over time. It would be worthwhile to explore what led to this outcome. Potentially, this could be attributed to the shot zone mechanic being difficult for our participants to use as none of the other minigames utilized this feature. Slingshot used the grab and release mechanic from the Virtual

STEM Buddy's (VSB) Slingshot minigame, and both Soccer and Volleyball used the new paddle mechanic developed for C2-A. This would also mean that the grab and release mechanic was relatively successful as it was during the VSB study and that the paddle mechanic would be another mechanic to utilize for other games during future studies given that both Soccer and Volleyball exceeded Slingshot in plays as the study progressed.

4.3.2 Participant Play Metrics

To determine if there were game play outliers that may be skewing our play data, we also looked at the number of plays for each participant both in terms of overall plays (Figure 4.19) and controlling for number of days each minigame was unlocked (Figure 4.20). There are participants who played more games but not to a degree that one would be considered at outlier.

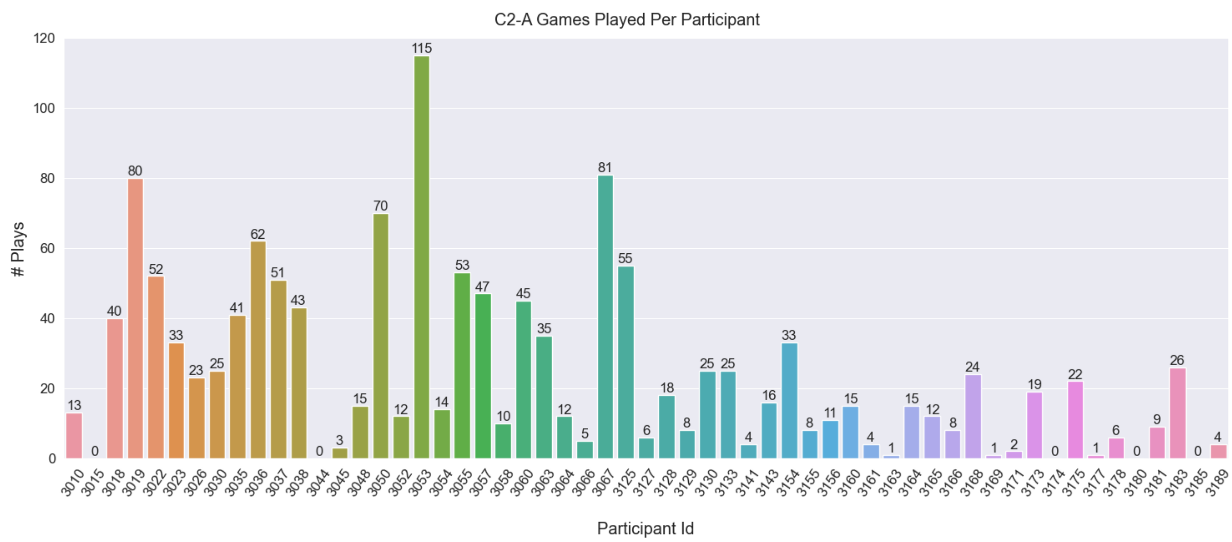


Figure 4.19: Graph depicting the number of plays for each participant during C2-A.

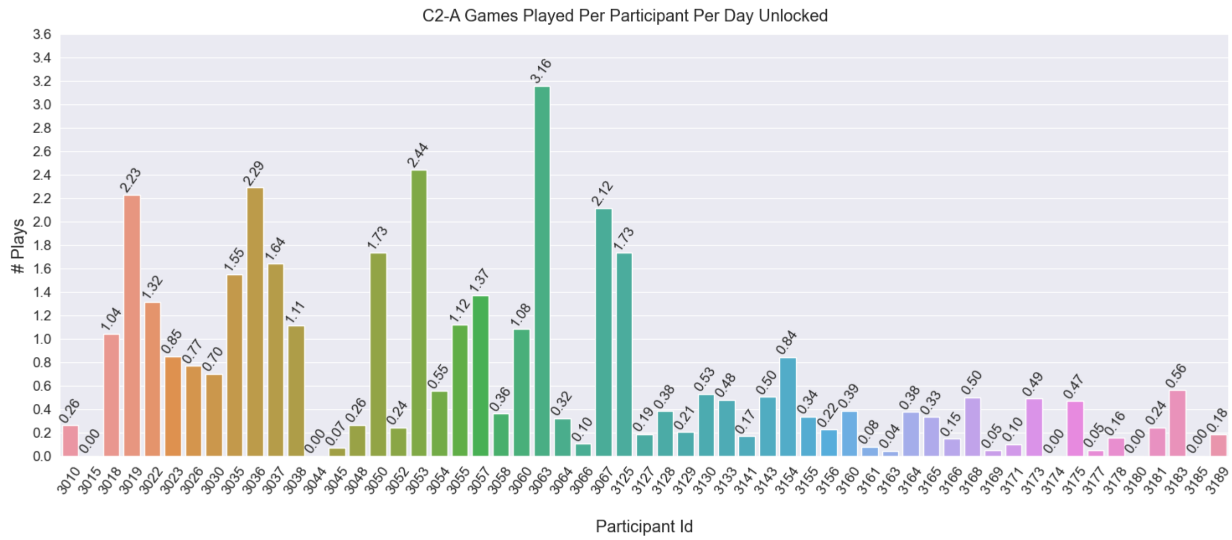


Figure 4.20: Graphs depicting the number of plays controlled for days unlocked for each participant during C2-A.

4.4 Conclusions

Overall, we did see a decline in game plays over time. We suspect that there were not enough customizations and/or minigame options and/or that the existing customizations and minigames were able to be unlocked too quickly to sustain interest over the course of several months. Our small team combined with our shortened timeline compared to professional game development makes it difficult to design, create, and implement many VFB customizations and minigames prior to the beginning of our studies. Additionally, given this shortened timeline for development, it was difficult to test the reasonability of the rate at which the VFB leveled up, participants earned points and unlocked customizations/minigames, or points were scored during each minigame in our lab prior to running our studies.

Additionally, there was a unique circumstance for each study which may have also contributed to this decline in engagement. The pilot study was effectively a testing ground for the new system. We tested and updated much of our core code during this time. For C1-A, participants had much difficulty in leveling up their VFBs as we had implemented a system where they could also level down, mimicking how our bodies fluctuate based on our PA habits. The rate at which VFB levels decreased was too extreme. By the time we realized this, it was already too late in the study. It makes sense that participants would be less motivated to continue engaging with the VFB-A system if they were unable to make reasonable progress over time. For all future studies, VFBs were only allowed to level up so that this did not happen again. C2-A was interrupted by the COVID-19 pandemic about halfway through the study at the beginning of 2020. As schools shut down and children transitioned to online learning, they could no longer access the VFB-A system. We were unable to test the effects of our new updates as a result.

While engagement was reduced overall, participants continued to interact with their VFB throughout Cohort 2. As a result, this indicates that participants were still excited to interact with their VFB throughout the study. Participants played a variety of minigames throughout the course of the study with Slingshot receiving more plays early in the study and Soccer and Volleyball receiving more plays as the study progressed. This provides support for participants preferring a variety of games to play or other activities to do over time. With this knowledge, we would expand the number of games available to participants for our next study.

4.4.1 Fitbit Physical Activity Syncing

Fitbit syncing problems continued to plague us throughout all of these studies. Given our issues detecting Fitbits during the VFB-C study, we tried testing if we could reliably detect Fitbits within a certain physical distance from the kiosk. However, there were troubles detecting the closest Fitbit in the field. With further experimentation, we found that the value we were using to determine this distance was not consistent with real-world distance from the kiosk. With this in mind, we opted to have the system start looking for a participant's specific Fitbit once they had already logged into the system for C1-A. However, we had issues where the Fitbit would not always maintain a connection to the computer while syncing, which was largely due to participants not always syncing consistently and, as a result, having a lot of data to sync at once. This caused the Fitbit to no longer broadcast a signal for approximately 5 minutes. Since we required the Fitbit to be recently synced in order to play with their VFB, our participants either had to wait or try soft resetting their Fitbit (which was also difficult) to try again. Obviously, this caused a lot of frustration for our participants. For C2-A, we returned to detecting and syncing nearby Fitbits in the background similar to the VFB-C system. This method seemed to work better than it had for the VFB-C study. However, we had issues where our detection process would crash, and the VFB-A system would need to be restarted. Although we did automate this restart process, this was still a big source of frustration for participants.

4.5 Lessons Learned

From the VFB-A studies, we learned that PA data should be synced prior to the user interacting with the system as it has caused numerous problems for many of our studies. Even with these PA syncing issues, it needs to be mentioned that we have not had any issue recruiting participants for these studies. The children and their parents are excited to receive their Fitbit and especially their VFB. Additionally, participants continue to engage with their VFB throughout the course of the study. Thus, it is not a matter of lack of interest in the VFB system. It is a matter of fitting the application design to the environment and audience while also having enough content to support extended use over time. Given that we have limited time to generate this content and that we have consistently revamped some major system for each subsequent study, it has been difficult to build up this pool of content that is required for sustained engagement. However, we have accumulated several mechanics and other approaches that would be useful for designing games and interactions for future studies with each subsequent iteration.

We would also use many of the minigame designs and implementations as a starting point for future minigames. For example, the paddle system used for Soccer and Volleyball seemed to work well in the field, and we would apply a similar system in the following study. We also learned that a precise aiming system would be beneficial to a game like Basketball where the goal is to get the ball to a precise location. Although we would no longer use the shot zone system, as it was hard for participants to understand and use the shot zones, especially without a researcher present to aid by explaining how they worked, they still inspired our aiming system used in the next study. Instead of shot zones, we would use a power meter with aiming by tilting the iPad, which is a mechanism also utilized by other mobile games. We would also continue to use the leaderboards we introduced as a part of this system as our participants enjoyed having these leaderboards available to compare scores and PA.

Once again, this kiosk-based system was robust with a design inspired by the Virtual STEM Buddy (VSB) kiosk. We ensured that there was sufficient ventilation to keep the system running cool inside the kiosk cabinet and hid the majority of the cabling inside the kiosk itself. Across both cohorts, there was not a major hardware failure. This means that for 6 weeks at a single site during the pilot, for 6 months across 6 sites during cohort 1, and roughly 4.5 months across 4 sites during cohort 2 there was not a hardware failure. Not to mention, these kiosks were used by hundreds of children during that time. The only update we would recommend on this mobile kiosk design would be to ensure that the TV has the capability to turn on alongside the computer receiving power, as it had done for the VSB kiosk. Additionally, the combination of a touchscreen for menu selection alongside motion controls for interacting with the VFB continued to work well as it had for the VSB system. This combination would continue to be used for our next study although it would utilize an iPad for both the touch and motion controls in lieu of an independent touchscreen and Kinect.

Chapter 5

Virtual Fitness Buddy - At Home Systems

Given the onset of the COVID-19 pandemic at the beginning of 2020, we were no longer able to run the afterschool-based Virtual Fitness Buddy (VFB-A) system. We pivoted once more and turned the public space VFB-A system into an at-home intervention (VFB-H). Instead of using the large screen kiosk from our prior studies, we used an iPad as the primary interaction device (see Figure 5.1). Our primary goal with this new system was still to motivate children to engage in healthier physical activity (PA) habits over time. With this version, we wanted to integrate the child's family more into the system, giving siblings and guardians of the primary child the ability to contribute to and interact with their VFB. This way each participant had a support system similar to their peers and site staff during the VFB-A studies. Two cohorts of 25 children used this new VFB-H system across a 4.5-month period, which consisted of 16 and 9 children (C1-H and C2-H) respectively. We also had control groups for both of these cohorts, resulting in a total of 29 and 15 children which started in Fall 2021 and Spring 2022, respectively. There was also a small pilot that was used as a way to beta test this new system and address any bugs that were discovered in the field. This allowed us to focus on designing even more minigames and update existing ones based on feedback and play metrics.

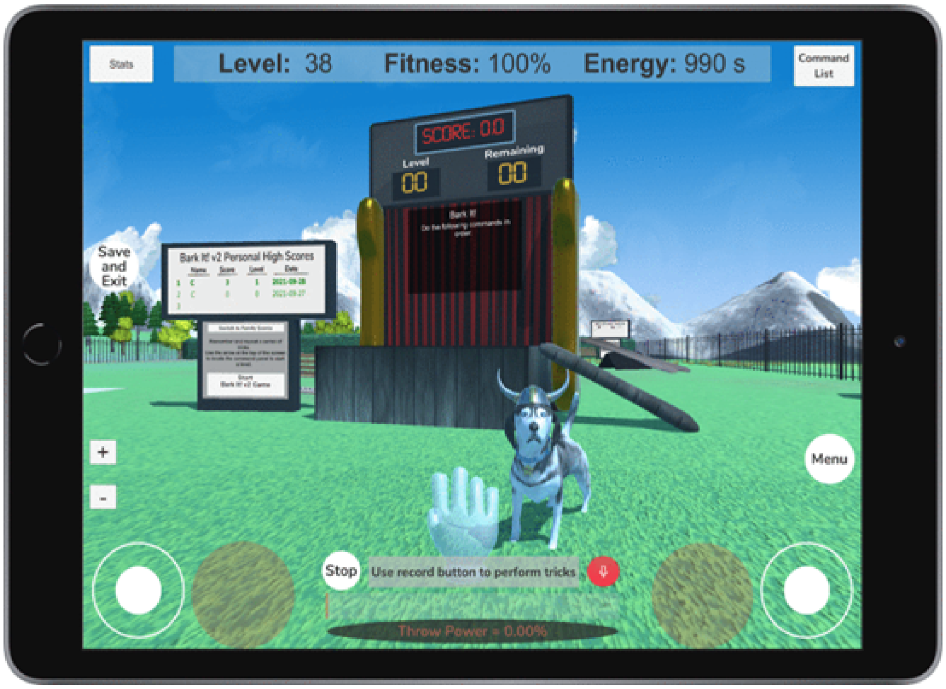


Figure 5.1: The VFB-H iPad interface, featuring the Bark It minigame. The personal leaderboard is shown on the left. The player's hand avatar is shown in the middle of the screen near the bottom.

5.1 Input System

Initially, we focused on incorporating augmented reality (AR) elements as part of the system, where the VFB and minigames would appear as if they were part of the real world. It was going to be a system where they were in fact interacting with their VFB in their own space. However, we abandoned this approach as it was not practical for us to deploy such a system with the amount of time available given all the different environments where this system could be used. Additionally, unlike a touchscreen system, we did not already have an established codebase using AR already, rendering this approach even less practical. Instead, we pivoted to a system we had already implemented for the previous virtual buddy (VB) experience: a combined motion- and touch-based input system. This way we could leverage our familiarity with these types of controls and most of the UI was transferrable as it was largely on a touchscreen already. Based on our experiences deploying both the Virtual STEM Buddy (VSB-M) and VFB-A systems, we knew that touch controls likely were familiar to our participants.

The resulting system used real-world iPad rotation to rotate the camera view and used touch controls, including virtual joysticks, for all other necessary inputs. They could also move their avatar around by moving in the real world, but we did not leverage this behavior when redesigning our minigames as we did not want lack of space to be an impediment for our participants. The skeleton avatar used during our previous studies was replaced by a virtual hand as shown in Figure 5.2 as this new version would be played in first person rather than the third person perspective we had been using for the previous VB systems.

Figure 5.2: The VFB-H user avatar was a hand that, when as item was being held, would change to that item.

As mentioned, we did design this to use both motion and touch controls. This is best exemplified by our new throwing system. We removed the shot zones from the VFB-A system as it was both difficult for our participants to use and was not practical to use with an iPad-based system. The shot zones were designed to show participants where to place their hands and make more precise aiming possible for the Basketball minigame. For this new system, they were no longer directly using the motion of their hands as their primary input system. Instead, the intent was to use the iPad's rotation to assist with aiming where an item should be thrown similar to some mobile games. In order to indicate when and how hard they wanted to throw, we added two red, virtual buttons for them to press down. The longer they held them down, the stronger their throw would be and the farther the item would go. In order to throw the item, they would release these buttons. The strength of the throw was displayed using an onscreen power meter (see Figure 5.3). Thus, our throwing system required the use of both touch (power up and throw) and motion inputs (aim) in order to work as intended. This system was used for the Basketball minigame, fetch, and the Frisbee minigame.

Figure 5.3: While aiming an item, the user avatar temporarily changed to that item. They would also hold down the red circles to charge the power meter.

Lastly, participants could now play fetch and perform tricks with their VFB at any time. During the VFB-A studies, participants had to navigate through the touchscreen menu and select the fetch or trick minigame prior to being able to throw a toy or give their VFB a command. Given that participants can now move around the park, we opted to add this mechanic so participants did not have to go to a specified station or even play a game in order to interact with their VFB. They could pick a toy from the popup menu and begin throwing it for their VFB or hold the mic button in order to issue a trick command. They could also navigate the popup menu to execute tricks without voice commands if desired.

5.2 VFB Park

In all of our previously discussed VFB studies, the environment was a park of some variety. This new VFB-H version was no different as we used the VFB-A park as a starting point for this new park. A core difference between VFB-H and those previous studies is that VFB-H was the first time our participants were able to move around the entire park rather than being anchored to a set position. With this new park to traverse and explore (Figure 5.4), we needed to fill this park with things for participants to do. Instead of having each game played in the same location as we had done in the past, we setup "play stations"

(Figure 5.5) for each of our minigames (Agility, Bark It, Basketball, Frisbee, Soccer, and Volleyball). The implementation of these minigames will be discussed further in the Minigames section below.

Figure 5.4: A view of the VFB-H dog park showing the various minigame stations.

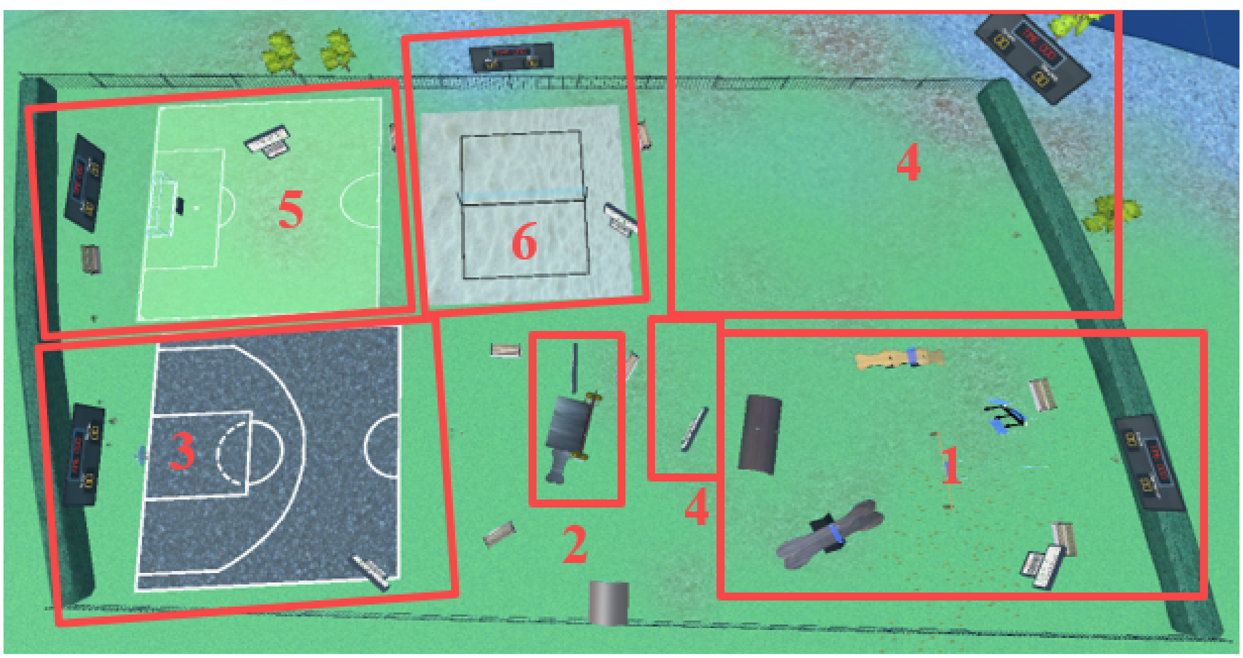


Figure 5.5: The layout of the VFB-H dog park. Each minigame has its own designated play area: Agility (1), Bark-It (2), Basketball (3), Frisbee (4), Soccer (5), and Volleyball (6).

As shown in Figure 5.5, each of these play stations consisted of a virtual kiosk, a scoreboard, a court where applicable, and props that were necessary to play the associated game. The virtual kiosks (Figure 5.6) served a similar function to the touchscreen from VFB-A, where they were used to start and stop the associated minigame, display its instructions on how to play, and display various high scores on a leaderboard. Similar to the high score leaderboards from VFB-A, the new leaderboards could display not only a participant's top three scores for the associated minigame but also could display their family's top three scores and the entire cohort's highest three scores, which they could cycle through with a button press. The remaining tablet functions, such as customizing their VFB and choosing a toy to throw, were placed inside a popup menu, using the same menu system from VFB-A. The courts were intended to resemble the courts used in the real world for each minigame, such as a half a Basketball court and an Agility course used in Agility competitions. Lastly, these play stations were all always displayed in the park, regardless of which game a participant was playing.

Figure 5.6: A virtual kiosk used to start minigames, display instructions, and display high scores.

Many of the props in the play stations we had already used in the past during the VFB-A interventions, such as the Basketball and Soccer goals. For the games designed solely for this VFB-H system, many of the props needed to be generated. To reduce development time and to fit the theme of a dog park given that the VFB model was a virtual dog, we repurposed object models we already had, such as the arch model inspired by the University of Georgia (UGA) arch as weaving poles for Agility and treat bones used as various ramps as shown in Figure 5.7.

Figure 5.7: The treat model (top left) used during the VFB-A study was used as various ramps and columns for the Agility and Bark-It minigames during the VFB-H study. The UGA Arch model (middle left) also served as weaving poles during the Agility minigame.

5.3 Minigames

When designing the VFB-H minigames, we still were constrained by the same three criteria from the VFB-A studies: they should be directly impacted by the health of the VFB (and thus, by the player's PA), should provide a variety of experiences, and should be based on games that can be played with a real-world dog. Additionally, we did not want our participants to remain sedentary while using this new VFB-H app. Our previous systems had this requirement built into them given that we opted to use a Kinect as our primary VFB interaction method, which meant that our participants would need to move in order to interact with their VFB. An iPad does not inherently necessitate mobility as we could solely utilize the touchscreen. Thus, this new system had a fourth requirement to incorporate motion as much as possible into our minigame designs. This way engaging with these minigames would not be a strictly sedentary endeavor.

Our six minigames were designed and implemented across our pilot and first long-term cohort, beginning with a single Basketball minigame during the pilot and ending with six minigames complete with leaderboards by the end of the first long-term cohort. As mentioned earlier, the six games consisted of Agility, Basketball, Bark It, Frisbee, Soccer, and Volleyball. Minigames that we had implemented in prior studies drew inspiration from their previous iterations, such as continuing to use paddles for Soccer and Volleyball, while adjusting to accommodate the new control scheme. Our two new minigames, Agility and Bark It, were designed to provide experiences that were different from Basketball, Frisbee, Soccer, and Volleyball, where participants either needed to throw a toy at a given target or use paddles to hit an oncoming toy. This way we added more variety of gameplay to the system, especially for participants who may not be as deft at gauging throw distance.

5.3.1 Agility

The Agility minigame was inspired by dog Agility competitions, where a dog and their trainer navigate an obstacle course with the goal of completing the course as quickly as possible, minimizing errors, such as hitting a hurdle while jumping over it. We had wanted to implement an Agility minigame for the VFB-C studies, but we were not able to conceptualize mechanics that we thought would work well for an Agility course and for the Kinect motion controls. However, with the new touch control scheme, an Agility minigame became a possibility. In lieu of throwing a toy, Agility required participants to navigate a series of obstacles while showing their VFB where to run next by placing treats along the way (Figure 5.8).

The course consisted of five obstacles that had to be completed in a specific order: weaving poles in the form of an arch, ramp, tunnel, seesaw, and hurdle jump. In order to assist participants, we added a blue banner to indicate which obstacle their VFB needed to complete next. This blue banner also served to indicate the exact location where a VFB needed to run in order to count the obstacle as completed. Given that the next obstacle banner may not be in the participant's view, we also implemented an arrow-

Figure 5.8: The Agility minigame from the VFB-H study, showing a VFB jumping over a hurdle to reach the treats on the other side. The blue banner indicates where the VFB should run next.

based navigation system to help them navigate through the course. While the next banner was not in the participant's view, a guide arrow would appear at the top of the screen, pointing in the direction of the next banner. This guide arrow system would be reused for several other minigames. In addition to the guide arrow, we also reduced the complexity of the obstacle course by having the VFB automatically complete certain obstacles, such as waiting at the correct spot for the seesaw to come down and jumping over the hurdle. This way the Agility course was more about reducing their completion time rather than how to get their VFB to perform certain actions that were not utilized anywhere else.

Lastly, participants' scores were based on how much time they had remaining on the 60 second Agility timer. This meant that participants achieved higher scores if they had more time remaining on the timer. In turn, this meant that Agility required participants to become familiar not only with the Agility course route but also the touch joystick controls to become better at Agility and reduce their completion time. This scoring system also incorporated their VFB's fitness as it could complete the course more quickly as it was able to run faster and faster the fitter it became, reducing the time it needed to reach the next treat.

5.3.2 Bark It

The Bark It minigame (Figure 5.9) was inspired by the BopIt toys, where players would need to memorize and complete an increasing series of actions in a specific order to continue playing. Our Bark It minigame was a trick memory game, where participants similarly had to memorize and issue the trick commands to their VFB in a specified order. The game would end when the participant missed a trick. Initially, our design included a "fatigue" element, where the VFB would have a random chance of failing (i.e., performing a trick different from the one commanded) after a certain time. As the VFB's health improved, the chance of failure would decrease and would begin after an increased number of tricks. We did not implement this feature as this game was designed to test the player's recall and not the VFB's ability to perform commands. By having the VFB fail to perform the correct trick, the VFB no longer enhanced the player's skill and inhibited it instead. As a result, we also thought that such a system being the sole way to play Bark It may provide unnecessary frustration for our players by having their high score attempt ruined by random chance.

Figure 5.9: The Bark It minigame from the VFB-H study, showing a VFB performing the lay down (left) and spin (right) tricks on the Bark It stage. Behind the VFB, tricks are displayed in the order they need to be repeated on the Bark It screen.

Given that Bark It scoring was solely based on how many levels (i.e., how many sets of tricks) the participant was able to complete, their VFB's health still impacted this game. As their VFB became fitter, it could perform more commands in a single play session, which meant participants could achieve a higher maximum score by being able to complete more levels before their VFB ran out of energy. This also meant that the Bark It minigame did not require participants to become more and more proficient using the virtual joysticks as several other minigames did. It was solely based on memorizing tricks and did not have a time limit. Once again, expanding the variety of options participants had to play. It also included the guide arrow utilized by Agility to point towards the Bark It stage and screen if they were not in the participant's view. The game would also pause the screen if it was not visible to the participant so that the commands did not disappear before they had the opportunity to read them.

Bark It incorporated a revised voice command system. Our previous VFB studies had issues with voice commands working consistently, presumably due to a high level of ambient noise and proximity of the player to the microphone. However, given that the VFB-H system was intended to be used at home on an iPad, players would be closer to the microphone while playing and presumably would be in an environment that was less noisy than a cafeteria after school, reducing the interference between the participant and the microphone listening for their command.

Participants were able to issue these voice commands by pressing the microphone to issue short commands to their pet. This system was designed to respond to the first valid command, which meant that it would accept longer phrases so long as a valid command was part of that phrase. We also included words that may sound similar, such as park in lieu of bark, or could be used as alternate phrases for the same tricks, such as speak in lieu of bark. This system was also used to issue trick commands to the VFB at any time (except during minigames) during play as mentioned earlier. Unfortunately, we were unable to implement trick gestures using the touchscreen prior to either of the VFB-H cohorts.

5.3.3 Basketball

Since our participants have only been able to stay in a relatively stationary location up to this point, we redesigned two of our previous minigames (Basketball and Soccer) to incorporate this new ability to move throughout the world. Initially, Basketball only required participants to make the basket from any point on the court. Some participants realized they could simply stand near the hoop and keep throwing the ball quickly to achieve the highest scores. As a result, we updated Basketball for our long-term cohorts. Instead of being able to stand in a stationary location, participants would need to move to randomly designated locations around the court to score. These locations were indicated by a red pad on the ground, which would ding, turn green, and emit a faint green glow to let the participant know that they were at the correct spot (see Figure 5.10). Given that the VFB was required to return the Basketball to the player, this update increased the impact of the VFB's fitness on the Basketball scores while reducing those scores overall compared to those from the pilot. As their VFB became fitter, the faster that it could retrieve and return the Basketball to the participant, resulting in less wait time between throws which could then be used to make more throws.

Figure 5.10: The Basketball minigame from the VFB-H study. The throw power gauge changes color from red to green, increasing how far the toy will be thrown as it fills.

Similar to the VFB-A Basketball minigame, participants increased their score by making more successful throws within 60 seconds. With the new throw system, we provided participants with a full trajectory that terminated when it hit a solid object. This was similar to the trajectory we used for the slingshot trajectory minigame from the Virtual STEM Buddy (VSB) system. Lastly, similar to Agility, Basketball used the guide arrow system to point towards the next throw location. When a participant was on the throw pad, the guide arrow would then point towards the Basketball goal.

5.3.4 Frisbee

The slingshot minigame from VFB-C was replaced by a new Frisbee throwing minigame. The goal remained the same: pop as many balloons before the 60 second timer runs out. Instead of their VFB collecting treats in the order they were popped, they could now catch the Frisbee to score additional points (see Figure 5.11). This change was made so that players would not always maximize their throw power every time, which would be a relatively easy way to score points as the Frisbee was guaranteed to go far enough to hit its target. In order to get the highest score, they would need to account for the speed of their VFB along with hitting each balloon. As during the VFB-A study, the player's PA improved the fitness of their VFB, which also increased its speed. By increasing their VFB's speed, it could complete its minigame tasks more quickly, which increased the highest potential score that could be earned playing Frisbee. Like the other minigames, Frisbee also used the arrow navigation system to point toward the balloons if they were not in the participant's view.

Figure 5.11: The Frisbee minigame from the VFB-H study. During Frisbee, players must gauge how hard to throw the Frisbee so that it both hits the target and is caught by their VFB before hitting the ground to earn the most points.

5.3.5 Soccer

Similar to Basketball, the Soccer minigame had players move to random locations around the field in order to kick the Soccer ball into the goal while avoiding the blocker, utilizing the guide arrow system to point towards the next location and then towards the goal (Figure 5.12). The goal was to earn the most points in 60 seconds. The VFB would roll the ball towards the player once they were facing the goal. If the ball missed the goal or was blocked, the VFB would retrieve the ball and roll it back towards the player. This meant that the VFB's health impacted how quickly the VFB could retrieve the ball and return back to its rolling location, where a faster VFB would complete these tasks more quickly. In turn, this meant that the player had more time to score points and, thus, increased the number of points that could be earned. Instead of using the throwing system, motion controls were used to kick the ball towards the goal, where the player would move the iPad as if it were a paddle. This paddle-like system was similar to the one used for both the Soccer and Volleyball minigames from the VFB-C studies except that there was no paddle visualization.

Figure 5.12: The Soccer minigame from the VFB-H study. During Soccer, a foot avatar replaces the hand avatar, using this virtual foot to kick the ball.

5.3.6 Volleyball

The Volleyball minigame remained almost identical to its VFB-C counterpart (see Figure 5.13). It used a paddle-like system similar to the one used for Soccer, where a participant would need to use their iPad as if it were a paddle to hit the Volleyball back to their VFB. While we did incorporate elements to make Volleyball a competitive game, we realized that would present a similar problem as Soccer from the VFB-A system, where the game became harder as the VFB became faster as it could reach the ball faster. Thus, we opted to make Volleyball a cooperative game. The player would work with their VFB to maintain the longest streak of volleys in 60 seconds without the ball hitting the ground. Similar to Bark It, we were going to implement a "fatigue" system where their VSB would randomly fail after a certain number of volleys.Similar to Bark It, we did not want the sole version of Volleyball to rely on the VFB not randomly failing in order to make the highest score.

During the first part of C1-H, the Agility minigame score did not compute properly. It would seemingly randomly jump all over the place rather than maintaining the longest streak count. This was addressed and corrected by the minigame update during C1-H and persisted through C2-H.

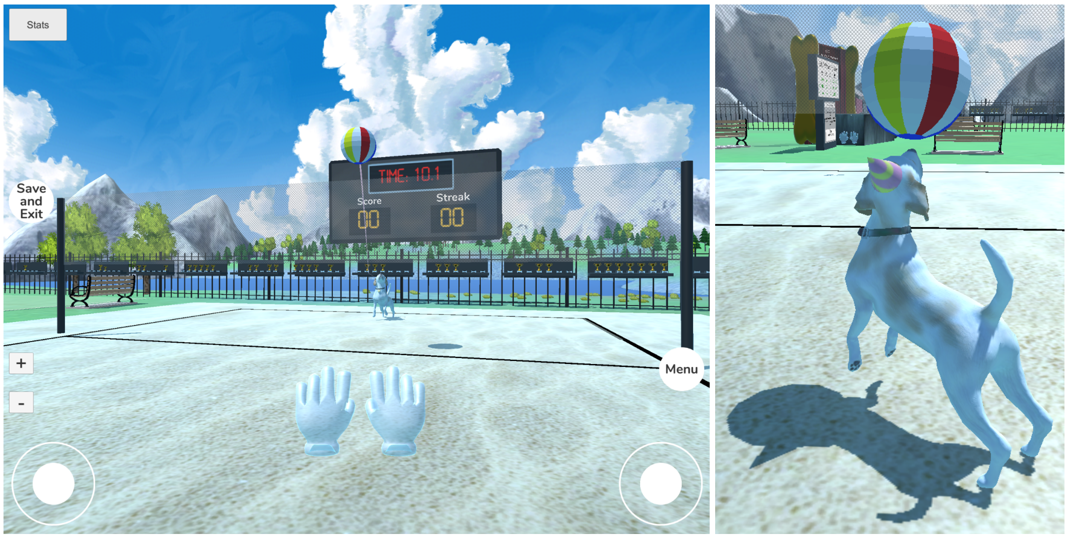


Figure 5.13: The Volleyball minigame from the VFB-H spackagetudy. During Volleyball, players work with their VFB (shown serving the ball (middle)) to maintain the longest serve streak using their virtual hands to serve.

5.4 Social Elements

In addition to these new minigames, we also expanded the social elements included with the VFB-H system. The messaging app from VFB-A returned, where players could text their parents from within the app. Given positive feedback from VFB-A where some of our participants were motivated by the overall and weekly PA leaderboards, we implemented a minigame high score leaderboard system. As mentioned in the VFB Park section above, these leaderboards would maintain three different sets of high scores: personal, family, and public. The public leaderboard consisted of the highest scores from all of the participants of a cohort. It was a way to connect players to each other as they could do in person during the VFB-A study. Lastly, we incorporated "family reviews", where parents would discuss their children's PA progress every week, explaining their progress and encouraging them to engage in more PA throughout the week. This family review would be required both to improve their VFB's health through their PA and to be rewarded points through meeting PA goals. The rationale for this requirement was that it would incentivize children to remind their parents to complete their family reviews so that they could play new games and buy new items. These new additions were designed to increase players' feeling of connectedness to each other, their family, and/or their VFB.

5.4.1 Trophy System

In addition to earning points by completing PA, we also designed and implemented a trophy system. Everyday players would unlock trophies that would change based on their PA, increasing in size as they completed higher PA goals (see Figure 5.14). Additionally, if they met a very high goal, a copy of their VFB performing a random trick was placed atop the trophy (see Figure 5.15).These trophies lined the park perimeter so that players could see their progression over time. By providing our participants with a tangible representation of meeting their PA goals, we thought that we could potentially further increase players' motivations to meet those goals.

Figure 5.14: A series of PA trophies, which increase in size as higher PA goals are met. The leftmost plaque is awarded when daily goals are not met. Lastly, if a daily PA goal exceeds 11,000 steps, a randomly animated copy of the VFB is placed on top of the trophy.

Figure 5.15: Examples of a VFB performing sit (left) and stand (right) atop a PA goal trophy.

5.5 Physical Activity Data Syncing

Lastly, given our previous troubles with syncing participants' Fitbit data, we changed our methods for syncing. Each family was provided with one iPad (treatment) or iPod touch (control), which meant that our primary participant would have a dedicated device syncing their Fitbit in the background. Since we pivoted to using the Fitbit application for syncing rather than our own system, neither Fitbit detection nor a recent Fitbit sync were required to login. Both of these were pain points of our previous systems. To login, players entered their family code and then selected themselves from the family member list. This code could be saved for convenience as the iPad stayed with the same family for the duration of the study. In our experience, we found this new system less frustrating to use during testing.

5.6 Results and Observations

The goal of this dissertation is not only explaining our lessons learned by implementing these systems but also to discern if there are particular elements that increased participant engagement. As such, this was an exploration of the depth of data that we have from this study. For the purposes of analyzing this data it should be noted that where participants are not explicitly labeled as belonging to C1-H or C2-H, their cohort can still be determined by both their participant and family ids, where C1-H participants have ids in the 50,000 (5000 family) range and C2-H participants have ids in the 60,000 (6000 family) range.

5.6.1 Participant Focused Game Play Metrics

During preliminary analysis, we found that, once again, there was a decline in logins over time (Figure 5.16). However, logins may not be the best proxy for engagement in this case. Participants could log in often but that does not mean that they were engaging with their VFB as they may not have stayed logged in long enough to do so. To address this drawback, we began looking at how many times and for how long participants spent playing minigames. Similar to overall login time, simply because they had started a minigame does not mean they always used this time to actually play the minigames. However, the impact of not utilizing this time is likely lower than that of being logged in and doing nothing for a long time. This is due to the fact that the minigames are timed, so, at most, a single minigame would add 60 seconds to the minigame play time. The one exception to this rule is the Bark It minigame, which does not have a time out. Additionally, the minigames were designed such that participants would be directly interacting with their VFB. As such, exploring how often and how long they were played may provide more insight into what it means to be engaged with the system. The participants showcased here are participants who at least played one game throughout the course of their respective study. There are 19 participants from C1-H and 6 participants from C2-H in this dataset, which includes the child participants cited above along with their family units.

As shown in Figure 5.17, there seems to be a similar trend between the number of games played and the amount of time the games were played across participants. This may indicate that many of the games were played to completion and/or that participants did not press the start/end game buttons repeatedly. There are also two individuals who played the minigames much more than the rest both for number of game plays and amount of time played. Given that games were unlocked at different levels, participants likely did not unlock minigames at the same relative time during the study. Given this, not all play counts

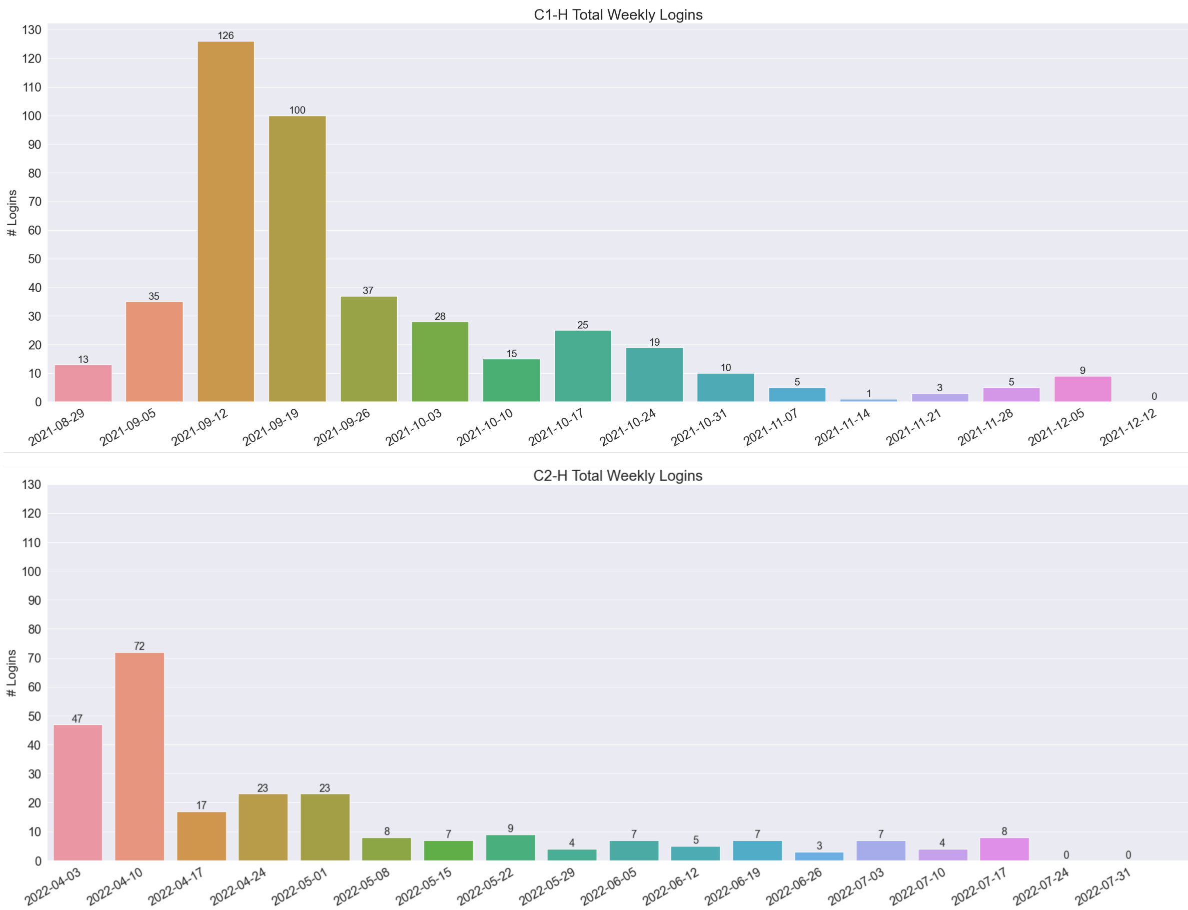


Figure 5.16: Graphs showing the number of times participants logged in weekly to the VFB-H system throughout the course of the study separated by cohort. The top graph refers to C1-H weekly logins and the bottom one refers to C2-H weekly logins.

nor play times are created equal. For example, C1-H participants received an update on October 5, 2021, which was, at most, around 38 days after they began to have access to their VFB, pending participant start date. This update released new versions (V2) of each minigame and removed the old versions (V1). This means that C1-H participants had access to the V2 versions for at most 75 days (pending participant start and end dates). C2-H participants had access to V2 games for at most 105 days.

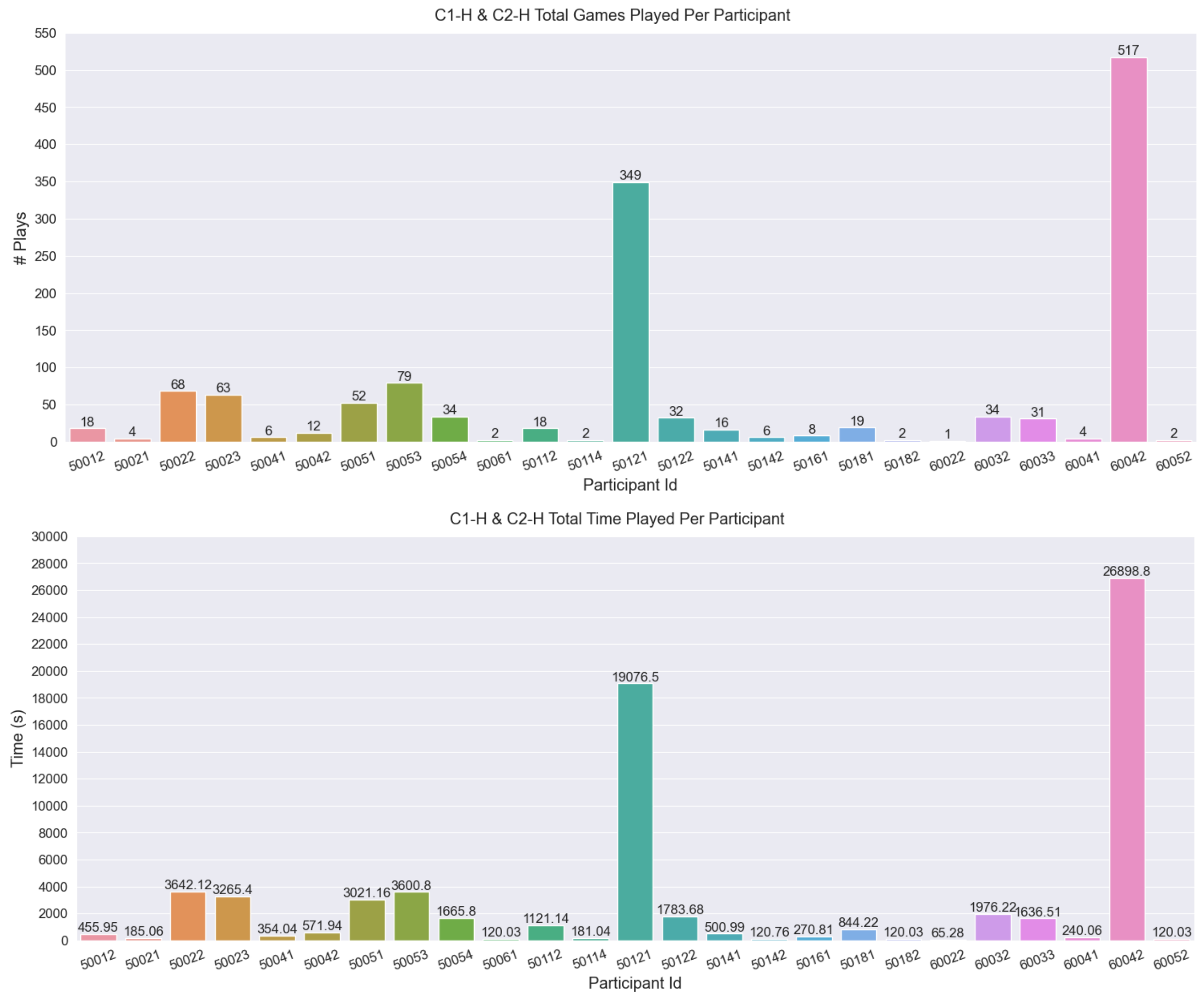


Figure 5.17: Graphs depicting the number of plays (top) and amount of time played in seconds (bottom) for each participant for both C1-H and C2-H.

Given this difference in duration of VFB access, we opted to examine how many games and how much time participants played while controlling for the number of days they had access to each game (Figure 5.18). This results in participant 50121 overtaking 60042 in relative play time and games played. This means that while participant 60042 played more games, they did so across more unlock days compared to participant 50121, which is true given than participant 60042 had access to all games for 105 days and 50121 had access to V1 games for 31 days and V2 for 67 days for a total of 98 days. Figure 5.18 also shows us that most participants (approximately 92%) played games for less than two minutes per day with approximately a third of participants playing under 10 seconds per day. This is much less than we had anticipated.

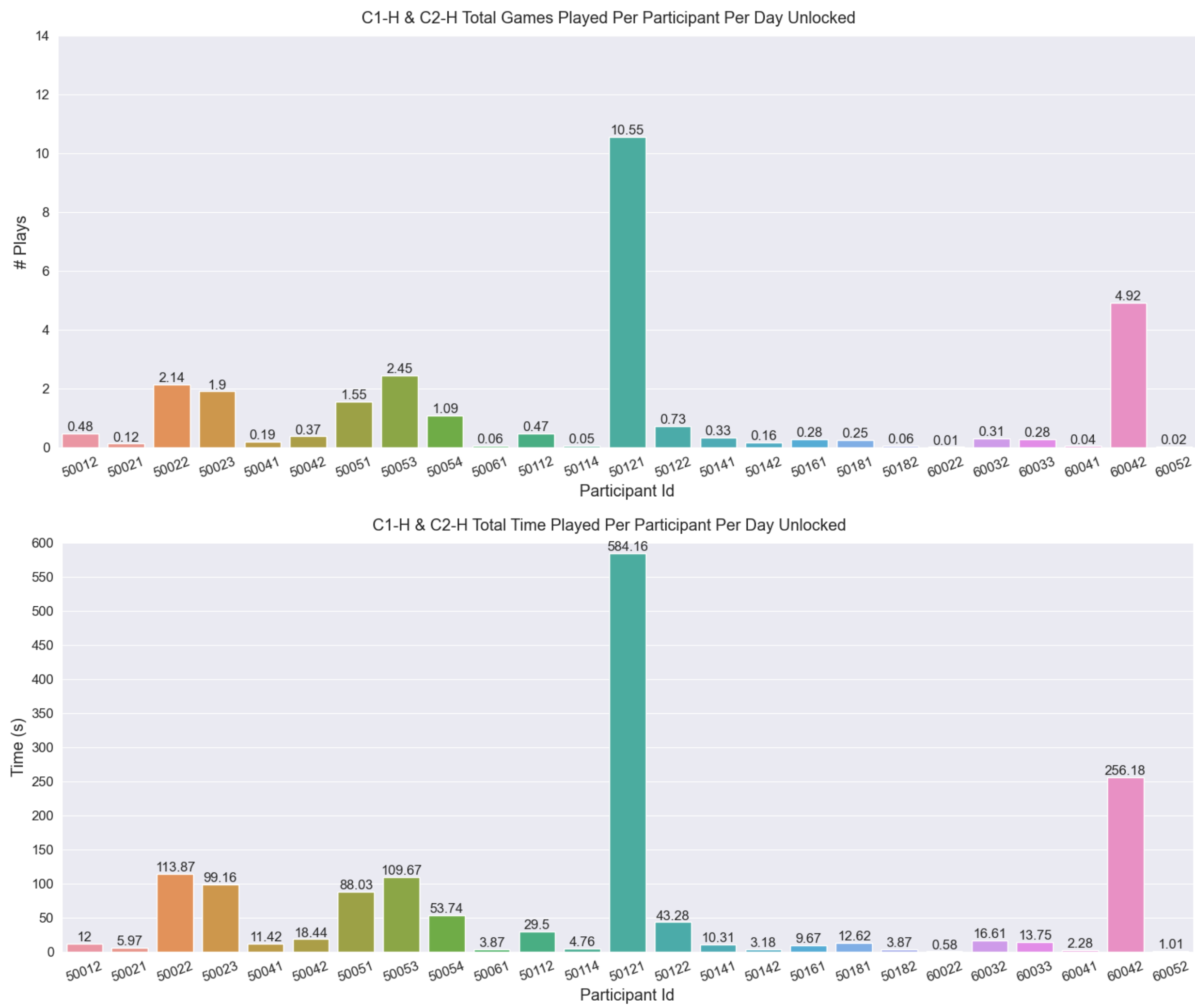


Figure 5.18: Graphs depicting the number of plays (top) and amount of time played in seconds (bottom) controlled for days unlocked for each participant for both C1-H and C2-H.

Given that some participants were adult guardians, perhaps they did not play as much as the child participants. As shown in Figure 5.19, guardians only account for 4 of the 9 participants with time played per day under 10 seconds with three guardians playing around 30 seconds or more per day. Thus, this is not a sufficient explanation to solely explain the low play time per day.

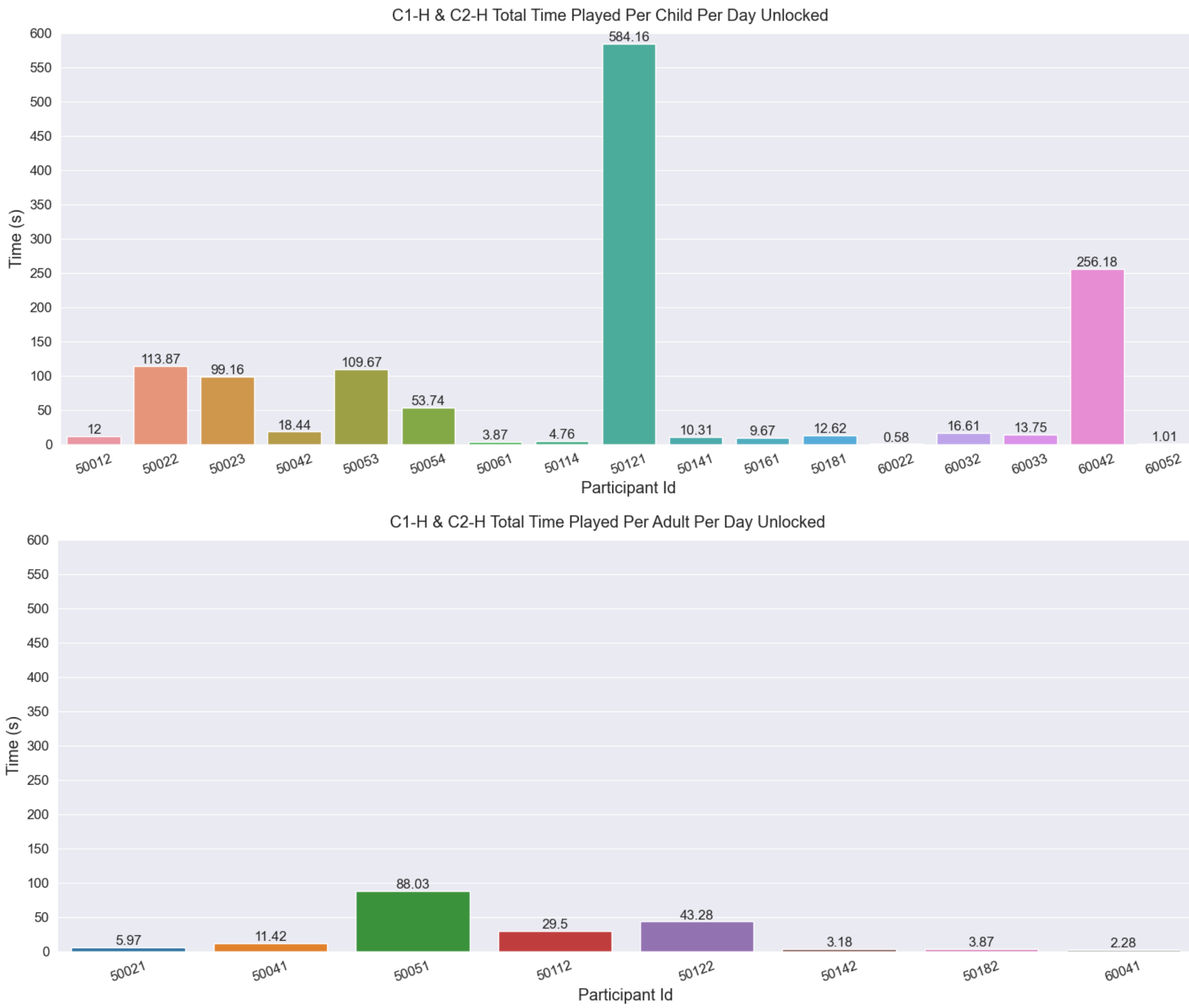


Figure 5.19: Graphs depicting the amount of time played in seconds controlled for days unlocked for each child (top) and guardian (bottom) participant for both C1-H and C2-H.

5.6.2 Minigame Focused Metrics

In addition to how much time participants spent playing the minigames, the variety of games they played is also of interest. We expected that participants would prefer a variety of games over a single game in particular. As shown in Figure 5.20, there seems to be a preference for Soccer in both cohorts with Agility and Bark It being the least preferred. There also seems to be the same number of relative plays across both versions of the minigames. However, as mentioned earlier, different minigames were unlocked at different levels and unlocked by participants and their families potentially at different times. Agility and Bark It are the last two games to be unlocked at levels 4 and 5 respectively. By controlling for the number of days each family had access to each game, we can account for these different unlock times. This also allows us to control for the fact that the first versions (V1) of the minigames were only accessible for at most approximately 45 days by C1-H, whereas the second versions (V2) were accessible for the remainder of C1-H and the entirety of C2-H. As shown in Figure 5.21, the V2 minigames were played much less controlling for days than the V1.

Rather than being indicative of the relative success of each version of the minigames, this could be partially due to the novelty effect, where we generally have seen much higher plays earlier on in our VFB studies than compared to later. In that case, the V1 minigames would have been played at the peak of interest in the system, inflating their overall play metrics compared to V2, which provides a view into how games were played throughout the duration of the study. Additionally, as previously mentioned, V1 games were only accessible for around 38 days whereas V2 games were accessible for around 67 days (C1-H) and 105 days (C2-H). V2 plays and time played per day may be suppressed due to V2 minigames being accessible for most of the study rather than solely at a potential peak play period. Although there are 13 more C1-H participants than C2-H, the number of participants who played each version are much closer with 17 participants who played the V1 games and 15 participants who played the V2 games.

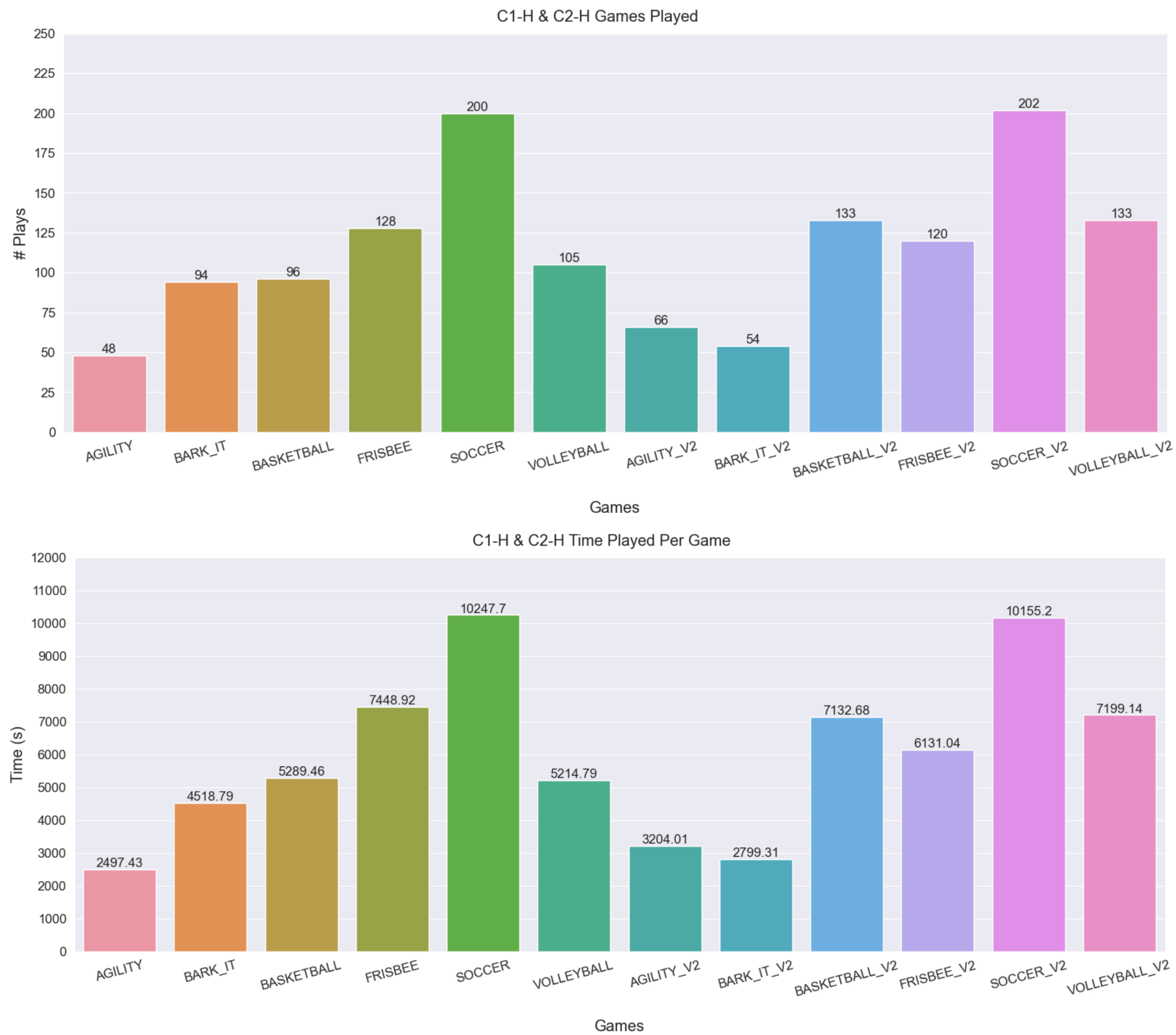


Figure 5.20: Graph depicting the number of plays and amount of time played for each game played for both C1-H and C2-H.

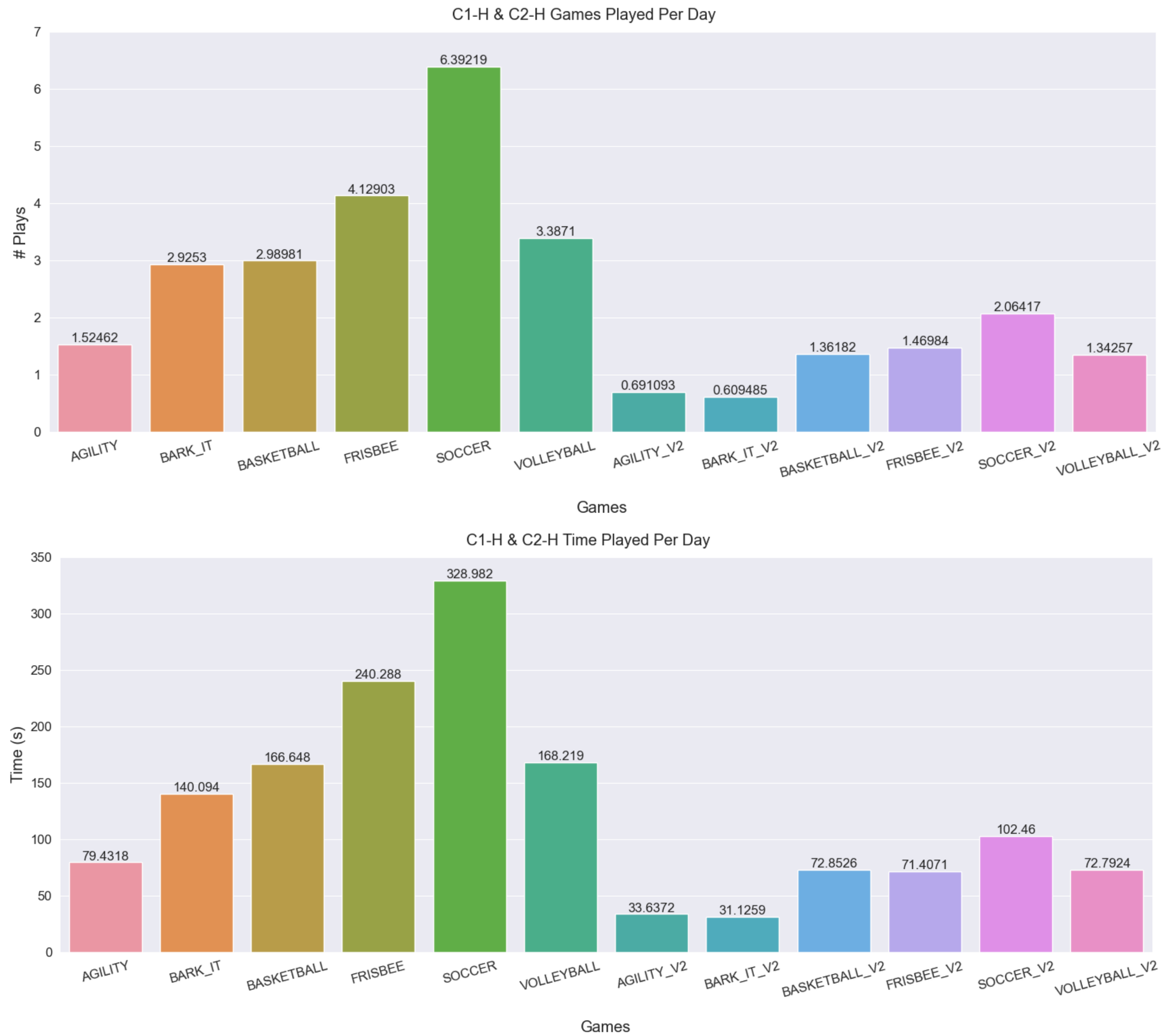


Figure 5.21: Graph depicting the number of plays and amount of time controlled for number of days unlocked for each game played for both C1-H and C2-H.

As shown in Figures 5.17, 5.18, and 5.19, we have two participants that played far more than the rest. As such, when examining the number of games played and time spent playing them, our previous graphs are skewed by those two participants' preferences. By looking at their play time individually across all of the games they played, we see that both of these participants had a substantial preference for the Soccer minigames (Figures 5.22 and 5.23).

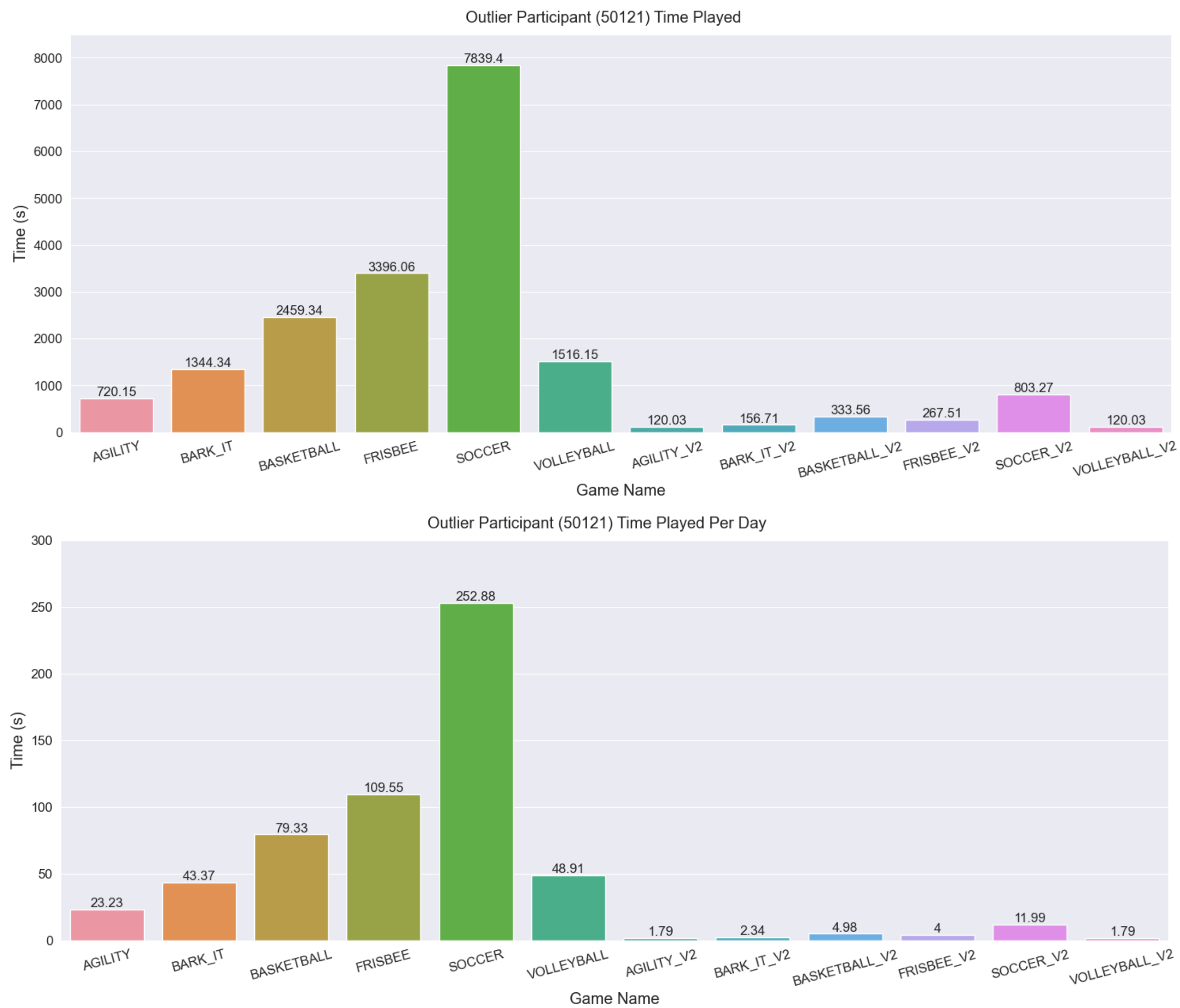


Figure 5.22: Graphs depicting the time played (s) and time played (s) per day for the C1-H game play outlier shown in the top (time played) and bottom (time played per day) graphs.

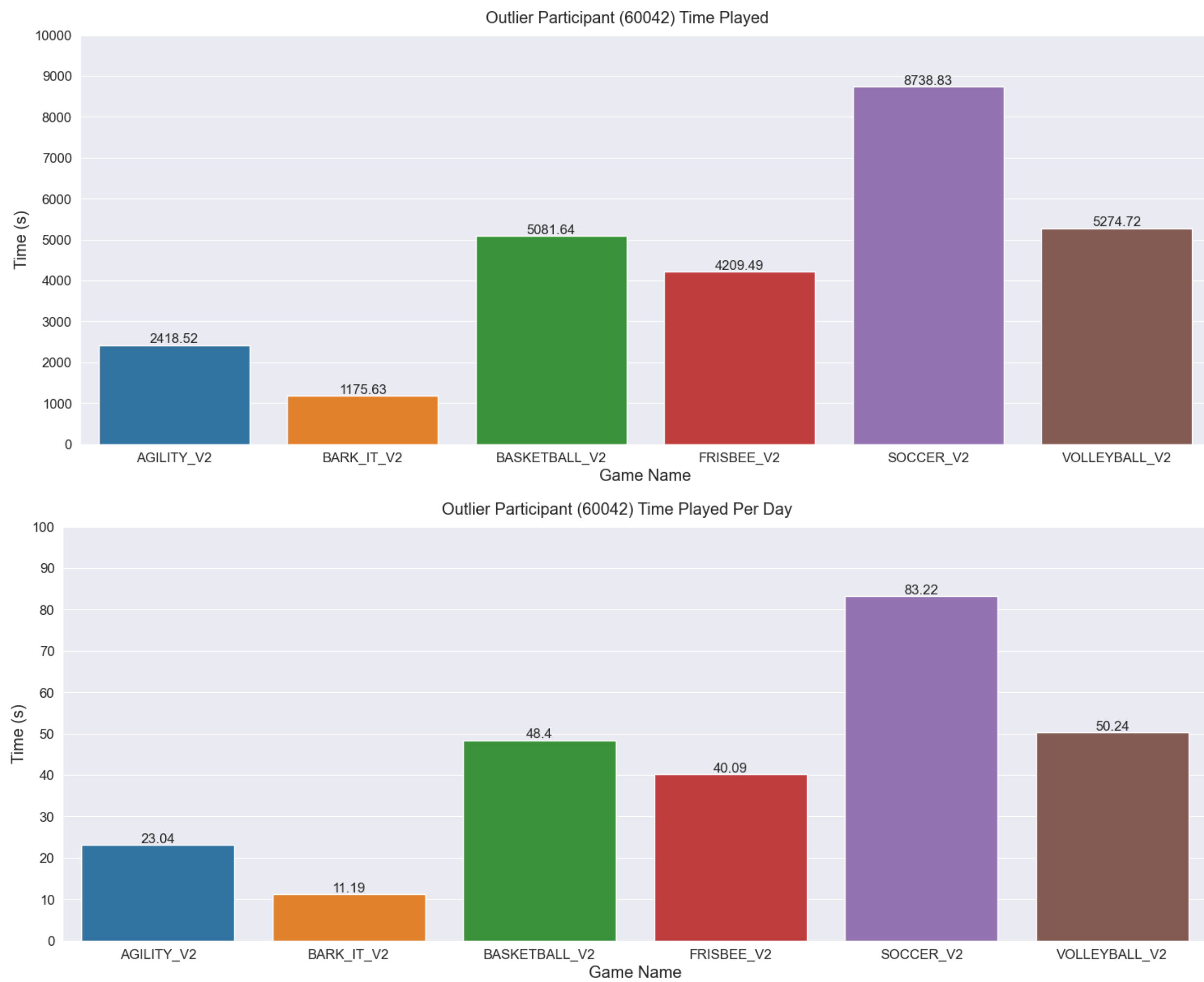


Figure 5.23: Graphs depicting the time played (s) and time played (s) per day for the C2-H game play outlier shown in the top (time played) and bottom (time played per day) graphs.

As shown in Figure 5.24, the preference towards the Soccer minigame was reduced for both V1 and V2 upon removing these participants from the overall play data. The play time was reduced so much that other minigames overtook Soccer in terms of overall playtime across both C1-H and C2-H. Additionally, with those outliers removed, the amount of time played for each game became more comparable than those shown in Figures 5.20 and 5.21.

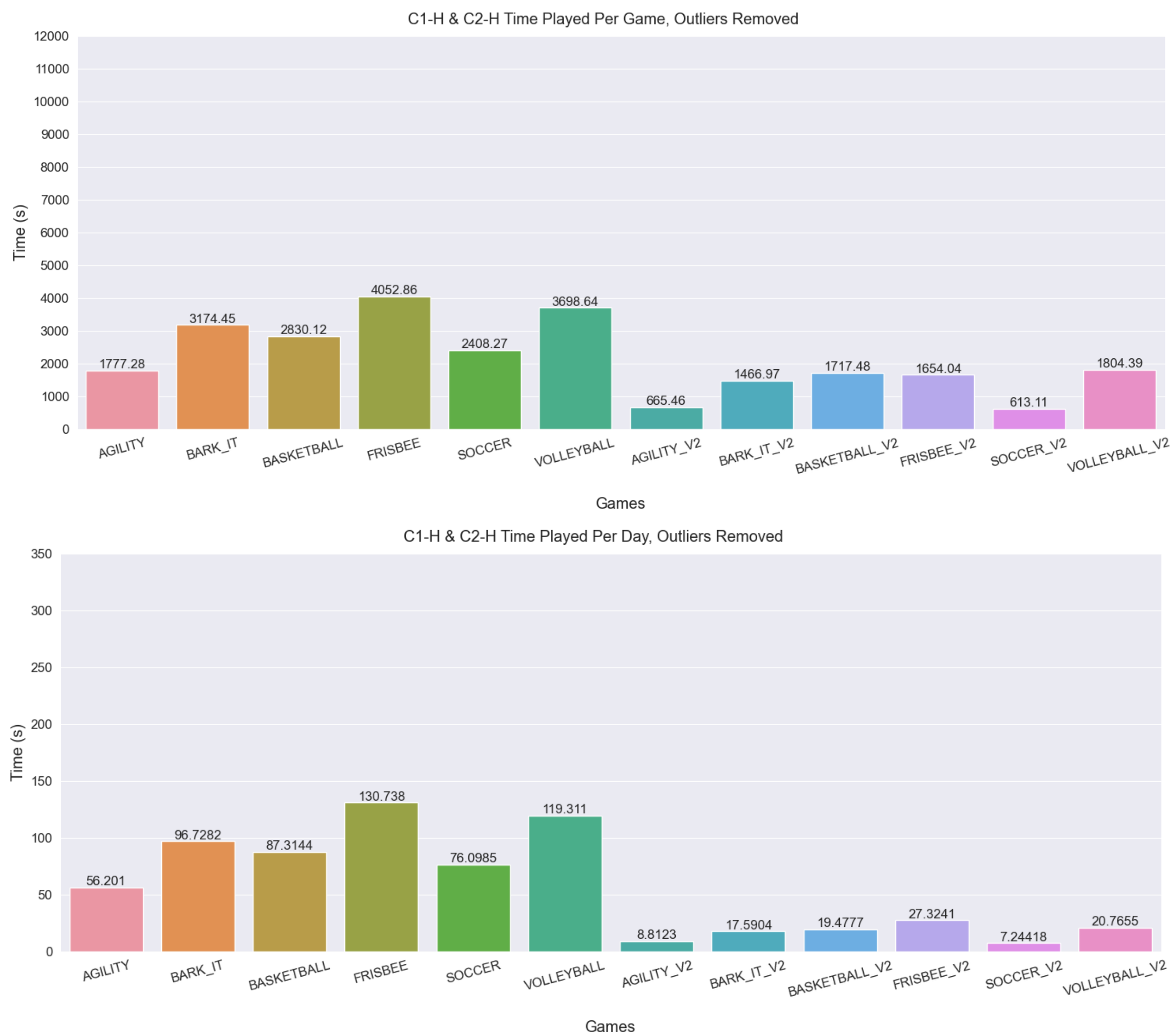


Figure 5.24: Graphs depicting time played (top) and time played per day (bottom) for all participants, excluding the two individuals with increased gameplay.

Also shown in 5.24, both versions of Agility and Soccer V2 were played about half as long as the other minigames. It also happens that Agility is the last game unlocked at level 5. However, when controlling for days, this trend still persists and as such, there are likely other factors contributing to this lower play time. That being said, Agility along with Basketball and Soccer all require participants to maneuver quickly, including rotating the camera. Bark It, Frisbee and Volleyball can all be played by standing in a single position without moving the camera. Thus, revisiting Agility's gameplay mechanics for future iterations may provide more insight here.

Lastly for minigame metrics, as mentioned, the variety of games participants played over time is of interest. We expected that participants would tend to prefer a variety of games throughout the course of the study. Initial attempts at visualizing gameplays in a timeline format were incredibly crowded and hard to read. Instead, we used a combination of Gantt charts (Figure 5.25) and line graphs (Figure 5.26). Due to the sporadic nature of daily game plays, we binned game plays into weeks since the start of the study.

Figure 5.25 shows the study weeks with contiguous plays for each minigame. A contiguous play is consituted as at least a single minigame being played across chronological weeks with smaller bars representing weeks where a game was not played the week prior nor the week after. This means that the progression of a bar on the graph does not represent individual plays occurring each day of the week. As shown, a variety of games were played throughout the course of both cohorts. The provides support that participants preferred variety over the course of the study if they interact with their VFB and play games.

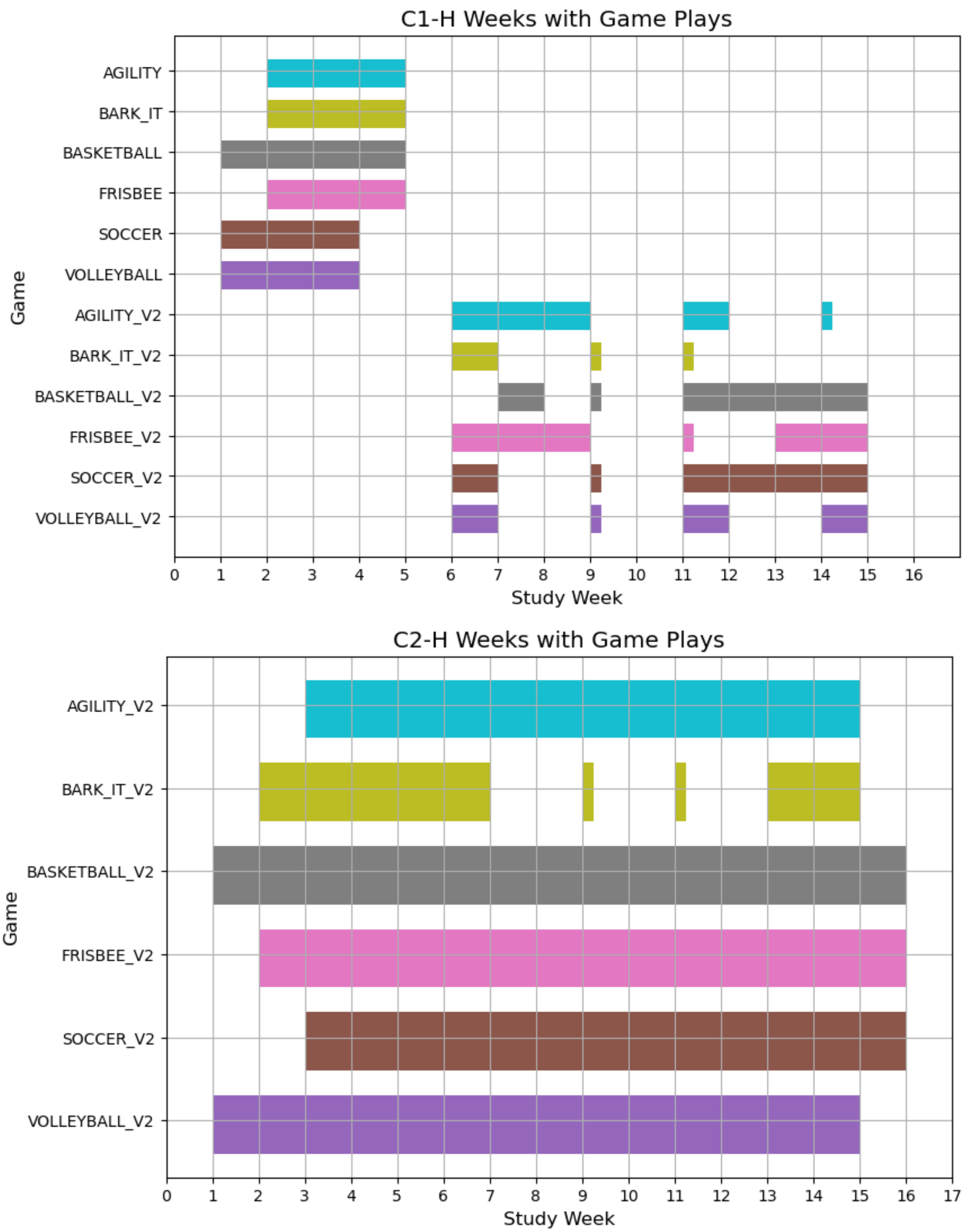
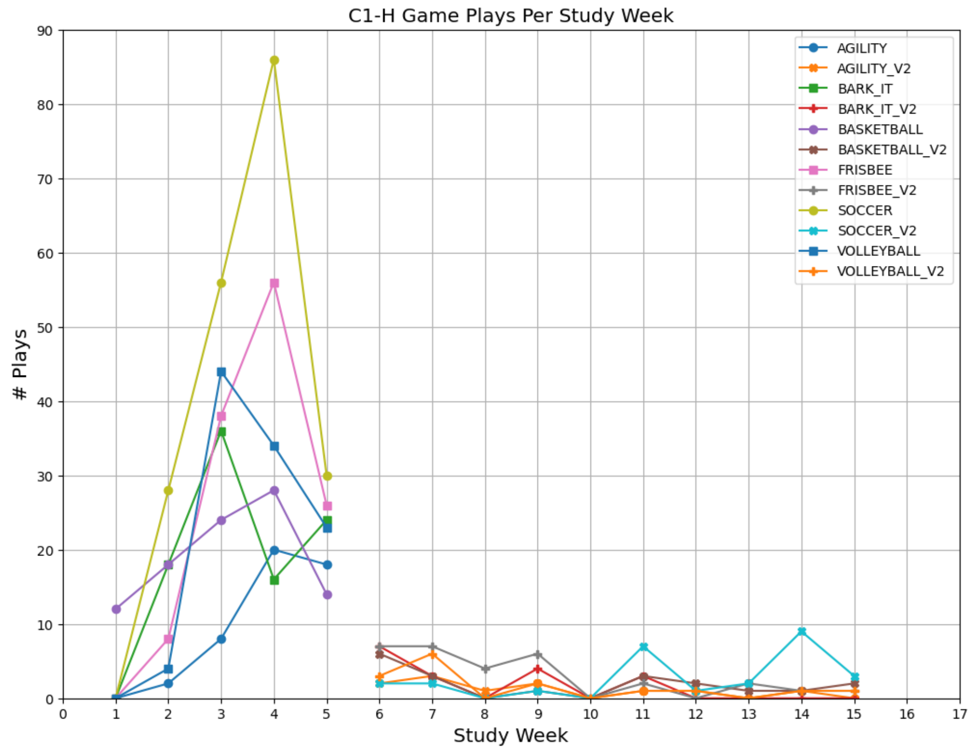


Figure 5.25: Graphs depicting study weeks where a given minigame was played at least once where a contiguous bar represents weeks where a game was played consecutively. The top graph represents C1-H and the bottom represent C2-H.



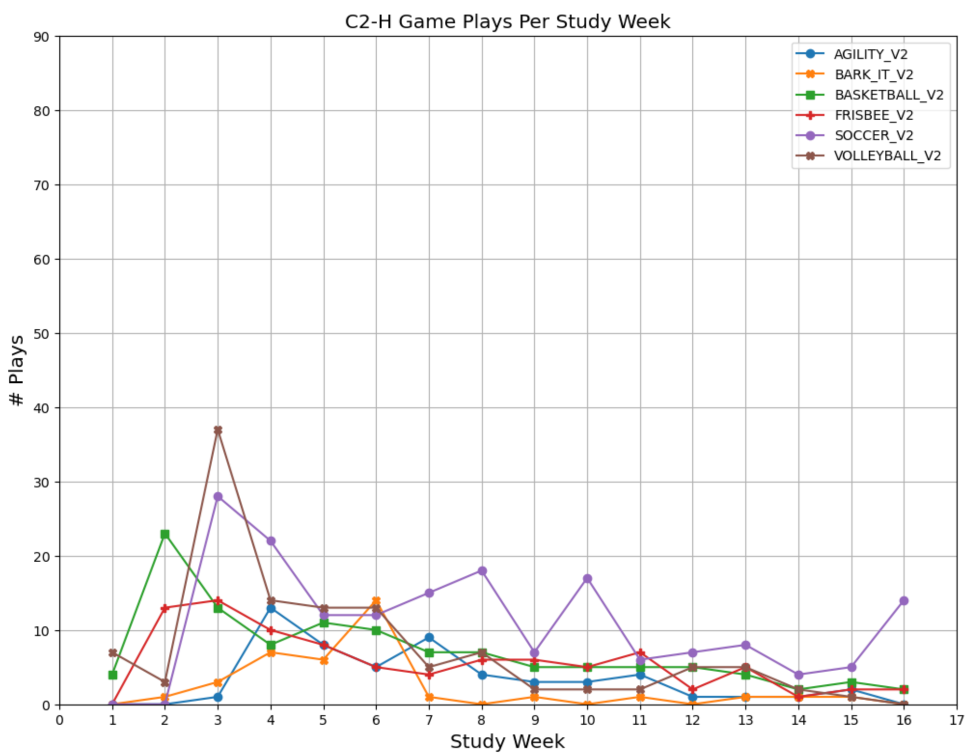


Figure 5.26: Graphs depicting minigame plays per week over time for C1-H (top) and C2-H (bottom).

Figure 5.26 depicts the quantity of game plays for each game during the week. As shown, C1-H V1 games were played more than their V2 counterparts for both C1-H and C2-H, which is similar to our previously mentioned findings. They also follow the trend of decreasing over the course of the study. The immediate drop off in plays for C1-H after week 5 can be explained by the participant 50121, who had many more game plays than the rest of their cohort, not playing as many games as before the V2 update (Figure 5.27 5.28), greatly reducing the difference in game plays between V1 and V2. Similarly, the C2-H participant 60042 contributed many of the plays to C2-H each week (Figure 5.29 5.30).

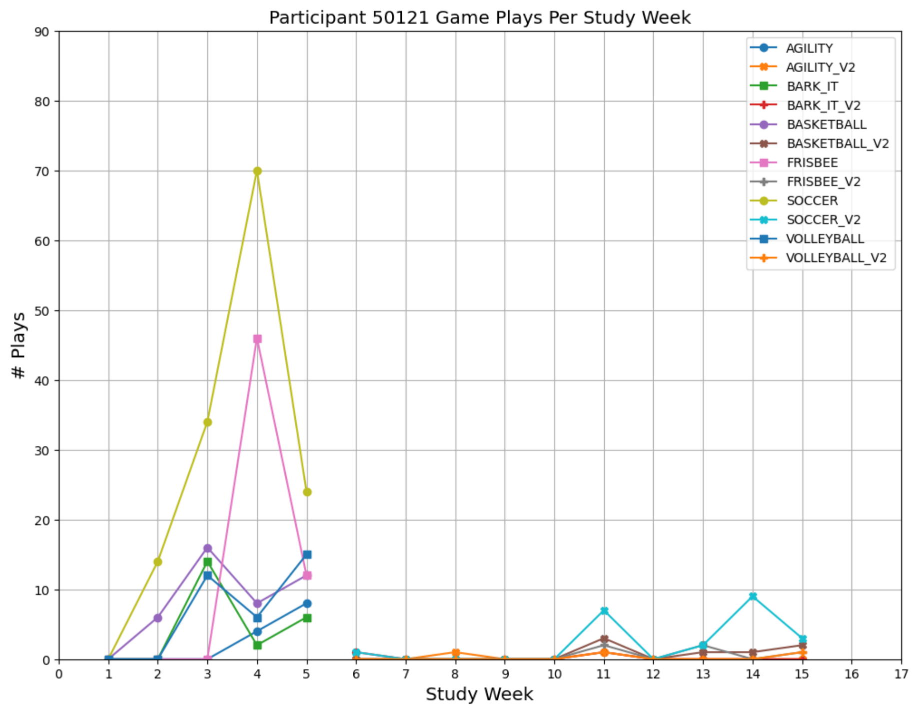


Figure 5.27: Graph depicting the number of game plays for each game each week for the C1-H game play outlier.

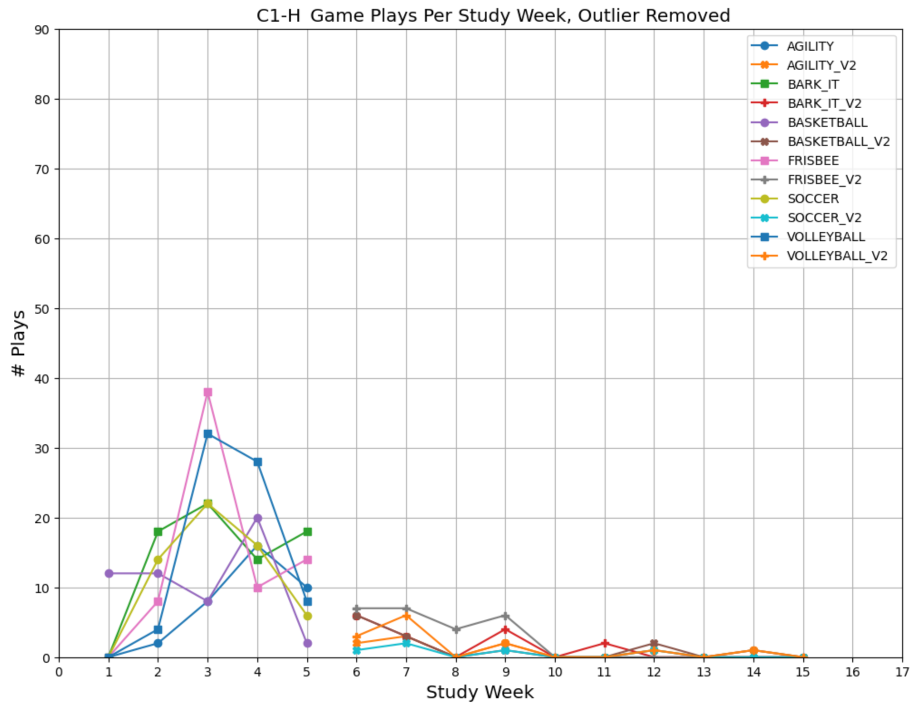


Figure 5.28: Graph depicting the number of game plays for each game each week for C1-H with the game play outlier removed.

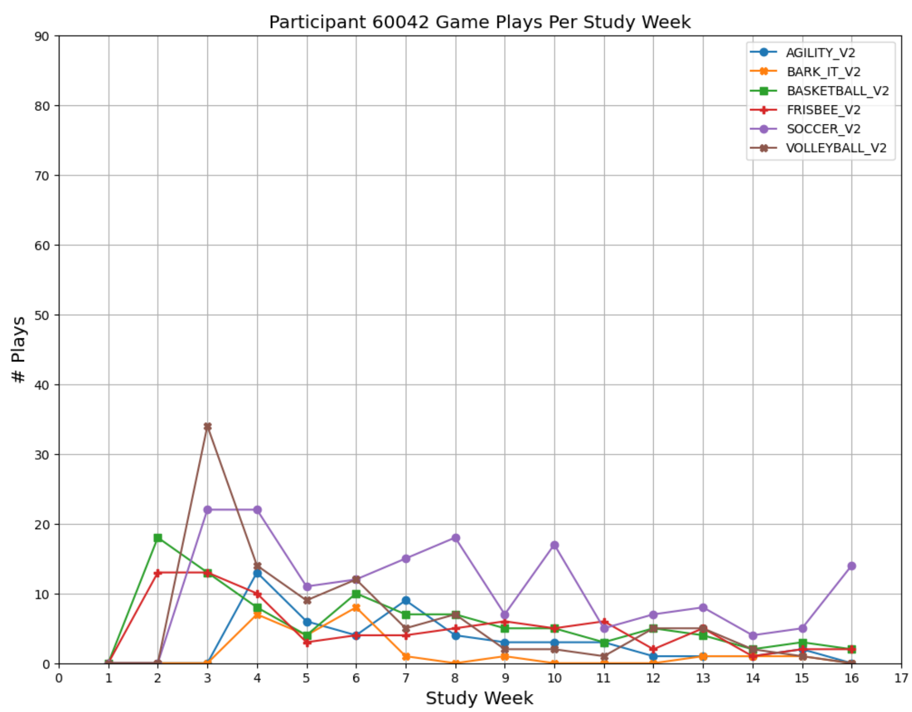


Figure 5.29: Graph depicting the number of game plays for each game each week for the C2-H game play outlier.

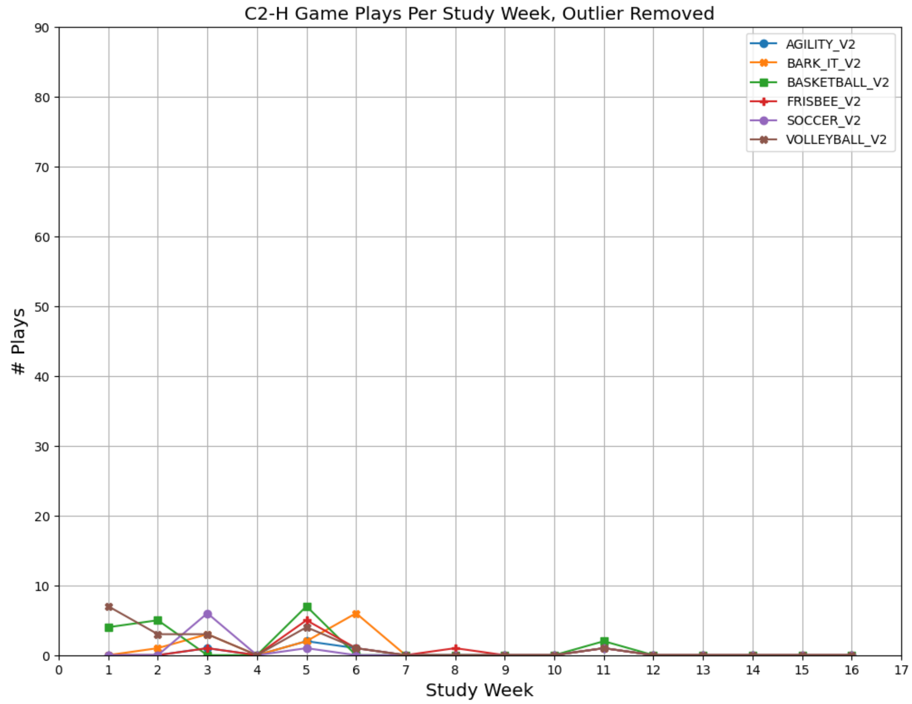


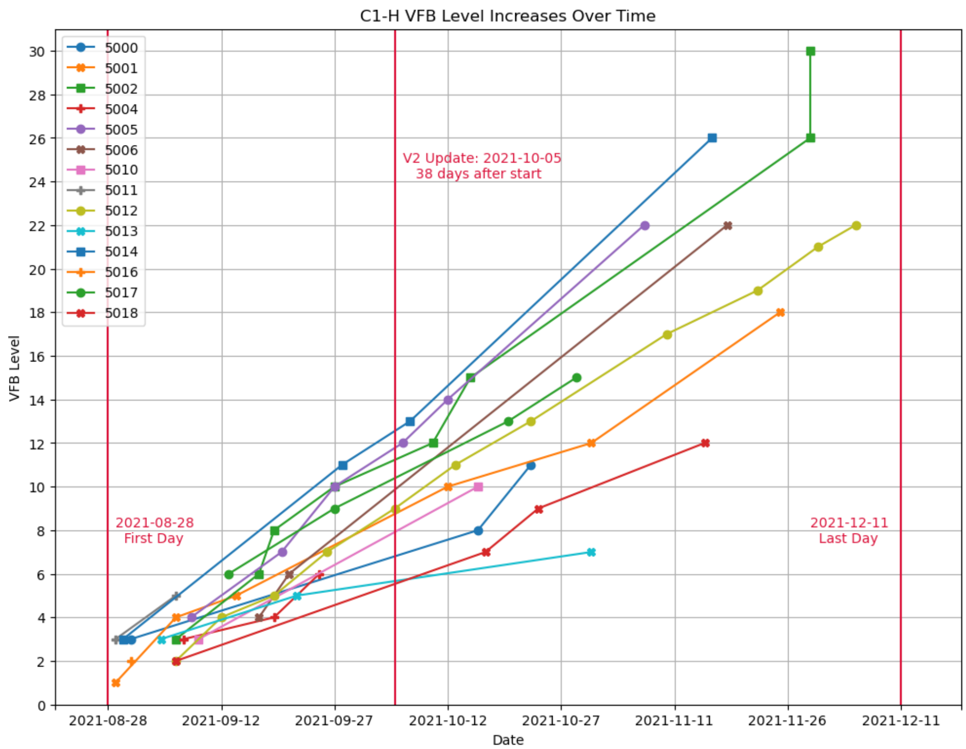
Figure 5.30: Graph depicting the number of game plays for each game each week for C2-H with the gameplay outlier removed.

5.6.3 VFB Level Increases

The dataset used to examine VFB level increases is not the same data set as the previous one. While there is overlap, this data set includes participants from both cohorts who had their VFB's level increase at least once. This captures most of our participants as a level increase occurs immediately following VFB creation to set its initial level. Lastly, participants are grouped together into their family units as when the VFB level increases for a single member, it increases for their entire family.

As previously mentioned, each game unlocked at a different level. This may contribute to the differences in relative gameplay metrics. Figures 5.31 show VFB level increases by family for C1-H and C2-H respectively. Depicted in these figures are three red, vertical lines depicting the start and end dates for each cohort with a week removed from the start given that participants did not have access to their VFB for the first week for both cohorts. The third vertical line depicts 38 days after the earliest start time for each cohort. This line corresponds to the V2 update C1-H received on October 5, 2021, with the equivalent date (May 3, 2022) shown for C2-H. Given that all games were unlocked by level 5, this means that most participants for both C1-H and C2-H had all of the available games unlocked between 2 and 3 weeks after receiving their VFB.

Given that C1-H participants continued to level their VFB not only for a longer period but also higher levels after the V2 update compared to C2-H, it may be beneficial to consider adding additional content intermittently throughout the study as a means to sustain participant engagement throughout the course of the study.



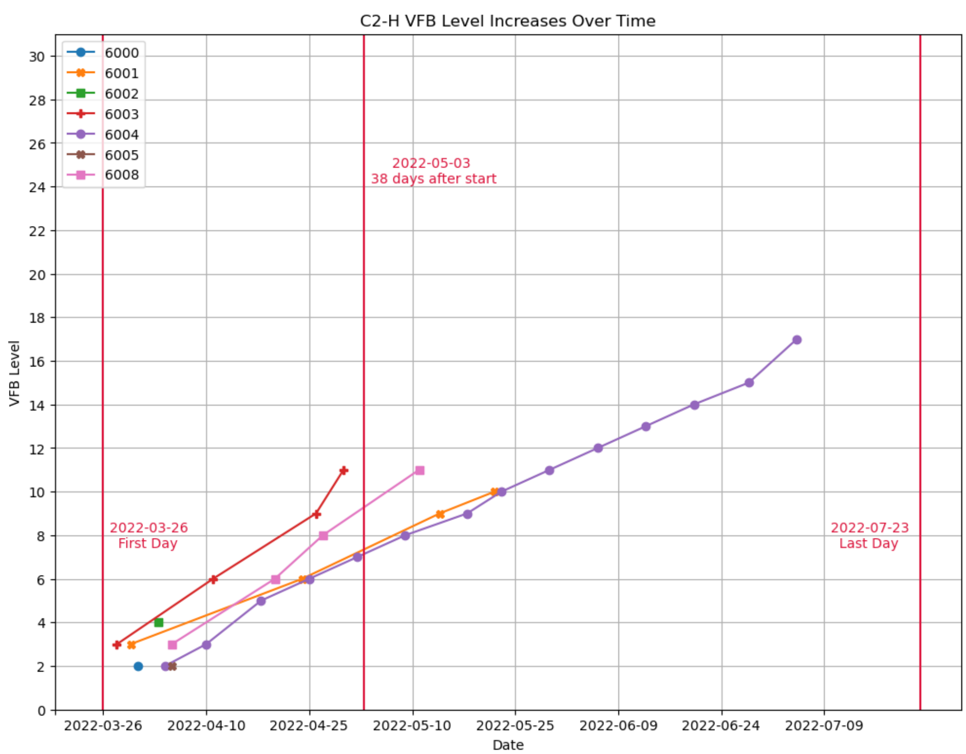
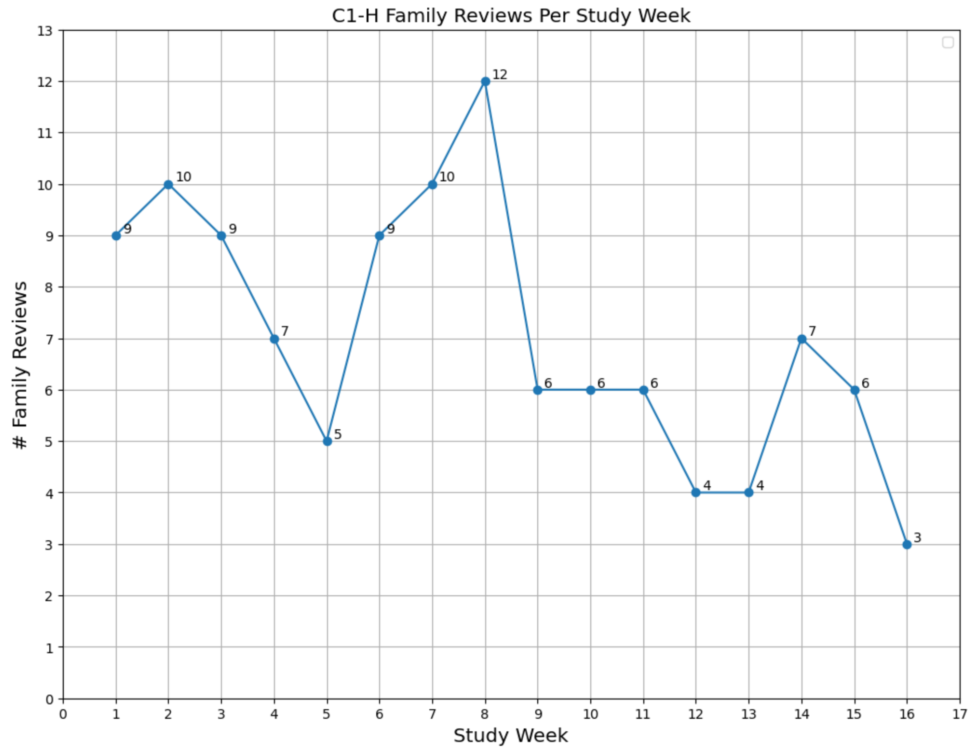


Figure 5.31: Graphs depicting VFB level increases over time for C1-H (top) and C2-H (bottom). The red vertical lines represent the earliest start, the V2 minigame update for C1-H or its equivalent for C2-H, and the latest end date for this cohort.

5.6.4 Family Reviews

In order for the participants to be able to increase the level of their VFB and, thereby, to unlock more games and earn more points, they needed to complete a family review so that their physical activity (PA) data would be applied to their VFB. The family reviews were intended to be used for the family to assess and discuss their physical activity (PA) data. We anticipated each family would complete a family review once per week. However, as shown in in Figures 5.32, this was not the case given that there were 16 families in C1-H and 9 in C2-H, that goal was never met. Although, C2-H did have eight family reviews during the first week. As with our other metrics, family reviews also saw a decrease over time.

Figures 5.33 the number of family reviews for each participant family per week, where a solid bar connecting weeks denotes that there was at least one family review each week contiguously. Family 6004, which contained our gameplay outlier mentioned earlier, had the most weeks with a family review for C2-H, which may be a contributing factor as to why they played more games than every other participant in their cohort combined. The same does not hold true for C1-H as the participant with the most gameplays was a member of family 5012. In fact, family 5001 was amongst the families with the lowest play time and game plays. Thus, by simply looking at the quantity and overall timing of family reviews, this seems to indicate that quantity nor consistency of family reviews relate to the quantity of time played nor game plays. However, given that many participants had all of the games unlocked by the third week of the study, there may not have been time for the consistency of family reviews to impact gameplay as they already had everything in that regard.



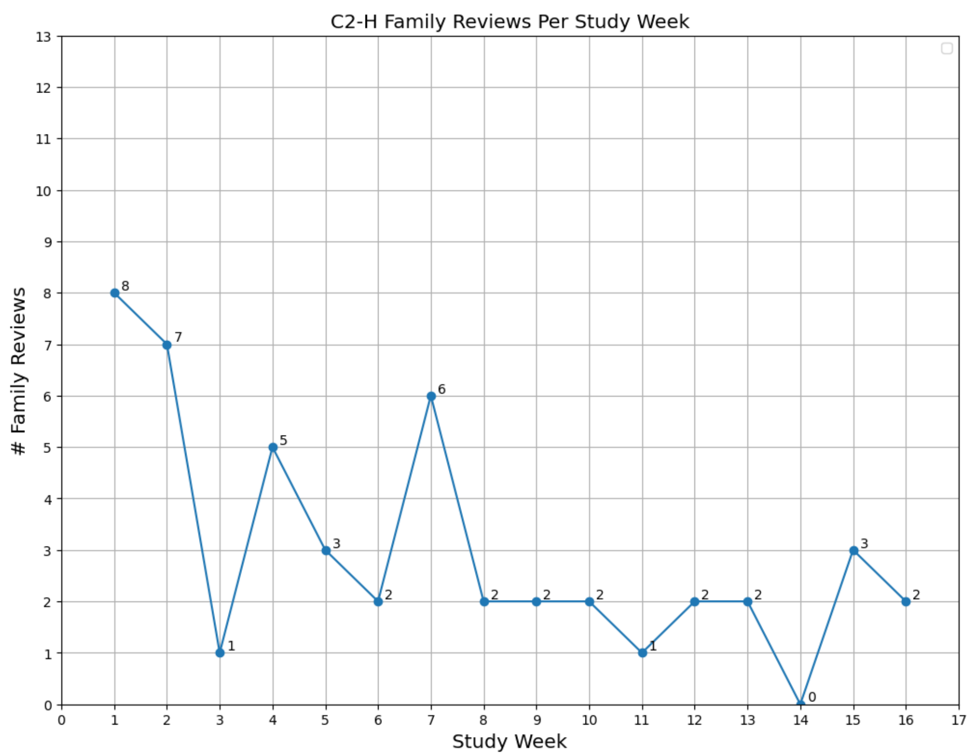
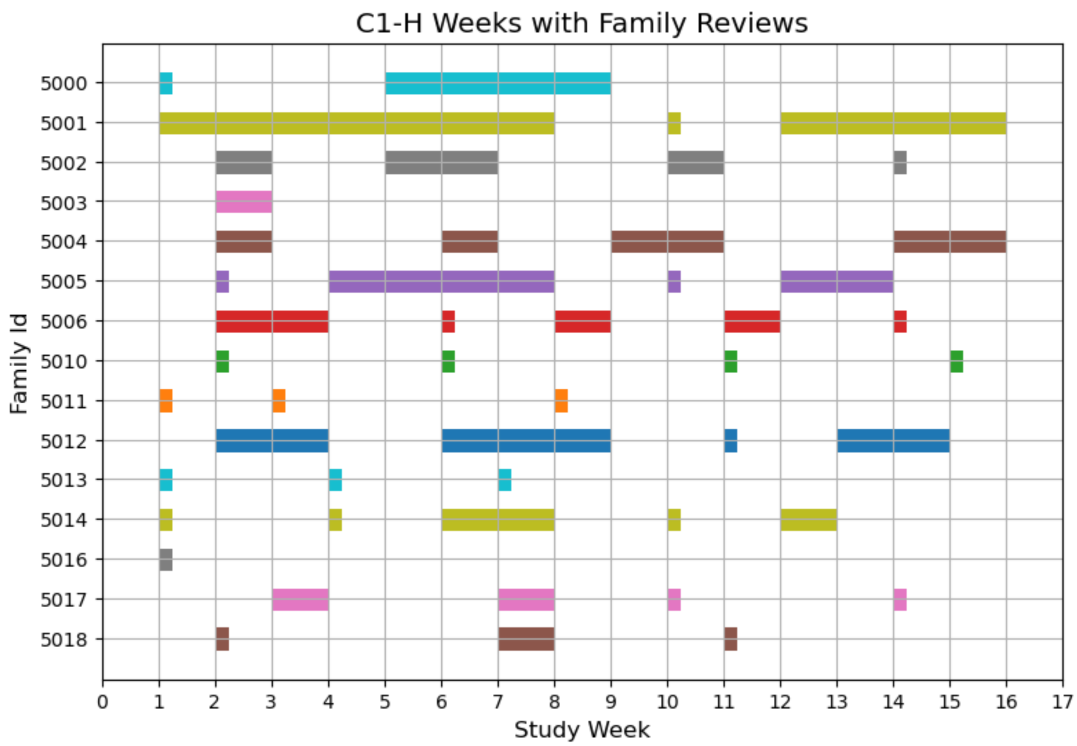


Figure 5.32: Graphs depicting the number of family reviews each week for C1-H (top) and C2-H (bottom).



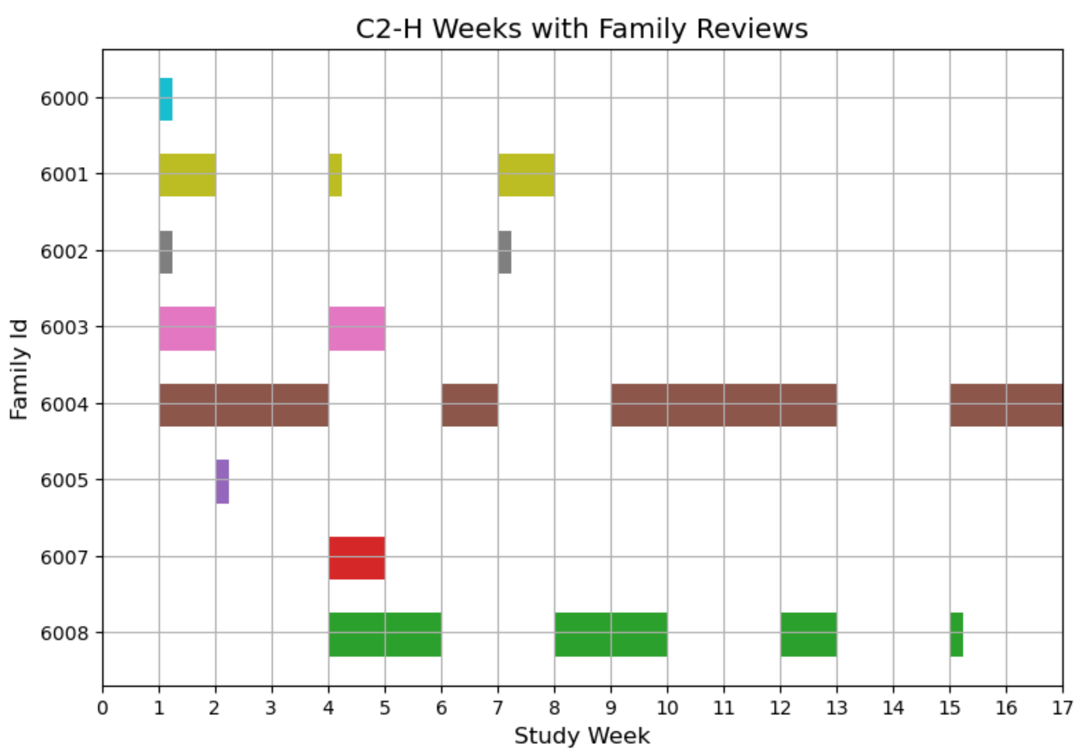


Figure 5.33: Graphs depicting the weeks with at least one family review for C1-H (top) and C2-H (bottom). A contiguous bar represents weeks where family reviews were completed during consecutive weeks.

Lastly, a Spearman's correlation was run to determine the relationships between quantity of family reviews and any of the previous stats discussed, such as number of level ups and play time per day. Figure 5.34 depicts the results of this correlation as a heatmap with the significance results for family reviews in Figure 5.35. There were strong, positive correlations between the number of review days and most of the other metrics except for login days. Of those, max level ($r=.70$, $n=25$, $p<.01$), number of level ups ($r=.86$, $n=25$, $p<0.001$), plays per day ($r=0.77$, $n=25$, $p<0.01$), and play time per day ($r=.71$, $n=25$, $p<.01$) are significant. All of this seems to indicate that there is a relationship between family reviews and interaction with the VFB system that needs to be explored further. The relationship between number of family reviews and level ups also seems to indicate that individuals who did complete a family review tended to level up, which was to be expected. The reverse is always true as a level up could not happen without a family review. However, there are at least two conditions in which participants could complete family reviews without leveling up their VFB. The first is simply not meeting the required physical activity necessary to reach their VFB's next level. The other is that they never logged into the VFB system again but continued to complete family reviews. As indicated in previous sections, we do have participants that did not engage with the VFB system beyond the first few weeks of their cohort.

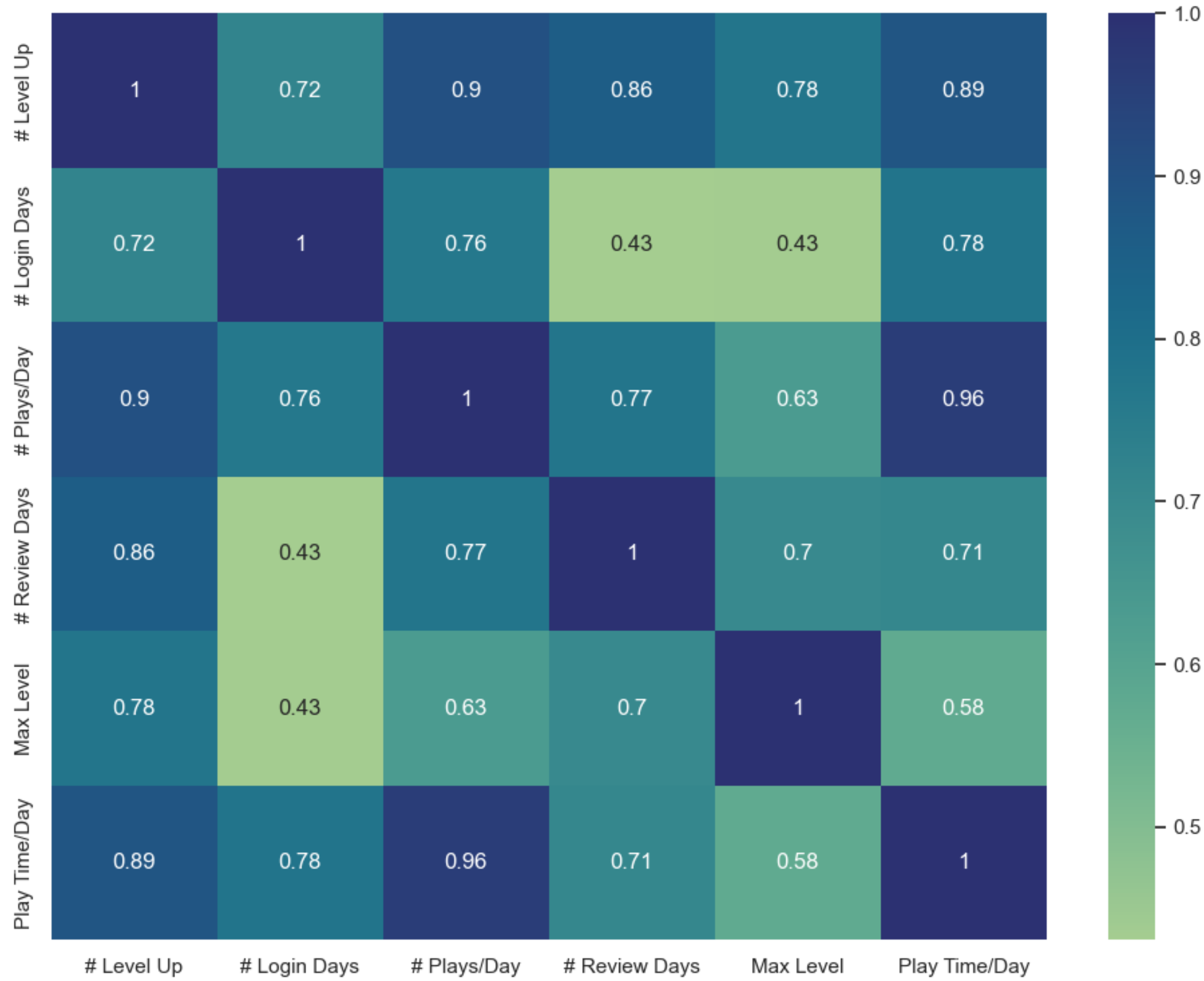


Figure 5.34: A heatmap visualization of Spearman's correlation between the number of review days and max VFB level, number of level ups, number of plays per day, play time per day, and the number of login days.

Feature	Feature 2	Correlation	p value
Max Level	# Review Days	.7008	.0052
# Level Up		.8619	.0001
# Plays/Day		.7747	.0011
Play Time/Day		.7103	.0044
# Login Days		.4305	.1244

Figure 5.35: Spearman's correlation between the number of review days and max VFB level, number of level ups, number of plays per day, play time per day, and the number of login days for 25 participants.

5.7 Conclusions

From the C2-H results, most participants stopped playing games, completing family reviews, and leveling their VFB with over a month left still remaining in the study. In fact, no other participant leveled their VFB after late May 2022 with two months left in the study except for participant 60042. This explains why their game play metrics were so high compared to the other participants in their cohort as they continued to engage with the VFB-H system for at least a month longer than the remainder of C2-H. Similarly, only one other family had any family reviews after the eighth week of the study, which would be around mid-May 2022. Other participants did continue to play games with their VFB until the eleventh week of the study (early June 2022). Thus, it may be worthwhile to explore if there were other external factors that may have contributed to this lack of engagement during the C2-H cohort. For example, C2-H took place during Spring and Summer 2022. Prior to the end of the study, our participants started their summer break, which approximately coincided with the aforementioned time when most of the C2-H participants ceased engaging with their VFBs. Conversely, C1-H took place during Fall 2021 and concluded prior to winter break. The timing of these studies may have contributed to their overall engagement levels.

C1-H did not experience the same degree of low engagement as C2-H had. Even with the gameplay outlier removed, there were still games being played through week 14 (early December 2021) by other participants. Several participant families continued to level their VFBs almost through the end of the study. There were 11 families who continued to level their VFB beyond two months prior to the end of the study, which was when C2-H stopped having increased levels apart from family 6004. Similarly, at least 10 families continued to have family reviews after week 8 (late October 2021). Given this, it would be worthwhile to further explore why C2-H had such low extended engagement compared to C1-H.

Regarding whether or not participants tended to prefer variety in gameplay versus focusing primarily on one or two games throughout the study, both of the participants with the most plays preferred the soccer minigame. Although, they both did play other minigames throughout the course of the study with participant 60042 playing a variety of games nearly every week throughout the course of the study. All games continued to have plays through the end of the C1-H study except for bark it, which was not played after the eleventh week of the study (mid-November 2021). The agility minigame had the least number of plays throughout the study without excluding the outlier and soccer receiving the least number of plays otherwise. It may be worthwhile to revisit the agility gameplay mechanics if it is included as a game in future studies. It may also be worthwhile to explore how participants played the agility minigames utilizing additional data we collected regarding participants' virtual locomotion.

In summary, the data seems to indicate that having a variety of games to play is likely to be beneficial. Certain participants may find a particular game to be their favorite and focus on it, as was the case for participants 50121 and 60042, but overall, many of the minigames continued to be played throughout the course of the study. Even participant 60042 continued to play other games while playing the soccer minigame each week. Participant 50121 also played different games each week with soccer as the predominant game.

Lastly, the correlation data seems to point toward there being an interaction between family reviews and VFB game play metrics. As mentioned earlier, it was expected that there would be a correlation between increasing the level of the VFB and completing a family review as family reviews are required for a level up to occur. This held true as there was a strong, positive, and significant correlation between the number of level ups and number of days with a family review. There were also strong, positive, and significant correlations between the number of days with a family review and plays per day and play time per day. Thus, further exploration into the timing of family reviews and gameplay metrics may reveal more details about these relationships. This, in turn, would help inform our decision on whether to keep progress gated behind family reviews or to lax this requirement. For example, a compromise might be delaying the impact of participants' physical activity (PA) for a short while without a family review while completing a family review immediately allows their PA to improve their VFB. This way we are still encouraging the family reviews while not causing a complete standstill of VFB progress.

5.7.1 Future Directions

There is a lot more data to examine from the VFB-H data set. For example, we enabled both real-world and virtual movement systems for VFB-H and recorded this data for every session. We intended for participants to use the virtual joysticks to locomote through the virtual world with a combination of real-world and virtual joystick-based movement for rotating their view. Figure 5.36 shows our preliminary results from this data set, which only consists of locomotion data without any view rotation data. We expected participants to largely use the joystick locomotion system due to potentially restricted real-world space, which is what happened. It was unexpected for real-world locomotion to constitute over 20% of the overall locomotion as we did not design our mechanics around real-world locomotion, only real-world rotation. With both their locomotion and rotation data, we can recreate their path and gaze direction and match this movement with our event log to determine if this movement was used during a particular minigame.

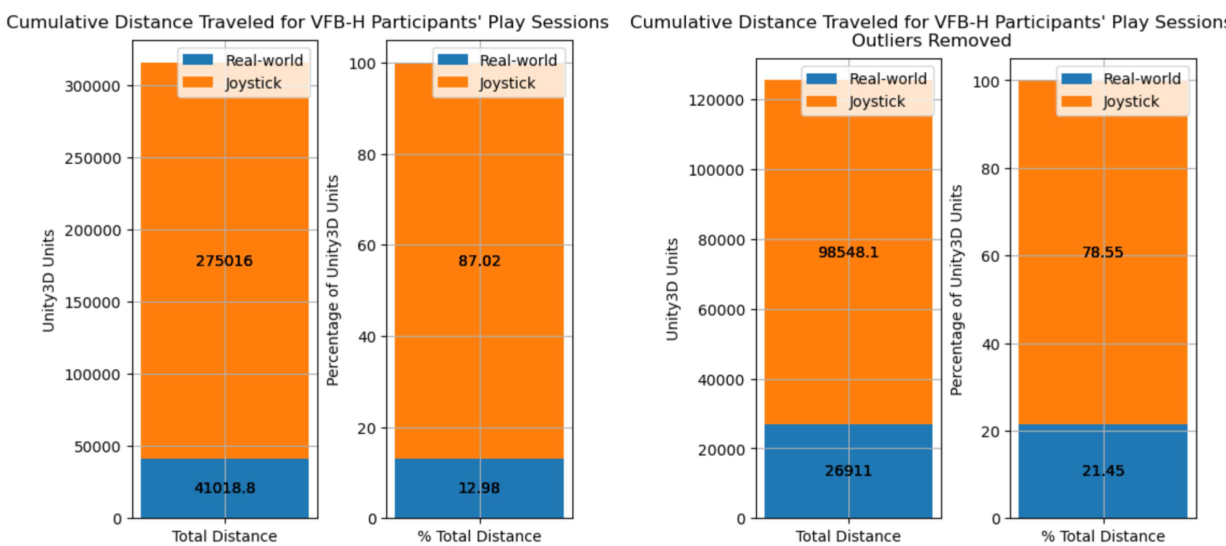


Figure 5.36: Graph depicting the relative use of real world locomotion and virtual joystick locomotion for the VFB-H study, where distance traveled is on the left and percentage of use is on the right (left). The graph on the right side depicts the same data with outliers removed. The units are "Unity 3D units".

The additional data from these studies include metrics such as how much energy participants used per play session, items they purchased, tricks they had their VFB perform, and their minigame high scores over time. We could also further explore the data from this dissertation, such as combining our knowledge of the participants who played the bulk of the games for their respective cohorts with how they moved throughout the virtual world and what other actions they performed in their play sessions. A final example would be further exploring the relationship between family reviews and VFB interactions, such as to assess whether participants generally interact with their VFB more following a family review or not.

Additionally, we had designed a few new mechanics that we were unable to implement into the C2-H VFB system. For example, given the continued engagement decline over time, we had two main categories of changes: alerts and new content. The alerts primarily targeted their physical activity data, such as alerts upon login indicating how many points and levels were waiting for them to complete a family review and another pop up to show participants the trophy or trophies they earned based on their PA since their last login. Both of these alerts are intended to indicate to participants the impact of their PA while also providing additional incentive to complete a family review. While removing the requirement of completing a family review to incorporate their PA into the VFB-H system may increase gameplay, the family reviews are still an important part to the VFB ecosystem as a whole as they provide an opportunity for participants to learn the impact of their PA throughout the week, and thus, the impact of their PA on not only their VFB's health but also their own. Thus, an approach where perhaps participants are still able to unlock minigames but not earn points to spend at the shop until they complete a family review may be more appropriate for the overall goals of this project rather than cutting their impact on the VFB-H interaction entirely.

The other category of updates included additional content for participants to unlock. As uncovered in this dissertation, many of our participants had unlocked most of the minigames rather early on in the study, leaving them with no new games or tricks to unlock for the remainder of the study. A direct way to address this, apart from extending the PA required to unlock everything, would be to add new content. This new content could include new minigames (e.g., tug of war or baseball) or new modes for existing minigames (e.g., competitive volleyball, bark it random fail mode, playing as a goalie during soccer in order to block the VFB's oncoming shots). Another avenue of increased content includes adding additional items to the VFB shop for purchase. For example, we could add the ability to customize their VFB level up or trophy animations, such as being able to select which trick appears for the highest-level trophy or additional fanfare when they level up, such as clapping or fireworks. This could also include adding new VFB and VFB toy customization options into the virtual shop.

5.8 Lessons Learned

This at-home VFB system is the first time any of our VFB system directly competed with other forms of entertainment. Previously, our studies took place in public places where our participants were not likely to have a tablet or a gaming system. As such, this is likely a contributor regarding our lower engagement statistics with these two cohorts. As we have discovered in our previous studies, we tend to have high levels of novelty effect. The novelty of our systems is an effective way to maintain engagement with our participants. Unfortunately, as we have seen, this novelty effect only supports engagement on its own for so long, which was showcased with this data set especially as engagement decreased over time, especially for C2-H. An approach to maintain engagement through this novelty factor is to introduce more content over time, which was another difference with these at-home cohorts as participants unlocked all of the minigames relatively early in the study. This meant that there was no additional content for participants to unlock for the duration of the study. Given that there are other entertainment pressures at home, all of this means that we should reconsider our approach for designing minigames and other interactions for future at-home systems.

We did learn that participants tended to play different games over time, which provides support toward adding additional content to help sustain engagement for longer durations. Interestingly, once we removed the effect of our outlier plays, Frisbee, the VFB-A equivalent of Slingshot, was the most played game for this at-home system with the Volleyball minigame also having high play time. This nearly mimics our results from the afterschool VFB system, where Slingshot, Volleyball, and Soccer were the most played games. Given the mechanical similarities between Frisbee and Slingshot and between the two Volleyball games, this would indicate that the mechanics, e.g., large targets to hit and paddle-like interactions, behind these games are enjoyed by participants. Thus, it may be worthwhile to leverage this information to design other games with these or similar mechanics.

Lastly, while engagement did decrease over time, participants still engaged with the VFB system for a time. This means that we did successfully compete with the aforementioned additional entertainment pressures in the home environment in the short term. Similar to how we learned many lessons through the course of all of our previous public space-based studies, this study is the beginning of learning new lessons with this entirely new environment. Additionally, these two at-home cohorts had vastly fewer participants than their afterschool counterparts, which means lowered engagement from these participants has a much larger impact on our outcomes. Thus, perhaps, what we considered to be game play outliers may actually be more representative of typical engagement outcomes instead of exemplary ones.

Chapter 6

Discussion of Environmental Considerations

Across the previous chapters, we have discussed the evolution of features that we designed and implemented for our Virtual Buddy (VB) systems. We have also enumerated our primary design constraints for these systems. For example, our Virtual Fitness Buddy (VFB) systems needed to have features which were relatively realistic in order to facilitate the connection between the impact of a participant's physical activity (PA) and the health of their VFB and, thus, their own. These features encompassed their VFB shrinking in size, becoming faster, and able to play longer as they became healthier due to their real-world PA. This realism constraint also applied to our minigame designs, where their mechanics should roughly parallel the capabilities of a real-world dog. These design constraints also applied to our Virtual STEM Buddy (VSB) system, where its minigame mechanics needed to be based on and utilize various STEM concepts in order to assist participants in learning these concepts and, potentially, sparking interest in STEM areas. However, we have not sufficiently explored an important design constraint: environmental conditions.

These conditions were critically important to incorporate into our system designs. If our VB systems were not suited to their respective environments, they could be difficult or even dangerous to use. This, in turn, also means that a design that worked well within a certain set of environmental conditions does not guarantee that it would work well in another context. For example, our kiosks have withstood being used by hundreds of participants across several sites simultaneously for months (the VFB systems) or even more participants across years (our museum-based VSB system). As such, we consider the robustness of these designs to be a success. However, this does not mean that our kiosk-based designs were practical for use within the VFB-H home environments. Our prior studies were conducted in environments which had sufficient open space to accommodate our motion-based gameplay, such as in the lunch room at a summer camp or an afterschool program, and to store the kiosk itself. This large amount of open space may not be available or may be impractical to accommodate in a home environment, which is why we pivoted our designs to utilize an iPad for these at-home studies instead of our previous VB kiosks. In these next sections, we will explore some design decisions that were impacted by environmental conditions.

6.1 VB Command Design

An example environmental impact on our designs would be in our decision to include an alternate method for participants to command their VFBs to perform a trick. When we installed the kiosk in the field, the environment was loud compared to our lab testing environment. This meant that it was difficult for the Kinect to hear participants' voice commands as they would be difficult to discern from the ambient chatter and bustle. In addition, participants already had to stand away from the Kinect in order to utilize the motion controls, putting them far away from the microphone. One solution could have been to provide a microphone for our participants to wear. However, this would not only add another potential point of failure to our system but it would also mean that participants would have to share a device that they could easily forget to remove, leaving other participants without the ability to interact with their VFB. Additionally, we wanted our participants to be able to walk up to the kiosk and begin interacting as quickly as possible, which meant minimizing the number of steps involved in the login process. By allowing participants to issue commands by selecting them from a menu, we were able to address the environmental factor without adding another component to maintain and ensure was available to use at the kiosk. In turn, this also meant that we did not add another task for site staff to perform for us everyday for several months. Lastly, it meant that participants would not need to setup an additional device prior to logging into the VFB system and to remember to removed once they were done interacting with their VFB.

On the other hand, when we transitioned to using an iPad for our VFB-H system, participants no longer needed to stand away from the microphone as they would be holding it. This made voice commands more practical to use. We still included the ability to initiate commands from a list. However, doing so would mean that participants would need to open the menu, select the tricks submenu, and then finally select the trick they wanted their VFB to perform. They did not need to navigate the menu system to initiate voice commands. They only needed to press the microphone button near our primary locomotion controls and say the command out loud. This, in turn, would keep them more directly engaged with their VFB, which would likely benefit our overall goals of establishing and maintaining the bond between the participant and their VFB.

6.2 Museum Exhibit Physical Space Limitation

During the Virtual STEM Buddy (VSB-M) study, our kiosk was setup around other museum exhibits. Given that our VB systems utilize body motion as their primary interaction method, we needed to ensure that participants could interact with all of the parts of the experience within the limits of our real-world space. Otherwise, participants could inadvertently hit the wall or a fellow museum-goer by going out of the designated real-world bounds. Thus, our system needed to be designed such that staying within the bounds of the exhibit happened as naturally as possible. This was achieved by scaling participants' real-world motions in the virtual world based upon the physical size of our exhibit space. Additionally, this space and the optimum location to play were marked on the floor by the museum so that museum-goers would know where to stand in order to play the minigames and where not to stand if they were not playing.

We also needed to consider the types of motion necessary to play these minigames both for safety and for ease of use as the exhibit would not have a dedicated staff member assigned to it. If our minigames required rapid movement, participants would be more likely to hurt themselves or others in this public space. If the controls were overly complicated, participants may not understand and, thus, not interact with the system. Intuitive controls that were quickly mastered were critically important for the VSB-M study as our participants would not be interacting with the system over the course of several months as they would for the VFB systems. As such, there would not be much time for our participants to learn and practice the necessary controls needed to interact with the VSB-M system before they moved onto another exhibit.

6.3 Additional Encouragement from Staff

Physical environmental factors were not the only factors that needed to be considered when assessing the viability of our designs. For example, when we visited the various sites during the afterschool VFB (VFB-A) studies, we observed site staff at different sites provided different levels of participant encouragement. Some sites provided additional encouragement to engage in PA and to wear their Fitbits while other sites did not. As a result, this additional encouragement or lack thereof could have had a greater impact on participant compliance and engagement with our system and/or could have completely obscured the impact of new features that we designed and implemented to encourage participant engagement.

6.4 Conclusions

In summary, environmental factors were important considerations as we designed our VB systems as these factors dictated what participants were able to do. While designing around a physical environment could be difficult, especially when there were many different environments each with their own unique circumstances that need to be accommodated, it was still crucial that our application was well suited for the target environment. A poor fit between application and environment could lead to participant and/or staff frustration, which, in turn, could impact study outcomes. Additionally, despite varying environmental conditions increasing the difficulty of designing these systems, it is these different conditions that made these field studies so crucial as these conditions could potentially reflect how these systems may be used outside of our research study.

Chapter 7

Conclusions

We have covered our various Virtual Buddy (VB) systems that we have developed over nearly a decade. In this time, we have learned invaluable lessons on building and utilizing these systems in the field, iterating on our previous designs with each subsequent study, which has culminated in the iPad-based, at-home Virtual Fitness Buddy (VFB-H) system, which integrates the lessons we have learned from all of the previous VB studies, such as utilizing a dedicated device for collecting integrating the data required to use the system in lieu of requiring the system itself to do so and how to design different input mechanisms to accommodate the target environment and audience to be used long-term, unassisted in the field. Some of our designed features worked well and continued to persist since their introduction, such as our primary kiosk design and our VB customizations and minigames, while other designs did not and lead to participant frustration, such as using our VB applications to sync Fitbit physical activity (PA) data or the shot zone aiming mechanics from the afterschool Virtual Fitness Buddy (VFB-A) system, which were subsequently abandoned for future systems.

7.1 Beneficial Setbacks

Some of our not-so-successful designs led us to reconsider others we had initially considered a detriment to our overall design goals. One such example is the transition from exclusively using real-world motion and mid-air based interactions without during the summer camp-based VFB (VFB-C) systems to the combined touchscreen and real-world motion interaction design that continued to be used after its introduction during the museum-based Virtual STEM Buddy (VSB-M) study. Initially, we did not want to add additional devices to our kiosk as each new component introduced another potential point of failure and was yet another component participants would need to learn how to use to interact with our VB systems. However, the inclusion of a touchscreen provided an interface that was familiar to our participants given the prevalence of tablets and smartphones both at home and in public spaces. This familiarity allowed us to design menu systems, such as the VSB customization menu, that were otherwise difficult and cumbersome to navigate with our mid-air designs as demonstrated by our 3D keyboard design from the VFB-A pilot, where the 3D buttons were either often inadvertantly hit or so far away that they were difficult and tedious to use. It was these failed designs that led us to our primary input mechanism used during the remainder of our studies.

Another important example of this phenomenon was our slingshot aiming interface designed for the VSB-M system. While participants enjoyed playing fetch with their VFBs using our initial throwing mechanic, it was difficult to use this system to aim shots, limiting the games we could implement. The VSB slingshot provided an easy to use solution to this problem as demonstrated by not only the success of our VSB Slingshot minigame but also by the successes of our subsequent VFB Slingshot and Frisbee minigames, which were among the most popular games for both the afterschool and at-home cohorts.

Thus, in summary, a frustrating design is not necessarily a failed design. They still taught us important lessons on how to design these VB systems. For example, one of lessons learned from the previous examples was that participant frustration was caused, at least in part, by lack of familiarity. Our designed solutions to these frustrations were based on concepts that our participants would more than likely be familiar with, such as touchscreens and bringing their hands together to pick up objects. This incorporation of the familiar lead us to some our most consistently successful designs.

7.2 The Virtual Buddy Kiosk

We have learned that it is not easy to design features that successfully improve and extend engagement. In fact, we found that it was easier to design a robust hardware system that ran for years without failure than it was to design successful engagement-focused features that maintained the same level of success during that same time period. Additionally, if our kiosks were not able to endure these circumstances, it did not matter how successful our engagement-focused features were as they could not utilize those features if the system they ran on consistently had issues related to hardware failure. Thus, the evolution of our kiosk design into a system which was able to run unassisted in the field for months or even years with hundreds, and likely thousands of users for the VSB kiosk, has been a critical success for our VB projects.

7.3 Minigame Preference Outcomes

However, because we were able to more quickly achieve a robust kiosk design does not mean that these engagement-focused designs were unsuccessful nor does it mean that we did not learn valuable lessons from them. While we saw engagement declines over the course of our various VFB studies, our participants have always been excited to receive their Fitbits and play with their VFBs. Additionally, there were participants who continued to engage with these systems for the duration of their study despite any of our previously mentioned difficulties and engagement declines.

From our second afterschool cohort and both of our at-home cohorts, the overall most popular games were the two based on the Slingshot minigame from the Virtual STEM Buddy system: Slingshot for the afterschool cohort and Frisbee for the at-home cohorts followed by our paddle-based minigames: Volleyball for all cohorts and Soccer for the afterschool cohort. Although, we did have a couple of participants in the at-home cohorts who vastly preferred the Soccer minigame. This seems to indicate that features of these games kept participants playing them over time. All of these minigames were likely easier to control than the others, where all Volleyball minigames and the afterschool soccer minigame utilized paddles to either maintain the longest volley streak or avoid a blocker to score a goal. The Slingshot and Frisbee minigames also did not have complex controls as participants were tasked with hitting relatively large, stationary targets from a single position. This meant participants only had to focus on hitting those targets rather than hitting those targets while running to the next throw location as they did in the at-home Basketball and Soccer minigames. While there were preferred games, most of our games continued to be played throughout their respective studies. This seems to indicate that although participants have their game preferences, they still utilized the variety of games we designed.

Thus, it does seem that participants prefer a variety of interaction options during these longer term studies and,thus, that it would be worthwhile to continue either adding additional minigames or alternative minigame modes for future VFB systems. By continuing our iterative design process, we may be able to offset the engagement declines we have seen in our studies.

7.4 Future Directions

Exploring the designs we generated for our VB studies in this and previous chapters highlights specifically what was successful and what was not in order to provide potential solutions for those with similar circumstances. However, it is the why behind these decisions and not necessarily the decisions themselves that provide broader lessons learned. Exploring the rationale behind our design decisions illustrates what factors influenced these decisions and, thus, allow us to elucidate what components of our specific circumstances impacted our design outcomes. It is this elucidation that allows us to apply our lessons learned here to our other work that may not target children or may utilize entirely different hardware than what we used for our VB systems.

7.4.1 Immersive VFB

Extending what we have learned in our decade of building VB systems, we have built another version of our Virtual Fitness Buddy (VFB) system: the Immersive VFB system (Figure 7.1). During the writing of this dissertation, we began a pilot study where participants would interact with a version of the VFB-H system adapted for the Oculus Quest 2 HMD.

Figure 7.1: An example of a VFB from the immersive VFB system.

In lieu of using Fitbit activity trackers, we are using BangleJS2 [31] watches running our custom software for physical activity (PA) tracking. These watches also allow participants to bring their VFB with them even when they are not using the HMD, revisiting this concept from the Virtual STEM Buddy system. This watch version of their VFB helps them track their progress towards their PA goals. To address the PA syncing hurdles we have had in the past, we have implemented syncing base stations that connect to the watches via bluetooth and upload their data to our servers. These stations were set up in a location where the participants congregate. This way their PA data syncs while they go about activities in the space. For future studies, we intend to send a base station with each participant to use at home. This way they do not need a dedicated smart device to sync their PA data nor do they need to wait for this data to be uploaded as it should sync in the background throughout the day.

Once again, this new input system provides opportunities to design new minigames or other experiences for our participants. For example, we have allowed participants to pet their VFB in many of our previous iterations. However, there is a visceral difference in doing so in virtual reality (VR) as compared to our other platforms. New experiences could include more up close interactions with the VFB, such as grooming them, having them roll over for additional pets, or include a trick-learning system to teach them new commands (e.g., give paw or moonwalk). Given what we have learned over this last decade, we think that this new system will further reinforce the bond between participants and their VFB given the transformative nature of VR experiences transporting users from their real-world environment to being an integral part of the designed virtual experience.

Appendix A

Minigame Unlock Information

Table A.1: The VFB-H levels needed to unlock each minigame.

Game	Level Unlocked
Agility (V2)	5
Bark It (V2)	4
Basketball (V2)	1
Frisbee (V2)	0
Soccer (V2)	2
Volleyball (V2)	3

Table A.2: The number of days each V2 minigame was unlocked for all participants.

Family ID	Agility	Bark It	Basketball	Frisbee	Soccer	Volleyball
5000	0	0	38	38	38	38
5001	38	38	38	38	38	38
5002	31	31	31	31	31	31
5004	31	31	31	31	31	31
5005	31	31	31	31	31	31
5006	31	31	31	31	31	31
5010	0	0	31	31	31	31
5011	38	38	38	38	38	38
5012	31	31	31	31	31	31
5013	38	38	38	38	38	38
5014	38	38	38	38	38	38
5016	0	0	38	38	38	0
5017	31	31	31	31	31	31
5018	0	0	31	31	31	0

Table A.3: The number of days each V2 minigame was unlocked for all participants.

Family ID	Agility v2	Bark It v2	Basketball v2	Frisbee v2	Soccer v2	Volleyball v2
5000	60	60	60	60	60	60
5001	60	60	60	60	60	60
5002	60	60	60	60	60	60
5004	0	0	0	0	0	0
5005	60	60	60	60	60	60
5006	60	60	60	60	60	60
5010	67	67	67	67	67	67
5011	0	0	0	0	0	0
5012	67	67	67	67	67	67
5013	60	60	60	60	60	60
5014	60	60	60	60	60	60
5016	0	0	28	28	28	0
5017	31	31	31	31	31	31
5018	67	67	67	67	67	67
6000	0	0	119	119	119	0
6001	119	119	119	119	119	119
6002	0	112	112	112	112	112
6003	119	119	119	119	119	119
6004	105	105	105	105	105	105
6005	0	0	119	119	119	0
6008	105	105	105	105	105	105

Appendix B

Additional Gameplay Figures

Given that some of the graphs in the main chapters use the same axes bounds for ease of comparison, additional details are lost. These are copies of some of those graphs with different axes bounds to show these additional details.

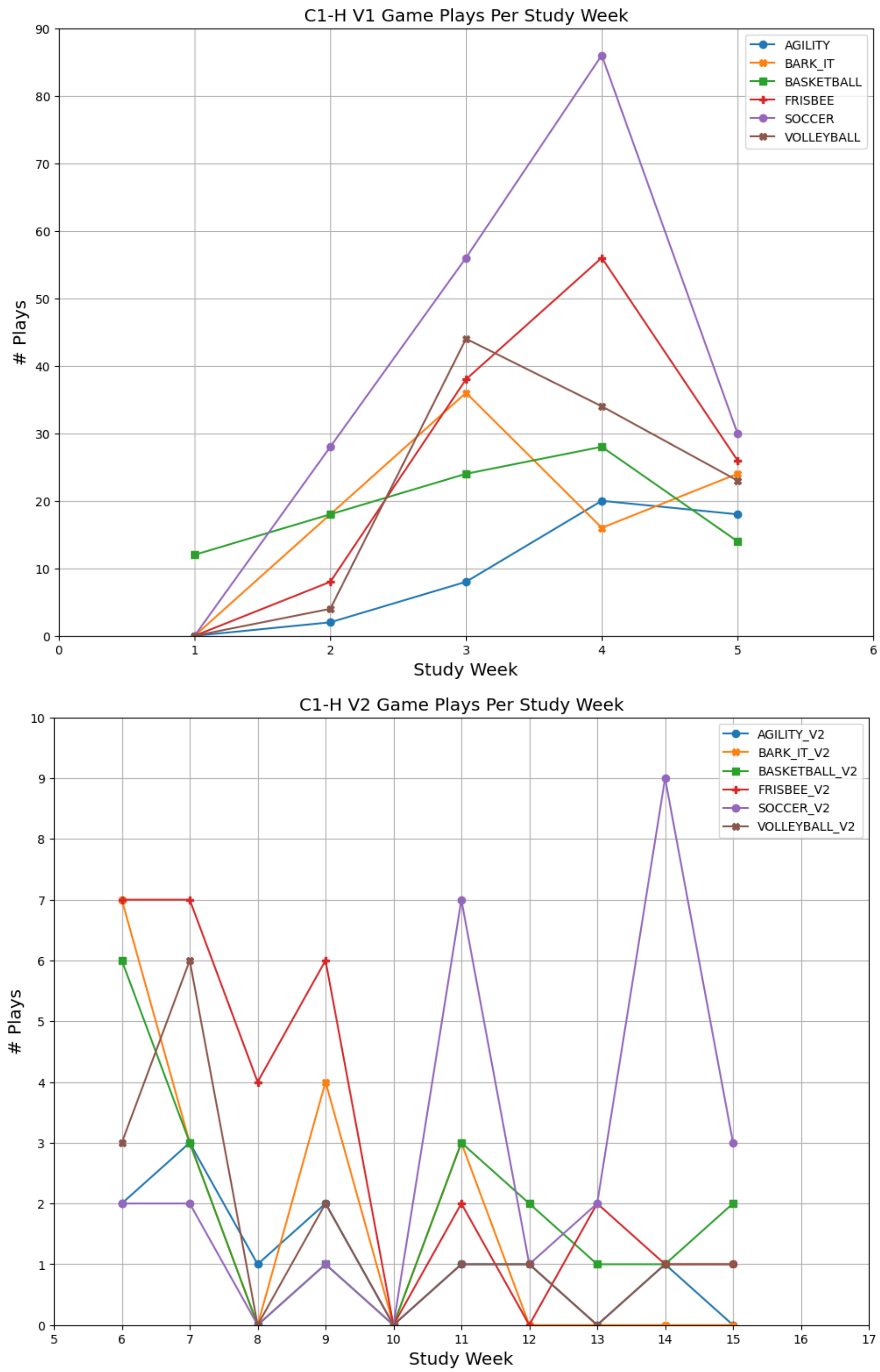
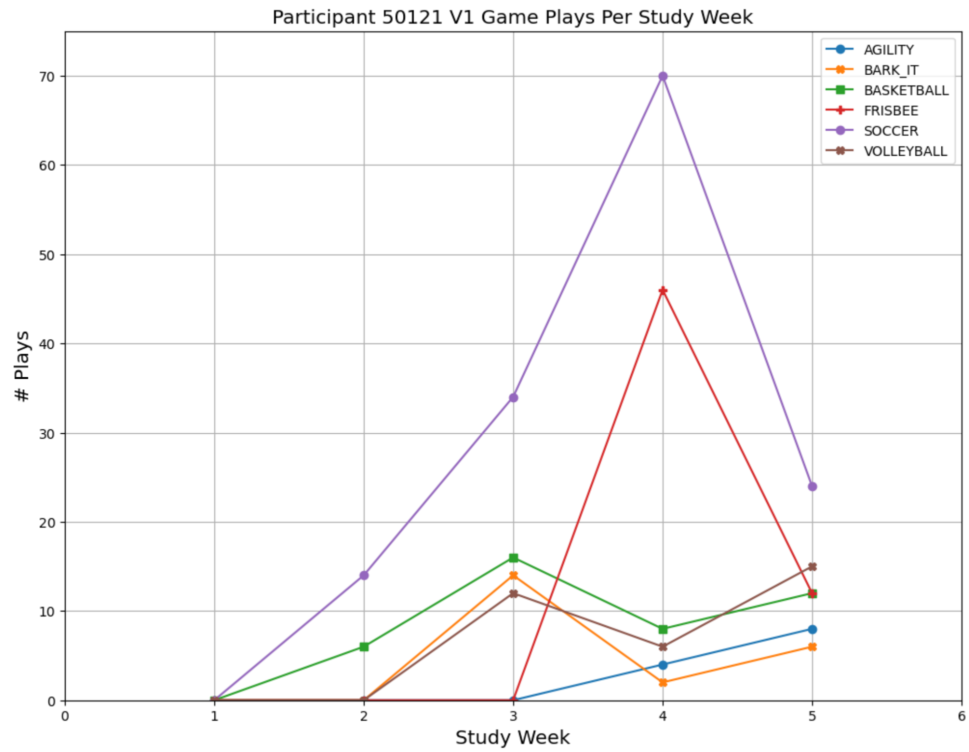


Figure B.1: Graphs depicting the number of game plays per week for C1-H V1 (top) and V2 (bottom) games. Variant of Figure 5.26.



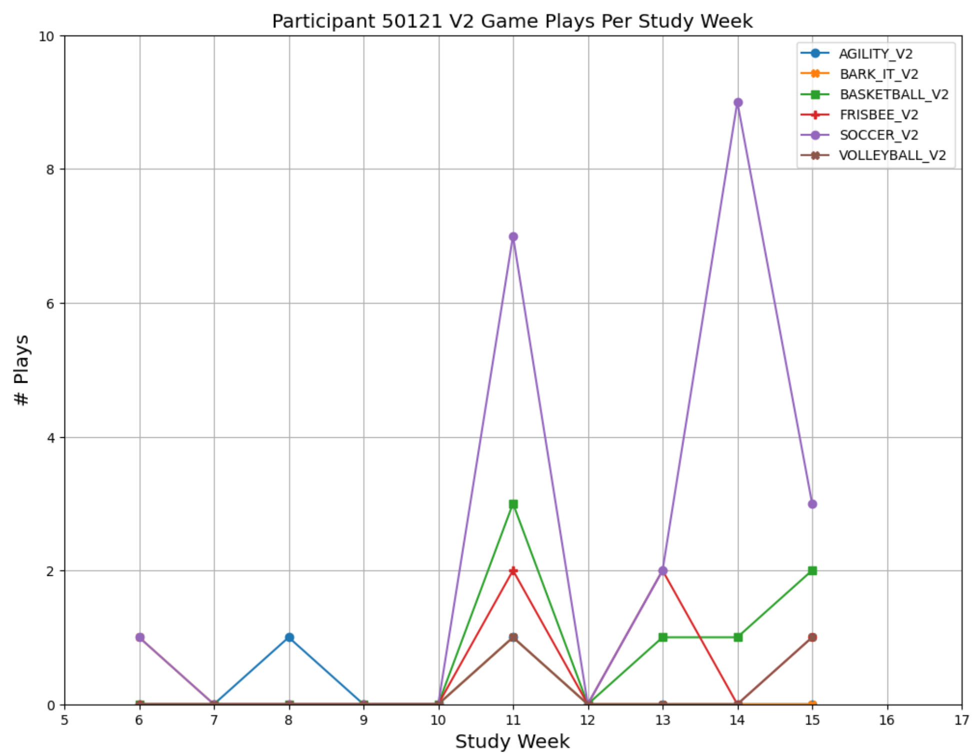


Figure B.2: Graphs depicting the number of game plays per week for the C1-H game play outlier for V1 (top) and V2 (bottom) games. Variant of Figure 5.27.

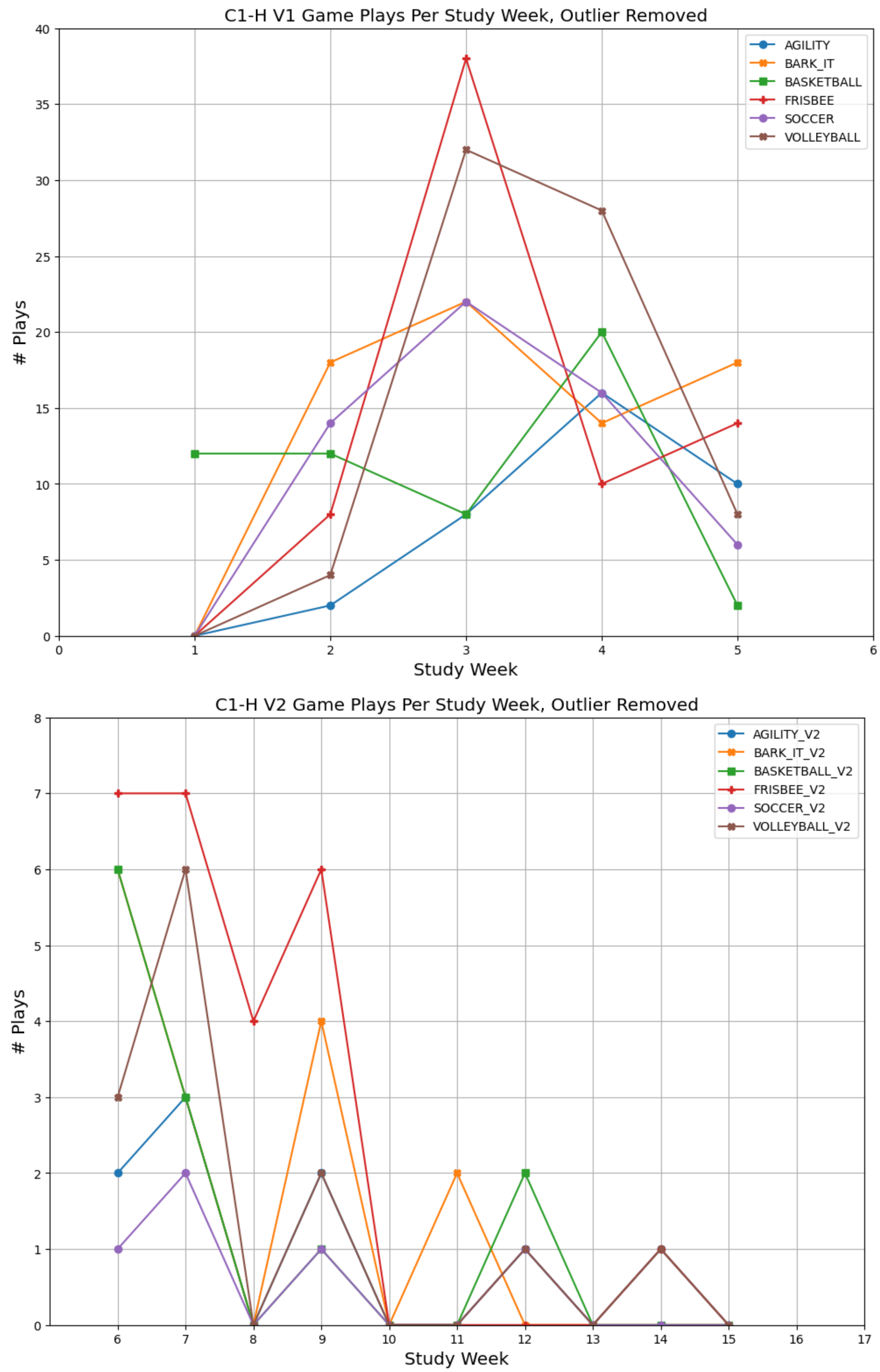


Figure B.3: Graph depicting the number of game plays for each game each week for C1-H with the game play outlier removed for V1 (top) and V2 (bottom) games. Variant of Figure 5.28.

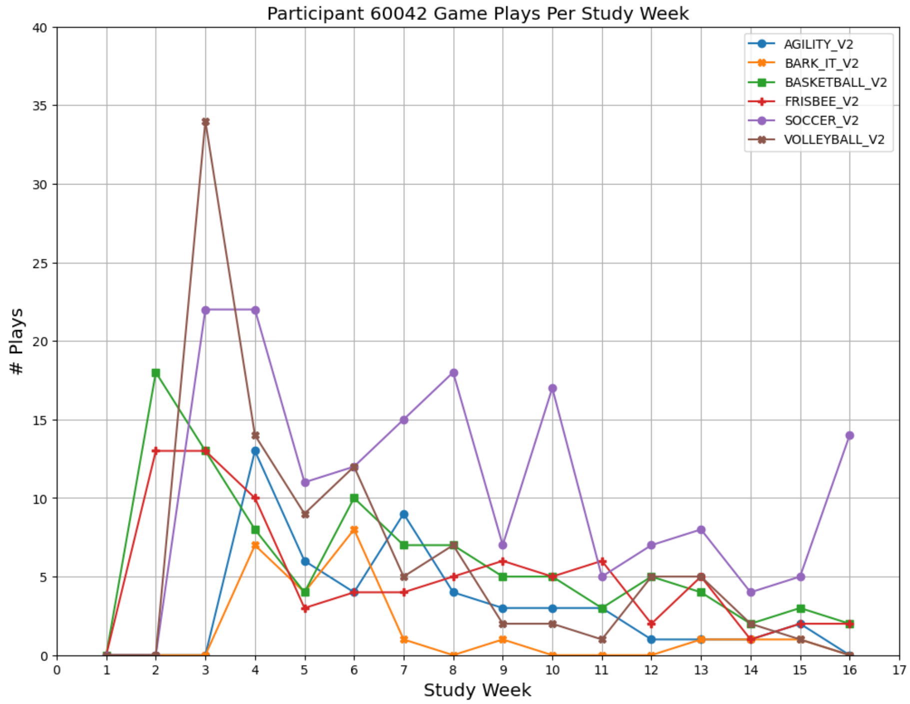


Figure B.4: Graph depicting the number of game plays for each game each week for the C2-H game play outlier. Variant of Figure 5.29.

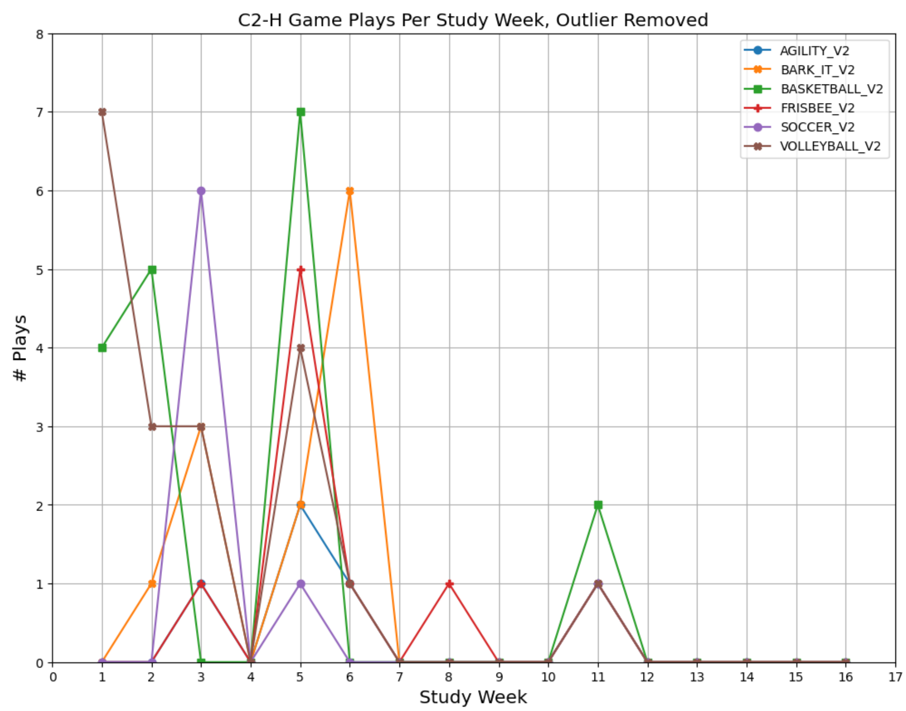


Figure B.5: Graph depicting the number of game plays for each game each week for C2-H with the game-play outlier removed. Variant of Figure 5.30.

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