The Effect that Mismatch from Preferred Camera Controlled Y-Axis Mapping has on Performance in First Person 3D Virtual Environments

by

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Abstract

First person camera controlled 3D virtual environments, such as those utilized in video games, virtual simulations, virtual worlds, and serious games, continue to grow as a popular method for providing educational experiences. The method of interaction for manipulating the y-axis of the first person perspective camera in a virtual environment is subject to a phenomenon of preference between a normal and an inverted mapping of the controller. The goals of this study are to 1) determine the effect that y-axis mapping mismatch to user preference has on performance, and 2) determine whether or not there is a performance difference between those who prefer normal or inverted mappings while using their preferred or non-preferred mapping. Participants (N=139) completed a target selection task as well as a target following task in a 3D virtual environment using both their-preferred and non-preferred mappings. Performance measures for response time and accuracy were measured while controlling for covariates of age, previous exposure and previous experience with video games, spatial ability, and eye-hand coordination. Hierarchical linear modeling was used to analyze the performance data of this repeated measures design. Results indicated that during the target selection task, when forced to use their non-preferred mapping, users did not perform significantly better or worse with respect to accuracy but did perform significantly worse with respect to response time. They also indicated that during the target following task, while forced to use their non-preferred mapping, users performed significantly worse. The results also suggest that those who preferred the normal mapping performed better than those who preferred inverted, but the results were limited by an imbalance in group sample sizes. The findings can be extended to affect the understanding of conceptually similar applications such as construction equipment, robotics, user interface or menu navigation, and even modern remotely controlled robotic surgical tools.

Preface

This thesis is an original work by Erik deJong. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, Project Name “Y-Axis Mismatch In First Person 3D Virtual Environments,” Pro00077790, Feb 24, 2018.

Acknowledgments

This thesis represents a significant portion of my life both directly and indirectly. I am a product of my experiences and the choices I have made along the way. The continued pursuit of educational endeavors has been one of the greatest choices I have ever made in my life, one that will continue to guide me long past the completion of this document. I am thankful for everyone who has helped me bring this thesis to fruition, specifically Qi Guo, Peter Sterling, and my most excellent supervisor, Dr. Patricia Boechler.

Of course, there is no amount of thanks that can be sufficiently given to all the friends and people in my community who helped me along the way, directly or otherwise. Similarly, I am nothing without my family. I owe much of what got me to this point to my parents, John and Johanna de Jong, and I will continue to thrive on the unwavering support of my loving partner in life, Joanne.

That said, after spending considerably more years in post-secondary education than I ever did in *primary education,* this thesis also represents the end of an era—I'm done… *for now.*

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Introduction

Virtual environment (VE) use has seen considerable growth in both commercial and educational contexts through recent decades (Reisoğlu, Topu, Yılmaz, Yılmaz, & Göktaş, 2017). Their use and prevalence in these venues are limited only by the imagination and creativity of the designers and developers that utilize them. From video games, persistent online virtual worlds, virtual simulations, to digital serious games, the possibilities for new and interesting learning opportunities and experiences continues to grow and expand. Much of the available research has confirmed the value of authentic experiences, both for commercial and educational purposes (Gregory, Scutter, Jacka, McDonald, Farley, & Newman, 2015; Hew & Cheung, 2010; Seymour & Røtnes, 2006; Steils, Tombs, Mawer, Savin-Baden, & Wimpenny, 2015; Wang & Burton, 2013). Whether realistic or imagined, virtual environments can transport users to places that they would never be able to visit otherwise, to have experiences that they would not—or could not—otherwise have. The power, then, of a virtual environment as a tool for learning becomes apparent to educators as a means for providing learning experiences beyond the physical classroom. But, as Wang and Burton (2013) have shown, the idea of virtual environments used for learning has become so accepted by educators and students alike, that the next step in research is to now focus more specifically on the details which can determine how they can be more effectively developed and utilized so that their value is not squandered.

There are, of course, challenges when creating authentic experiences that are as valuable for users to interact with as they are enjoyable. Research into the development of three dimensional (3D) virtual environments specifically, has identified some of the following generalized challenges: technical constraints experienced by users or developers (Abersold, 2016; Coban, Karakus, Gunay & Goktas, 2015), the expertise required to develop a VE being beyond that of a typical educator (Kluge & Riley, 2008), high costs associated with development (Adams, Margaron, & Kaplan, 2012; Kerr, 2006; Torrente, Moreno-Ger, Fernandez-Manjon, & Sierra, 2008) as well as the difficulties in developing realistic and believable objects for users to interact with, which has been found to be a requirement for simulation training software (Seymour & Røtnes, 2006). The challenge identified by this study focuses very specifically on a particular element of VE development, namely, the method in which perspective or camera control is ultimately given to a user when interacting with a first person 3D virtual environment. This research considers the previous research of Dardis, Schmierbach, and Limperos (2012), who found that when interacting with a driving simulator using two different methods of control, one less natural than the other, users experienced different levels of object recall ability with respect to the elements in the virtual environment. Also, the previous research of Frischmann, Mouloua, and Procci (2015) who found varying levels of user presence and frustration when experiencing a first person 3D virtual environment while being forced to use a non-preferred method for controlling the camera perspective. While it may seem that the control of something as simple as camera perspective shouldn't be given more than a surface level of consideration, one could speculate that it might undercut the learning potential of that environment if the control of said camera hindered the user in any way which could negate the intended positives of the environment all together.

The first person camera perspective is one of the more common ways in which 3D environments are represented to the user. This perspective is meant to represent, on the screen, what the user would see with their own eyes if they were to inhabit the environment in which they are interacting. While 3D virtual environments are relatively uncommon in the educational realm when compared to the remarkably large market of consumer video games, when it comes to video games, 3D virtual environments that present a world from the first person perspective are some of the most commercially popular (Jones, 2019). In fact, their prevalence in the market has become so vast that an entire genre of video games is commonly referred to using an aptly named category: “First Person Shooter,” or “FPS.” FPS games had their genesis following the release of Wolfenstein 3D (id Software) in 1992. Since then, video games that utilize the first person perspective have seen many of the principles that were pioneered by early FPS games (e.g. view and control) become standards of the genre. These principles have even been adopted in educational or non-entertainment gaming venues, such as training simulators and, more recently, serious games, which have seen dramatic growth in recent years (Mayer et al, 2013).

Typically, control of the camera in a first person perspective 3D virtual environment is limited to one control device or one part of a control device. Through the control device, a user may manipulate the pitch and yaw of the camera’s perspective about the y-axis and the x-axis, respectively. However, a difference in preference has separated users into two distinct camps with respect to the y-axis specifically. Some prefer an upward motion of the control device paired with an upward change in pitch of the camera about the y-axis. Others prefer the opposite, an upward motion of the control device paired with a downward change in pitch of the camera along the same axis. This study is particularly interested in that difference in preference. Because this difference has become so commonplace among users, the ability to customize the control “has become a ubiquitous component of gaming since the introduction of [3D] environments” (Frischmann, Mouloua, & Procci, 2015, p. 1792). Many modern video games that are played from the first person perspective allow the user to simply flip a switch or change a setting to have the control of the camera change between “normal” or “inverted” y-axis. However, there has been very little research done to understand not only why some people prefer one over the other, but also what is lost if a user is forced to switch to their non-preference. This is an important avenue of research because while video game software often allows users to switch the control, that option is not necessarily available in virtual simulations, real-world devices or educational applications with similar control schemes.

The focus of this study is the measurement of performance when users are forced to use the style of y-axis camera control that would be considered their non-preference in a first person 3D virtual environment. The basis for the study relies heavily on psychological literature, particularly performance and learning (Munn, 1962; Stagner & Kowroski, 1952) in the psychomotor domain (Harrow, 1972). It also draws on literature from the field of neuroscience, particularly visuomotor adaptation (Cunningham & Pavel, 1991; Stratton, 1897a) which strongly informed the methods and analysis of this study. The study begins with a literature review of the psychological and neuroscience literature relevant to the topic. In addition, a review of the pertinent methodological literature will precede the description of the methods and results of this study. While this study involves video game-like scenarios, virtual environments, and tasks, it is important to note the findings have implications for virtual environments that are designed to promote learning, especially those which can be found in video games, virtual simulations, education based virtual worlds, serious games, and the like. The findings can be extended to affect the understanding of any number of other scenarios where controls that are conceptually similar are used including construction equipment, emergency response robotics, user interface or menu navigation, and even modern remotely controlled robotic surgical tools. As Frischmann et al. (2015) state in their previous study of Y-axis preference, “any application wherein a user must provide input into a system directing the movement of some object or environment can benefit from a greater understanding of this gaming application. The goal is simply to better understand the way a person views the relationship between their inputs and the resulting change of another object in space, whether that space is real or virtual" (p. 1792).

Literature Review

What is a Virtual Environment vs Virtual World… What is a Digital Game vs Simulation

The term virtual world and virtual environment have been used somewhat interchangeably in much of the research being presented, as well as during popular discourse. Unfortunately, this is done erroneously. While it may seem that the two terms are synonymous, there are some important differences in the two constructs that they represent and using the labels without considering those differences could lead to false assumptions made by both the researcher and the audience. Add to that, further confusion with terms like video games, serious games, or simulations, all being used in similar contexts and the level of confusion experienced by the reader has the potential to increase. It is therefore important to develop a definition of terms, so as to ensure the researcher and the readers have an equal understanding of that which is being discussed or argued.

In 2008, Ralph Schroeder, of the University of Oxford's Internet Institute, submitted an argument for a common definition for both a virtual world and a virtual environment. Schroeder (2008) argued that such a definition was important because it would serve to help guide research and "set the social implications of virtual worlds or virtual environment technology aside from other ones" (p. 2). He continues that even the word virtual itself is used in popular discourse erroneously, as an adjective to describe anything being used online. This error has led to cases such as the term for 'virtual money' being used to describe both an electronic transfer of funds as well as the currency being traded *within* virtual world programs such as Second Life (Linden Lab, 2003) or World of Warcraft (Blizzard Entertainment, 2004). Similarly, the term 'virtual identity' could be used to describe both the collection of different identifications used to verify someone in the online space for online commerce or online government registration as well as the identity that a person might assume when using a virtual environment as part of a larger role playing game or experience as part of some level of escapism. Clearly, these are examples of similar terminology referring to very different constructs but using the same term to describe both could inadvertently lead to some very different conclusions for audiences. Thus, in an attempt to mitigate any level of similar confusion with the terms virtual world and a virtual environment, Schroeder (2008) offers up the following explanation:

> The difference between virtual reality or virtual environments as against virtual worlds is that the latter term has been applied to persistent online social spaces; that is, virtual environments that people experience as ongoing over time and that have large populations which they experience together with others as a world for social interaction. (p. 2).

This is supported by Bell (2008) who used a number of previous, informal, definitions from the literature in this field to come up with the definition of a virtual world as "a synchronous, persistent network of people, represented as avatars, facilitated by networked computers" (p. 2)

In essence, a virtual world is a *type* of virtual environment. A virtual environment, however, is not necessarily a virtual world. The difference being the persistence of the environment and the ability of others to interact with it when the user is not experiencing it. Virtual environments are the root term used to describe the virtual space where a user is able to enact some type of experience.

Of course, virtual environments can be used for more than just virtual worlds. Video games (aka digital games) also take place in virtual environments, as do virtual simulations and the relatively newer phenomenon of serious games. These terms, and the concepts they represent, have become increasingly prevalent in educational research as their use in the field has continued to grow. However, unlike the terms used to describe a virtual world vs a virtual environment, features that differentiate a video game from a serious game, for example, are relatively more well defined (Susi, Johannesson, & Backlund, 2007; Zyda, 2005). This is also true for the differences between virtual simulations and digital games (Sauve, Renaud, Kaufman & Marquis, 2007; Pratt & Spruill, 2011). To ensure that there is little confusion as to what features represent which construct, a review of the literature was completed and summarized into Table 1.

The feature differences presented were sourced directly from the literature and are listed in no particular order. Features that were described as crucial to defining the construct are listed with a “Yes” or “No.” For example, video games/digital games are described by Pratt and Spruill (2011) as being primarily designed to entertain, whereas virtual simulations are not. If a feature was not considered to be crucial but sometimes a possible characteristic of the construct, it was marked as “optional.” For example, Zyda (2005) described the possibility of serious games to have a fictitious, whimsical, or artificial premise like that of a video game/digital game, acknowledging that there are also serious games that are grounded in reality. As the list of defining features being described in the literature began to grow, it became clear that certain features, although not overtly mentioned by a particular work, could be inferred for each of the constructs when the works were considered as a whole. For instance, while Zyda (2005) asserts that serious games are a *type* of video game/digital game with some distinguishing features, the author does not make a direct comparison of features to those of a virtual simulation. Concurrently, however, Sauvé et al. (2007) make a number of comparisons that directly differentiate a video game/digital game from a virtual simulation. It is therefore possible that

Table 1.

Feature comparison of virtual worlds, digital games/video games, virtual simulations, and serious games

Feature	Virtual World	Digital Game/ Video Game	Virtual Simulation	Serious Game
Facilitated by Computers (ie. not a real world activity)	Yes [3][8][9]	Yes [3]	Yes [3]	Yes [ext]
Users Represented by Avatars (representation must have *agency*)	Yes [3][8][9]	Yes [3]	Optional [inf]	Yes [inf]
Persistent and Synchronous (Experienced by all at the same time, and exists when users are not connected)	Yes [1][3][8][9]	Optional [inf]	Optional [inf]	Optional [inf]
Designed to Entertain	Optional [inf]	Yes [4]	No [4]	No [5][7]
Designed to Train or Educate	Optional [inf]	No [4][5][6]	Yes [4]	Yes [5][6]
Has a Player or Players	Yes [inf]	Yes [2]	Optional [inf]	Optional [inf]
Fictitious, Whimsical, or Artificial Premise	Optional [inf]	Yes [2][4][7]	No [2][4]	Optional [6]
Conflict/Cooperation (Users against one another, or opposing a force together)	Optional [inf]	Yes [2][4]	Optional [4]	Optional [inf]
Rules (Clear, organized, complete, pre-set, and agreed upon)	Optional [inf]	Yes [2]	Optional [inf]	Yes [inf]
Goal(s) (Predetermined: how to win/lose, or otherwise end the experience)	Optional [inf]	Yes [2]	No [inf]	Optional [inf]
Model of reality, defined as a system (Model is dynamic, simplified, and a valid representation of reality so that skill developed within may transfer)	Optional [inf]	Optional [inf]	Yes [2][4]	Optional [inf]

[1] Schroeder (2008), [2] Sauvé et al. (2007), [3] Bell (2008), [4] Pratt & Spruill (2011), [5] Susi et al. (2007), [6] Zyda (2005), [7] Michael & Chen (2006), [8] Girvana (2013), [9] Bartle (2010), [inf] inferred.

some of the distinctions made between serious games and video games/digital games from one author can be *inferred* to differentiate serious games from virtual simulations by another author. These items are listed with an “inf” to identify them.

For the purposes of this study, we will be referring to research that has been conducted in virtual environments that may or may not also be virtual worlds, video games/digital games, virtual simulations, or serious games. Clearly there are several characteristics that differentiate the different constructs; however, this study aims to be all encompassing, as all of the constructs defined in Table 1 take place *within* a virtual environment. Rather than be exclusionary, and limit the study to a single construct, the study was conducted entirely in a virtual environment to test the single phenomenon of camera control related to controller use, thereby allowing the findings to be applicable to all of the related constructs. As a result, the implications of this research are potentially applicable to any activities which make use of a controller within a virtual environment. For ease of language, then, where possible we will refer primarily to whatever context is being discussed solely as a virtual environment, and refer only to a virtual world, video Game/digital game, virtual simulation, or serious game, specifically, when it is important enough to acknowledge the distinction.

3D virtual environments (What is “3D?”)

When referring to a three dimensional (3D) virtual environment, it is important to note that, in the context of this study, the user experiences the virtual environment entirely through a standard computer monitor. 3D graphics being rendered on two dimensional (2D) screens for consumer and educational use have become commonplace since the mid 1990’s (Luebke & Humphreys, 2007). “The task of any 3D graphics system is to synthesize an image from a description of a scene… for real time graphics” (p 96). Information is stored in the system which maps out objects in the scene and projects it on a virtual film pane that is displayed to the user on the screen. As a result, the user experiences the scene as a two-dimensional (2D) *representation* of a 3D environment, as there is no real depth being displayed to the user on a standard computer monitor or television. The environment will be represented to the user in real time, meaning that when the user is given the ability to manipulate the perspective of the camera on the virtual environment, the representation of the environment on the 2D screen will change accordingly and immediately.

It is also important to differentiate the 3D environments being represented on a standard monitor, so-called non-immersive systems (Sharples, Cobb, Moody, & Wilson, 2008), from technologies like virtual reality (VR) systems and augmented reality (AR) systems. The reason it is important to distinguish them lies in how the virtual environment is presented to and viewed by the user, as well as how the user interacts with or manipulates their perspective of the virtual environment, which is quite different. Virtual reality, or immersive VR systems (Bower & Sturman, 2015; Sharples et al, 2008), is a somewhat all-encompassing term that has grown in popularity in literature and popular culture which typically refers to wearable, head-mounted, technologies designed to immerse the user in a virtual environment. Consumer examples include the Oculus Rift or Quest, HTC Vive, or Playstation VR. Their designs include hardware that resembles an opaque SCUBA diving mask housing the two small screens in front of each eye. The result is the representation of a 3D virtual environment that appears to the user as having depth through a process known as stereoscopy (Bowman & McMahan, 2007). Augmented reality (Craig, 2013) systems, such as the Microsoft HoloLens and Magic Leap One, have a similar hardware design to VR systems but employ translucent screens in front of the user's eyes which project virtual objects on the real environment surrounding the user rather than within in a virtual environment. VR and AR systems differ from non-immersive systems as they allow for greater field of view (FOV) and field of regard (FOR) for the user. FOV and FOR describe the size of the visual field that can be viewed instantaneously and the total size of the visual field surrounding the user respectively (Bowman & McMahan, 2007). This means that to view the same amount of the virtual environment, a user would be required to manipulate the camera perspective more often and to a greater degree while using a non-immersive system than they would using a VR system. This would make their understanding of, and performance with, the control device used in non-immersive systems all the more important. In the non-immersive 3D environment, utilizing a typical 2D monitor, the user may manipulate the view or perspective of the camera by way of a handheld control device. The view of the scene changes but the physical monitor does not move on the desk, nor does the user. In head mounted VR systems the individual monitors that are part of the head mounted hardware change the scene being displayed to the user matching the natural movement of their head in real time. Of course, with a traditional 2D monitor and control device setup in a non-immersive system, a translation of the user's commands through a handheld controlling device is required to change the perspective in the virtual environment. While handheld controllers may well be included in VR and AR systems, they are used primarily for interaction with the virtual environment, ie. interaction with virtual objects, control of a User Interface (UI), or the locomotion of an avatar within the virtual environment. The most important difference to note then, is the user of a VR system is not required to interpret a control scheme to manipulate the perspective on the environment. Because this interpretation of the controls that is required in non-immersive systems is the main interest of this study, wearable VR and AR systems were not used and all references to a 3D virtual environment refer entirely and exclusively to a non-immersive 3D virtual environment being represented on a traditional, desktop mounted, 2D monitor.

VEs and Digital Game Based Learning being used in Education

The pairing of virtual environments and Digital Game Based Learning is a powerful combination for learning, and the field of education in general, according the 2007 Horizon Report commissioned by The New Media Consortium and the Educause Learning Initiative, which further predicted that virtual worlds would be adopted throughout the field in two to three years (The New Media Consortium, 2007). The authors claimed that virtual environments were “generalized rather than contextual,” and “are applicable to almost all disciplines” (p. 18). It was also anticipated that virtual environment use in education would continue to grow as the technology was further developed and refined, with the understanding that “3D construction tools allow easy visualization of physical objects and materials, even those normally occurring at cosmic or nano scales” (p. 18). As the potential for virtual environment use in education has become more and more accepted, coupled with their increased prevalence, the study of their effectiveness has continued to grow alongside them, as researchers and entire academic institutions have continually attempted to harness this promised potential (Gregory, Scutter, Jacka, McDonald, Farley, & Newman, 2015; Hew & Cheung, 2010; Seymour & Røtnes, 2006; Steils, Tombs, Mawer, Savin-Baden, & Wimpenny, 2015; Wang & Burton, 2013). Hew and Chueng (2010) suggest that virtual worlds, specifically, may be utilized as communication spaces, simulation spaces, and experiential spaces. While the early adopter luster of virtual environment use in education seems to have worn off in recent years (Gregory et al, 2015), continued increases in integration rates relies on exploration and research regarding utilization issues to gain a greater understanding of what potential pitfalls remain as obstacles to complete adoption in the field. This is supported by Wang and Burton (2013) who assert that “research attempts that focused on students’ or instructors’ acceptance of [virtual environments] is redundant” (p. 365), as it is already clear that the technology is accepted, but that research now must focus more on how they can be more effectively utilized.

A related area of research that has growing support in education is Digital Game Based Learning (DGBL). DGBL takes place in digital—virtual—spaces, as the name implies. DGBL has seen remarkable growth in education as researchers and practitioners have begun to understand what the design of good DGBL and good video games can offer both the field and the classroom (Gee, 2003, 2007; Mitchell & Saville-Smith, 2004; Moreno-Ger, Burgos, & Torrente, 2009; Papastergiou, 2009; Tsa, Yu, & Hsiao, 2011; Shaffer, Squire, Halverson, & Gee, 2004; Spires, 2015; Squire 2008). Good video games, commercially developed or otherwise, empower learners, provide problem based learning opportunities, and promote deep understanding of educational concepts, which Gee (2007) argues are the core ‘good learning’ principles that games can leverage, making them powerful tools for education. Squire (2008) adds that DGBL and video games “have the capacity to give learner situated, embodied understandings of complex phenomena” (p. 31), which is being realized by educators as their adoption continues to grow. This does not, however, mean that DGBL and video games have been heralded completely by educators as an infallible tool for learning (Tsai et al, 2011; Papastergiou, 2009). Students still have the potential to become distracted or confused by the game playing portion of the experience, thus hampering or blocking the potential learning that the game is meant to provide. It is important then for current research to try to narrow in on what may cause student performance to differ during DGBL and/or video game experiences so their potential as a learning tool is not squandered.

Control devices for Virtual Environments

SecondLife and Opensim are examples of VEs, specifically, virtual worlds, that have been used in educational contexts (Boechler, deJong, Ingraham, Fernando Marin, 2017; Aebersold, 2016; Coban et al, 2015; Gregory et al, 2015; Mayer et al, 2013; Moreno-Ger et al, 2009). Both require a user to manipulate and explore the environment via input from a mouse and keyboard. However, given the similarity of the VEs being used in education to those available in the consumer video game market, World of Warcraft (Blizzard Entertainment, 2004), Minecraft (Mojang, 2011), or Destiny (Bungie, 2014), for example, we must consider the possibility of video game specific controllers also being used to manipulate a VE in an educational context or setting. The currently available video game console specific controllers, such as the Microsoft XBox 360 and XBox One controller, are completely compatible with modern desktop and laptop computers with no modification and little to no additional software requirements. This makes the likelihood of such controllers to be used in VEs regardless of their context, consumer or education, very high. This is also relevant as VEs used for simulations are considered. The development of simulation VEs have been increasingly developed using VEs that require video game-like controller input as simulation software developers consider the familiarity, knowledge, and experience, many of their potential users have with video game controllers as a result of playing video games (Oppold, Rupp, Mouloua, Hancock, & Martin, 2012). This, in turn, has started to influence the actual tools they are meant to represent. For example, recent developments in the field of Unmanned Aerial Vehicles (UAVs aka. drones) have included designs for control devices for their pilots to use that take into account common video game controller design so as to reduce the training time involved in learning how to operate the UAV (Oppold et al, 2012). This idea can be extended to the design of remote-controlled surgical equipment, or construction equipment, and the simulation software used for their training.

Controller Conventions

A review of the evolution of video game control devices provides us with some background as to how and why modern control devices commonly used in first person perspective virtual environments are designed to operate. Video games of the early 1970’s and 80’s, did not allow for the manipulation of 3D virtual environments for a few reasons. First, consumer grade electronics had not yet advanced to the point where fully realized 3D virtual environments could even be displayed, let alone manipulated, so the controllers used to operate and play the video games available at the time often consisted of only digital push-button switches. Such buttons on controllers allow for only binary inputs into the electronics: on or off, pressed or not pressed. Analog sticks, track-balls, or dials allow for substantially more fidelity and/or range of input when they are implemented in a control device, allowing for a greater variation of input into a video game, for example. Video game console companies began to test what the market would bear and there were a few attempts to create analog controllers that allowed for more fidelity as early as 1977, though they were usually one-off designs intended to be used for a single piece of software, such as a steering wheel–like handheld dial controller for a video games that included driving a vehicle (Cummings, 2007). This would change, however, as Brown et al (2010) states, “each of today’s game consoles has a ‘standard’ controller that was

Figure 1. ATARI 2600 controller released in 1977. (2010, December 22). Retrieved October 10, 2017, from https://commons.wikimedia.org/wiki/File:Atari-2600-Joystick.jpg

designed with the capabilities of its console in mind and is tightly coupled to that system… a ‘standard’ controller, with support implemented in games in a uniform manner, can help ensure a consistent interface for the user while playing games on that platform” (p. 211). One of the first home video game console systems available, the ATARI 2600 (see Figure 1), came equipped with a standard controller that had a joystick as its major method of input along with one additional button. Although the joystick had the appearance of analog control, in reality the construction of the controller consisted of a series of digital button inputs hidden beneath the joystick’s cover, placed in the four cardinal locations, up, down, left, and right. The controller had been designed to look and feel that way for esthetic and ergonomic reasons, presumably it felt better in the player’s hand to hold and manipulate the joystick in a direction than it did to push one of the four individual buttons. As the video game controller continued to evolve, manufacturers concentrated on designs with button inputs and the invention of the directional pad as part of the controller (commonly referred to as a gamepad) was the result. The D-pad, as it is informally known, usually exists in the shape of a plus sign, with arrows pointing in four directions. The most influential, was that of the Nintendo Entertainment System (NES) in 1985

Figure 2. Nintendo Entertainment System (NES) controller released in 1985. (2014, January 11). Retrieved October 10, 2017 from https://commons.wikimedia.org/wiki/File:NES_controller.JPG

(Cummins, 2007) (see Figure 2). As Cummins (2007) describes, the reason this directional pad became so popular is, "the joysticks of games consoles of this age were not analogue... only digital, and hence could only tell what direction they were pushed in, not how much. Also, games of this age did not require any sort of extra analogue control" (p. 3). Cummins (2007) cites *Donkey Kong* as an example of a video game experienced in 2D virtual environments allowing the player to move only left and right at a single speed. The directional pad on gamepads available at this time were fitting input devices for this purpose, which stands to reason as Skalski, Tamborini, Shelton, Bucher, and Lindmark (2011) assert in their analysis of video game controllers, "the most basic manner in which controllers can be more naturally mapped is by producing a correspondence between the directions used to interact via a control device and the results in the world or on a screen," (p. 227). Early First-Person Perspective video games, that is games that put the player in control of the game through the eyes of the avatar, that used 3D virtual environments were widely available to consumers until the early 1990's and were experienced almost exclusively on Personal Computers (PC) rather than consumer video game consoles. One of the first in what would become a prolific genre of video games, the First Person Shooter (FPS), was Wolfenstein 3D, developed by id Software in 1992. As Cummins

(2007) points out, since Wolfenstein 3D was initially only available on the PC, until its release on console in 1994, and because it was one of the first of its kind, players often used the default control scheme of keyboard arrow keys to manipulate the character's basic movement, forward, backward, and turning left or right. Most notably absent in the control mapping, given the first person perspective, was a method in which the player could change the view of the virtual environment up or down, however, this was not yet necessary, as the game took place entirely on a flat plane. Id Software’s next title, Doom, released in 1993, did have a fully realized 3D virtual environment that included elevation changes requiring players to target enemies on higher and lower levels than the player, however the player was not afforded the ability to look up or down. Instead, the software automatically aimed projectiles or gunshots fired by the player at enemies that were visible but were higher or lower than the centre of the screen. Players also began to manipulate the game with the mouse in addition to the keyboard, mapping the rotation of the player’s view—first person perspective camera control—to the X-Axis left and right movement of the mouse. Following Doom’s release, Heretic (Raven Software, 1994), which was created using the same software engine as Doom, allowed the player to look up and down, but the ability to do so was restricted to buttons on the keyboard and could not be mapped to the mouse. Hence, “the last great evolution in the First-Person shooter control scheme… was brought about with id Software’s ‘Quake’ [in 1996] … [which] added a control option known as ‘Mouselook’” (Cummins, 2007, p. 4). Quake was not actually the *first* game to offer full control of the camera view via movement of the mouse, that is reserved for one of two titles. First, Marathon (Bungie, 1994), which was only available on Apple Macintosh Computers, limiting its influence, and a much less well-received title by Bethesda Softworks, Terminator: Future Shock (1995). Quake (id Software, 1996) was one of the first to set the new standard for camera control mapping entirely to one device and, because of its commercial popularity, also one of the most influential on the genre. Players were now able to look up and down, mapping the y-axis of the view to a mouse's forward and back movement and it can be argued that at this point in the evolution of FPS games and controllers to play them, the individual preference for inverted and non-inverted y-axis perspective control was born as an option to invert the 'mouselook' was included in the option menu of Quake. There is also a competing argument: that the influence of other software titles, specifically flight simulation titles, may have had on the controller mappings implemented in early FPS games. Frischmann et al (2015) noted this similarity of control during their study of y-axis camera control preference. Software such as the Microsoft Flight Simulator (Microsoft) series, which was released in 1982 and has been updated regularly every two to four years, predate all of the FPS video game titles previously mentioned. The potential for influence of these titles lies in the connection a flight simulator has to its control device and the aircraft controls they are intended to simulate. An aircraft yoke is operated by pulling back on it to pitch the aircraft up, while pushing forward pitches the aircraft down. A flight simulator mimics this operation, requiring the user/player to manipulate a control device such as the mouse, a joystick, or even keys on a keyboard, and because the user/player experiences the simulator in the first person perspective of the aircraft there is potential for some overlap in the understanding of the control mapping. To be clear, in FPS camera control terms, the operation of an aircraft using a yoke would be equivalent to the inverted camera control y-axis mapping. Though, it should be noted that the theory of flight simulators influencing FPS controls, does rely heavily on an overlap of players and/or designers experienced with both FPS games and flight simulators of the era, such that one could affect the other, which may or may not be true and could be researched separately to establish further clarity on the history of the evolution of this phenomenon.

Following the evolution forward then, video games that utilized 3D virtual environments continued to grow in popularity, but it was not until the mid to late 1990's that the video game consoles being developed and sold were finally able to produce the same types of environments as those that PC's available at the time could produce for years prior. The controllers that accompanied previous generations of consoles could not meet the challenge of 3D video game play: as Marshall, Ward, and McLoone (2006) explain "The D-pad, designed to navigate two-dimensional spaces, became unsuitable for the challenges presented by the extra dimension" (p. 2). Video game controllers began to evolve (or perhaps *regress*) to include the stick-like input devices they had previously shed in favour of the directional pad. These sticks were much more precise in nature than their 1970's counterparts and allowed for the fidelity that the new video games being created by developers required.

One of the earliest controllers to include a stick was the controller included for use with the Nintendo 64 console (see Figure 3), which was released in 1996 (Cummins, 2007), a video game console that would later receive titles which are still considered by enthusiasts to be some of the earliest and most well-made 3D First Person Shooters of all time (Alexander, 2017; Turner,

Figure 3. Nintendo 64 video game controller released in 1996. (2005, February 25). Retrieved October 10, 2017, from https://commons.wikimedia.org/wiki/File:N64-controller-white.jpg

Figure 4. Playstation Dual Analog video game controller released in 1997. (2012, May 17). Retrieved October 10, 2017 from https://commons.wikimedia.org/wiki/File:PS1_Dual_Analog_with_Box.jpg

2017; Williams, 2017), such as GoldenEye 007 (Rare, 1997) and Perfect Dark (Rare, 2000). The Sony Playstation's 'dual analog' controller (see Figure 4) would modernize the design to include two sticks, which would largely influence the design of controllers moving forward (see Figure 5). Thus, the control of the player's perspective in early console video games with 3D virtual environments could now be designed utilizing controllers with new analog sticks which often mapped right and left rotation along the x-axis to right and left movements of the stick. Pushing forward or pulling back on the stick made the character look up or down but the movement could be reversed corresponding to a setting matching the y-axis preference of the player (normal or inverted) to the input received from the controller. These analog sticks have remained a standard of video game controller design and has continued to be the trend. The XBox Controller, which is built on a modern iteration of these design principles, is readily available to consumers and was therefore selected for us in this study.

Console Standards

Figure 5. Evolution of video game controllers. Adapted from Lopez, D (2007) by Jace Boechler.

Controller Mapping

While the physical design of controllers used for video games and simulations continues to evolve as the technology allows it, it is the job of the designer of the virtual environment to decide how inputs into the controller made by the user will be received and represented as changes to what the user is viewing and/or interacting with. Steuer (1992) refers to the process of how a user interacts with a virtual environment via a controller as “mapping,” or “the manner in which the actions performed by users of interactive media are connected to corresponding changes in the mediated environment" (p. 86.) According to Steuer (1992), mapping exists on a continuum. At one extreme, mappings may be arbitrary, which is defined by the human actions required on the control device being unrelated to the function performed in the virtual environment, such as tapping one's left toe to increase volume of sound. On the other extreme, mapping may be completely natural, which is defined by control device use being designed to mimic the real-life action being performed in the virtual environment, such as a steering wheel controller used to match the steering of a vehicle in the virtual environment. Several studies have previously concluded that controllers and control mappings that would be considered more natural by the above definition have multiple benefits to the user including increased enjoyment and a greater sense of presence (Skalski et al, 2011; Shafer, Carbonaro, & Popova, 2014). However, mapping a single control stick on a device to the movement of a camera in a 3D virtual environment seems to lie somewhere in between the two extremes of the mapping continuum. In a first person camera perspective virtual world, because the user is given a camera perspective that is meant to mimic the movement of their head or eyes as they view the environment, a natural mapping would ideally be a controller that allowed the user to simply move their head or eyes. To this end, the previously mentioned head-mounted virtual reality systems such as the Oculus Rift or HTC Vive would be good examples. Conversely, if a user was expected to change their view of the virtual environment by typing commands such as 'look up 20 degrees' or 'look right 90 degrees' with a standard keyboard, it would be considered a less natural mapping of the controls, because the input of typing does not mimic the action of moving one's head. The two-axis control stick common to many video game console controllers, then, seems to lie somewhere in the middle of arbitrary and natural, and the extension of a y-axis preference being 'inverted' or 'normal' may exist as a phenomenon where, in this context, the binary choice may have the payoff of a more natural mapping for one user than it is for another.

The Effect of Poor or Unnatural Control Mapping

A strong reason for establishing why it is important to understand why a user might prefer one camera control y-axis mapping over another, as well as how it may affect their use of the software they are interacting with, particularly in a learning context, is that deficits may arise if there is a mismatch between the user's preference and how the software is set up. Returning to the concept of mapping, research that compared less naturally mapped controllers and control schemes to actions in virtual environments was found to negatively affect user experiences (Skalski et al, 2011; Shafer et al, 2014). One such study also found that users who were given a less naturally mapped controller to interact with a 3D virtual environment in the form of a typical video game controller-with-joystick compared with a steering wheel controller used in a driving simulator style video game, were less likely to recall elements such as informational billboards that existed in the virtual environment following the experience (Dardis, Schmierbach, & Limperos, 2012). When considering the advent of motion controlled devices and controllers such as those found on the video game console the Nintendo Wii, one might expect such a controller to have the potential to provide a more natural mapping of controls because of the open ended, free-wielding, nature of input by motions afforded by the motion sensing controllers. A user might, for example, simply point the Wii controller with their hand at a target on screen, rather than manipulate the stick on a controller to accomplish the same task. Conversely, however, the Wii's controller inputs were found to be *less* natural when compared to a typical controller-with-joystick mapping counterpart when playing a first person shooter, which resulted in lower performance by the user (Rogers, Bowman, and Oliver, 2015). This performance decline is in addition to the already expected decreased user experience based on previous research cited (Skalski et al, 2011; Shafer et al, 2014). An additional series of studies of note, Jalink, Goris, Heineman, Pierie, and Hoedemaker (2014a, 2014b, 2015), and Rosser et al (2017) looked to research the effectiveness of a custom made video game that mimicked the use of robotic laparoscopic controls using Nintendo Wii controllers to help train students of laparoscopic surgery or warm-up practicing surgeons. This research was the follow-up to the often-cited research performed by Roser et al (2017), in which a quasi-experimental approach was utilized to uncover a positive relationship between laparoscopic surgical skills and video game experience. Much of the desire for such research comes from the fact that laparoscopic surgical tools are manipulated by the surgeon in a way that when moving the main controls along an x and y axis *both* are inverse of the ultimate movement on the other end of the surgical tool, which is shown on the camera to the surgeon. The physical room for error is said by the authors to be literally very small during surgery, an unnecessary or incorrect movement in the wrong direction with a laparoscopic surgical tool, perhaps because of a misunderstanding of the tool's reversed input, could result in unnecessary harm to the patient. The researchers, therefore, posited that any and all additional practice in a virtual environment using an inverted control mapping could increase the effectiveness of the surgeon when it came time to perform real laparoscopic surgery. Their findings suggested that participants in the study who played the custom video game prior to performing a standardized task—similar to those performed in surgery with a laparoscopic device—were able to complete the tasks more quickly and with higher scores than their control counterparts (Jalink et al, 2015).

While these examples speak to a more extreme comparison of devices and controllers than the comparisons made in this study, comparing the effects of switching only the forward and back motion of a single control stick on the same device, it reinforces the negative effect that a less natural mapping (by Steuer's (1992) continuum definition) can have on the user experience or user performance in a virtual environment. Anecdotally speaking, many people with little to no video game experience, in particular, do not realize that there exists a difference in the y-axis camera control scheme available to them at all and often end up using whichever version is set by default at the outset. Others may simply inherit their first experience of a y-axis control scheme mapping from the previous user to have used the device, again, blissfully unaware that it could be switched. If the user is then being forced into a less natural, to them, mapping, there is clearly potential for negative effects on their experience as well as performance. Very little research, outside of the previously cited studies comparing performance while using different devices, has compared actual performance outcomes, rather than comparing measures of user experience, and this study looks to bridge that gap. This gap is perhaps made most apparent in the research done by Frischmann et al, (2015), who did look specifically into the effects that forcing a mismatch to what the user self-reported as being their preference of camera control y-axis mapping had on user experience via measures of presence and workload but stopped short of any actual measures of task performance.

Popular Culture and History of Industry Standards

While very little research has considered or explored the effects that a mismatched Y-Axis camera control has on performance in 3D virtual environments, we note that outside of academia there has been a longstanding battle of opinions among video game players, journalists, and even developers, as to which mapping is 'the best,' wherein the arguments most often revolve around which mapping affords users higher levels of performance (the most feverish arguments are amongst video game players). Video games have, and will continue, to influence the way in which 3D virtual environments are experienced, and video game developers, for their part, have most often offered a choice to their users, usually by way of simply accessing a selection for y-axis inversion in the options or settings menu of a game or other first person controlled virtual environment.

Speaking to the previously made point of novice video game players adopting whichever mapping is set to default, the history of the phenomenon of y-axis control mapping preference in popular video games offers some evidence of how the choice of a single developer could inform the choice of camera control y-axis mapping of an entire generation of video game players. For instance, the previously mentioned video game title Quake (id Software, 1996) while it was not the first video game with first person camera control to allow players the ability to look up and down, it is one of the most highly regarded among video game critics and players and is often cited by enthusiasts as being the most influential game on the First Person Shooter genre with respect to allowing for full camera control (Davidson, 2016; Gameskinny.com, 2016; Moss, 2016; Turner, 2017). Quake, did not, in fact, have full x and y-axis camera control enabled by default. Players had to either type a special command into the game, change an option in the settings menu, or modify a configuration file of the software before playing the game, to enable a feature called Mouselook. When players did activate Mouselook, the y-axis mapping was set to an inverted y-axis mapping by default. This was because one of the lead designers, John Romero, preferred the inverted y-axis mapping. “One of my jobs was to define our control scheme and get really good at the game... If the controls felt good to me, then I figured others would like it as well. There was never any discussion about control scheme or changing it – I just defined it and that was it… for some reason, pushing forward to look down felt more natural to me.” (J. Romero, personal communication, March 26, 2017). Because the default y-axis mapping was set to inverted, many players' first experience with looking up and down in the video game's 3D virtual environment would be influenced by this choice, and, as was speculated before, although there was an option to change it many did not know the option existed and they adopted the default as their assumed preference. As generations of video game enthusiasts would continue to play and develop new games inspired by Quake (id Software, 1996), the indirect effect the developer's choice regarding the default camera control y-axis mapping had on players' preference and future development would be difficult to quantify, but also should not be ignored or discredited.

As the genre of FPS video games began gaining popularity in the home video game console market, the difference in y-axis camera control preference also became an issue for modern developers of FPS games. Video game developers and designers were now tasked with adapting the genre to be played with the controllers that were included with the consoles they were designing for, the Sony PlayStation, for example. Modern controller mapping of FPS games has players control the movement of the locomotion of an avatar on one of two control sticks and the movement of the camera view on the other. This control scheme was first attempted as an optional control scheme (not default) in the title 'Medal of Honor' (DreamWorks Interactive, 1999) available for the Sony PlayStation video game console. During its development, choosing which mapping of the y-axis would be default was a decision the developers struggled with (C. Cross, personal communication, March 24, 2017). Many of the designers on the project were experienced FPS video game players on the PC and had become used to the inverted mapping of the mouse control common to the genre, again citing Quake (id software, 1996) as their biggest influence. But when it came time to select a mapping on a console controller with a stick as the main device for camera control, there existed a near 50/50 split of opinions and preference among team members as to which y-axis mapping should be the default (C. Cross, personal communication, March 24, 2017). When the final product was released, the default was set to the normal camera control y-axis mapping (for the alternate control scheme), largely as the result of one ranking member of the design team's preference. The first game to feature what is now considered to be the standard control scheme of the genre—left stick locomotion and right stick camera control—as its default and exclusive scheme was the title Aliens: Resurrection (Argonaut Games, 2000), also available on the Sony PlayStation, which was largely panned by critics for its controller mapping. Some critics went so far as to claim, "the game's control setup [was] its most terrifying element" (Garrett, 2000).

While the number of FPS games available to gamers/users on home video game consoles continued to grow, in 2001 Microsoft Studios released its flagship title, Halo: Combat Evolved (Bungie, 2001), for the X-Box video game console. Halo sold nearly 6.4 Million copies worldwide (vgchartz, 2017), and is often referred to by enthusiasts as the game that figured out how to make FPS games really enjoyable for players on a console system with a controller (Linneman, 2017; Turner, 2017; Dello Russo, 2016). The development of Halo was not immune to the decisions faced by the FPS game development before it, namely how to map the controller inputs to avatar movement and camera control, but the designers tested many different mappings to determine which afforded the game's intended audience with best gameplay performance. The team that designed Halo was also filled with experienced PC FPS gamers, who preferred the inverted y-axis mapping (J Griesemer, personal communication, March 7, 2017). Again, a lead designer can be credited with making the choice for which y-axis camera control, mapping was set to the game's default, but this time it would be the normal mapping that would be selected (J Griesemer, personal communication, March 7, 2017) and would go on to influence many other

FPS games on console that came after it, the same way Quake (id Software, 1996) did before it. However, it is also noted that the development team responsible for Halo found that when testing early builds of the game for quality assurance, play testers, particularly those who were novice video game players, even when *told explicitly* that the y-axis mapping could be inverted if they wanted, did not understand what was meant by the setting and often gave up playing the game all together citing a lack of control of the avatar as their main obstacle (J Griesemer, personal communication, March 7, 2017). Fearing the game would be considered ‘unplayable’ to any number of potential players (and thus, customers), the development team set out to create a method for determining a player’s preferences of camera control y-axis mapping, which they embedded in the game’s first minutes of gameplay disguised as a ‘technical diagnostic’ the protagonist character must undergo before proceeding with their mission. The result, was a “remarkably accurate” method for determining y-axis mapping preference for camera control which the team defined by the number of times a player would change the setting following the test being substantially lower than when it was not utilized (J Griesemer, personal communication, March 7, 2017). This method for determine camera control y-axis mapping preference, embedded in the opening narrative of the game, would become a hallmark of the Halo video game series, later to be adopted by other games in the FPS genre on available on multiple video game consoles and on the PC. As this method for determining camera control y-axis mapping preference is widely used in the consumer video game market and because the controller used in the study (XBox One controller) is also used for the Halo video game series, it was decided that the method would be adopted for this study to determine the camera control y-axis mapping preference of the participants. Please view the Methods section of this paper for a description of its implementation.

Performance and Learning

For the purposes of this study, the concepts of performance and learning will be used and referred to regularly. To be clear, then, it is important to distinguish between the two concepts, to build a base which can then be extended into the domain in which this study is interested, thereby providing context for the outcomes. As the terms are somewhat context sensitive, it will be important to consider definitions and interpretations from multiple fields, including Education and Psychology. Wayner and Sanberg (1989) summarize performance as “an empirical concept characterized by observable and measurable characteristics of responses” (p. 331), outlining the importance of measurement. Learning, they previously defined by referring to “any change in performance due to practice” (p. 331), effectively relying on the definition of one to define the other. However, in their summary of more recent research, and taking a more psychological approach, Soderstrom and Bjork (2015) provide a contradictory argument by stating:

> The distinction between learning and performance is crucial because there now exists overwhelming empirical evidence showing that considerable learning can occur in the absence of any performance gains and, conversely, that substantial changes in performance often fail to translate into corresponding changes in learning. (p. 176)

In fact, Soderstrom and Bjork (2015) provide a summary of research concluding that learning may be characterized as “relatively permanent changes in behaviour or knowledge that support long-term retention and transfer” while performance is characterized as “the temporary fluctuations in behaviour or knowledge that are observed and measured during training or instructions immediately thereafter” (p. 193). This study relies heavily on performance data and will conclude with assertions about learning only in specific contexts, for no other reason than the shorter time constraints of access to participants did not allow for more. This study is concerned with differences in performance that are not only measurably and observably different, but also different as a result of the manipulation of variables between participants. That said, it is still important to first characterize how performance has been and can be measured so as to frame, more accurately, the questions this study hopes to answer.

Individual Differences in Performance and Learning

There is a long history, in the field of Education and Psychology in particular, of research trying to determine and analyze or describe how people behave, perform, or learn, in general. However, while generalizations are quite often used, there is also significant variation between individuals as well. As Cooper (2010) states, “branches of psychology can predict behaviour better when they consider individual differences… by taking individual differences into account, statistical tests become more sensitive” (p. 2). Individual Differences refer to the way that individuals differ in their behaviour, thinking, and feeling (Jonassen & Grabowski, 1993). When taking into account individual differences, how people react to a treatment, how they perform an activity, or how long it takes them to learn, can (and will) vary from person to person based on any number of variables. While these individual differences could lead to difficult to interpret data, if they are controlled during analysis, it can also make for stronger conclusions. For instance, Cooper (2010) posits, “it might well be found that the effectiveness of a particular treatment is affected by the individual's personality and/or ability—a treatment that is successful in some individuals may be much less successful in others” (p. 2). Extending that, understanding which part of an individual’s personality and/or ability ultimately may have the greatest influence on the effectiveness of the treatment being researched, can help researchers determine how important or influential those factors of individual difference can be when measuring other levels of performance. Examples of research looking into individual differences affecting performance and learning are varied and vast. Recent research, exemplifying the breadth of the field, includes: a) the effect that learning styles, learning strategies, and other affective variables have on second language learning (Ehrman, Leaver, & Oxford, 2003; Aljasir, 2016), b) the effect that individual differences related to age, gender, and previous experience with different types of library resources, has on the perception and use of electronic resources (Zha, Zhang, & Yan, 2014), c) individual differences with respect to cognitive style, domain knowledge, computer experience, and gender leading to varying levels of disorientation, learning performance, and navigational abilities in hypermedia environments (Ford & Chen, 2000; Zywno, 2003; Dev Rutton, 2011), d) How individual differences in immersive tendencies can affect performance in a virtual route learning task (Walkowiak, Foulsham, & Eardley, 2015), e) The predictive role of processing speed and verbal knowledge in criterion based drop-out learning in old age (Kurtz & Zimprich, 2014), f) the potential for individuals to have different predispositions toward memorization versus rule abstraction in a single categorization task (Little & McDaniel, 2015). There are many other examples, which speaks to the overall importance that accounting for individual differences, regardless of context, has when researching a treatment and/or when measuring performance and learning.

Impact of Individual Differences on Performance in virtual environments

The impact of individual differences on performance may greatly affect performance in any number of situations. This study, which looks directly at performance in virtual environments such as video games, simulations, or otherwise, must adequately consider the impact that individual differences may have on the participant’s performance. Previous computer experience, or video gaming experience in particular (Barlett, Vowels, Shanteau, Crow, & Miller, 2009; Frey, Hartig, Ketzel, Zinkernagel, & Moosbrugger, 2006; Jalink et al, 2015; Jalink et al, 2014b; Mayer et al, 2013; Rosser et al, 2007; Sanchez, 2012; Smith & Du'Mont, 2009; Spence & Feng, 2010; Tsai et al, 2012; Walkowaik et al 2015) is a commonly studied individual difference impacting performance in research related to virtual environment use and/or development. Also, often studied factors in similar research includes: Immersive tendencies, that being the tendency of an individual to become immersed in a virtual environment (Frischmann et al, 2015; Walkowaik et al, 2015); Presence, referring to the illusionary perception of being in a mediated space or room that a user may experience when interacting with a virtual environment which can include subdivisions of spatial and social presence (Wirth et al, 2007; Frischmann et al, 2015; Lyons, 2010; Skalski et al, 2011; Klimmt & Vorder, 2003; Witmer & Singer, 1998); and Spatial ability, the level at which an individual can solve problems that demand spatial reasoning skills such as visualization, spatial orientation, closure speed, speeded rotation, spatial scanning, perceptual speed, and visual memory (Santone, 2009; Spence & Feng, 2010). Frischmann et al (2015) specifically targeted spatial orientation and immersive tendencies as individual differences in participants that would potentially impact their performance when using a camera control y-axis mapping either matched or mismatched to preference during in a video game task. All of the aforementioned factors which may contribute to performance by way of individual differences were considered for this study. Ultimately, though, measures of previous computer/video game experience because of the commonality to existing similar research, as well as measures of spatial orientation as was used by Frishmann et al (2015), were selected.

We must also consider the effect of individual differences with respect to motor skills. As this study asks participant to complete tasks using a handheld controller, individual differences could affect performance scores. Previous research which involved participants playing a FPS video game while testing the effect of an audience on performance, for example, considered the effect of individual differences related to fixed and moving targeting abilities, as well as measures of eye-hand coordination, reaction time, and fine motor skills which were found to have a positive correlation with performance in the video game based virtual environment (Bowman, Weber, Tamborini, & Sherry, 2013). This study then also considers the individual differences related to motor skill, specifically eye-hand coordination, to control for their influence on performance scores.

Review of the Psychomotor Domain

The development of a Psychomotor Domain in the Taxonomy of Educational Objectives was delayed, when compared to the other two co-domains: Cognitive and Affective (Bloom, 1956). While this third domain, which recognized the manipulation or motor-skill area, was so underdeveloped that at the time of publishing, Bloom and his co-authors stated the Psychomotor Domain had "so little done about it in secondary schools or colleges, that we do not believe the development of a classification of these objectives would be very useful at present" (1956, p. 8). The call to fill the gap or finish the taxonomy would finally be answered by Simpson (1966, 1971) who suggested the *Educational Objectives in the Psychomotor Domain*, and then, in more detail, by Harrow (1972) with the seminal work *A Taxonomy of the Psychomotor Domain: A Guide for Developing Behavioral Objectives*, according to Miller, Cox, and Imrie (1998).

Simpson (1966, 1971) outlined a framework for a classification system, or schema, for the development of a motor-skill that included, broadly speaking: perception, set, guided response, mechanism, and complex overt response, which were organized by complexity from least to greatest. Each category had two or three subcategories which would indicate different levels of performance with respect to each process. For instance, under perception there are three subcategories: sensory stimulation, cue selection, and translation. In the context of Simpson's work, for the purposes of this study, it will be important to note that some of the potential participants may be at a Guided Response level of Psychomotor development with respect to the task of manipulating the controller in a first person camera controlled 3D environment. More specifically, some participant's abilities may be described in the subcategory of Guided Response-Trial and Error, which is described as "trying various responses, usually with some rationale for each response, until an appropriate response is achieved" (Simpson, 1971, p. 65). This will very likely be true of novice users and will ideally be detected and accounted for in a measure of previous experience. Alternatively, other students (who would presumably score higher on a previous experience measure), could conceivably be performing at the complex overt response level, in the subcategory of 'automatic performance,' which is described as when, "the individual can perform a finely coordinated motor skill with a great deal of ease and muscle control" (Simpson, 1971, p. 66). One of the main goals of this study, however, was to observe the effect that forcing a participant to use a camera control y-axis mapping that is opposite of their preference has on the participant's performance, or to indicate the level/category in the psychomotor domain at which their performance can be best described using this framework.

In his review of Harrow's seminal, and oft cited, 1972 work, *A Taxonomy of the Psychomotor Domain: A Guide for Developing Behavioral Objectives*, Cooper (1973) described it as "the first complete and in-depth study relative to the development of a classification system of the behaviors existing within the psychomotor domain" (p. 325). Harrow (1972) proposed a taxonomy for classifying movement, based on a culmination of research, including that of Simpson (1966, 1972), resulting in a detailed model that consisted of six categories, each with two to five subcategories, for explaining a learner's movement:

1. Reflex Movement
    1.1. Segmental Reflexes
    1.2. Intersegmental Reflexes
    1.3. Suprasegmental Reflexes
2. Basic Fundamental Movements
    2.1. Locomotor Movements
    2.2. Non-Locomotor Movements
    2.3. Manipulative Movements
3. Perceptual Abilities
    3.1. Kinesthetic Discrimination
    3.2. Visual Discrimination
    3.3. Auditory Discrimination
    3.4. Tactile Discrimination
    3.5. Coordinated Abilities
4. Physical Abilities
    4.1. Endurance
    4.2. Strength
    4.3. Flexibility
    4.4. Agility
5. Skilled Movements
    5.1. Simple Adaptive Skill
    5.2. Compound Adaptive Skill
    5.3. Complex Adaptive Skill
6. Non-Discursive Communication
    6.1. Expressive Movement
    6.2. Interpretive Movement

Admittedly, much of attention in the Psychomotor domain has been in the development of educational objectives for younger children, as it is in the younger age groups that the greatest development occurs (Miller et al, 1998). Nonetheless, the levels of the domain can be generalized, to some extent, to the experience of a novice learner of any age learning a new skill or movement for the first time; therefore, the movements required to manipulate a controller for use with a first person perspective camera controlled 3D virtual environment can be determined to fall into a few of Harrow's (1973) categories: a) 2.3 Manipulative Movements, which are described as, "coordinated movements of the extremities… these movements are usually combined with the visual modality… [and] is concerned then primarily with movements of prehension and dexterity" (p. 53)—Dexterity is further described as "pertaining to the hands and fingers, [implying] a quick and precise movement" (p 54)—and b) 3.5 Coordinated Abilities, which is described as "[incorporating] activities which involve two or more perceptual abilities and movement patterns… [and] is primarily concerned with eye-hand and eye-foot coordinated abilities" (p. 66), where Eye-hand coordination "refers to the ability of the learner to select an object from its surrounding background and to coordinate the visually perceived object with a manipulative movement" (p. 67). These could be considered as appropriate descriptions of the task of manipulating the controller in two ways: either as the user selects the computer monitor displaying the 3D virtual environment from the background and is coordinating the manipulation of the controller, or within the 3D virtual environment the user is selecting virtual objects which are visually perceived and selected via manipulation of the controller.

Visuomotor Adaptation

In the Medical field or in the field of Neuroscience specifically, the term(s) used to describe coordination as it is referred to in Harrow's (1972) Psychomotor Domain, is visuomotor or visual-motor: "denoting the ability to synchronize visual information with physical movement" (visuomotor, n.d.). Experimentation and study of performance under conditions where perception is altered or perturbed in one way or another date back to the late 19th century (Cunningham, 1989). Most notable, is the work of Stratton (1897a, 1897b), who, during a series of self-studies, used prisms to completely invert his visual world. These studies introduced early ideas that visuomotor skills are not fixed but, instead, plastic and are subject to adaptation. However, the disruption in movement accuracy as a result of the optical inversion is not easily overcome simply by conscious effort (Cunningham, 1989) and the time it takes to adapt may vary by the individual (Welch, 1978). Early work in this then newly formed field of study involved the alteration of the entire visual world of an individual, such that everything the individual could see would be inverted, or ‘flipped’ (Stratton, 1897a, 1897b). Stratton performed his self-study by wearing a headset that flipped his visual perspective for the entirety of his daily activities for the duration of one week. The experimental tasks Stratton performed amounted to enacting skills or movements that would otherwise be considered normal to everyday life, such as walking, reaching, or manipulating common objects. His early experiences resulted in nausea and discomfort, which dissipated in a matter of days, but as the experiment continued, and ultimately came to a close, he had all but overcome the perturbation only to again find it strange when his vision was returned to normal after removing the headset (Stratton, 1897b). As the field continued to evolve much of the recent research of visuomotor adaptation has revolved around motor performance under transforming spatial mapping, i.e., instances when a specific alteration to a particular movement or the visual representation of that movement is altered. The setup for such an alteration has previously been accomplished using an input device such as a digitizing tablet input surface, which is laid flat under a participant's arm or hand (Bedford, 1994; Cunningham & Welch, 1994; Cunningham & Pavel, 1991; Cunningham, 1989; Krakauer, Pine, Ghilardi, & Ghez, 2000; Wigdor, Shen, Forlines, & Balakrishnan, 2006), a manipulandum/robot arm (Shadmehr & Mussa-Ivaldi, 1994; Smith, Ghazizadeh, & Shadmehr, 2006), or a joystick (Abeele & Bock, 2001; Miall, Jenkinson, & Kulkarni, 2004; Shmuelof, Krakauer, & Mazzoni, 2012), that is coupled with a visual feedback surface which, in the studies cited, is always some form of screen or monitor oriented vertically and facing towards the participant. A cursor is placed on the screen indicating the position of the input device to the participant. Targets are then presented on the screen and the participant must manipulate the input device to successfully match the cursor to the designated target, sometimes with distinct paths that must be followed from the starting position to the target. The apparatus can be setup such that a one to one correlation of movement of the input device exists, which is used in the studies cited as a training or learning phase of the experiment. A transformation or alteration is introduced to the participant, such that the movement of the input device results in a similar motion of the cursor on the screen but the cursor instead moves in a new trajectory with a translated angle of a certain degree. For example, when the participant inputs a leftward motion into the input device, which previously resulted in the cursor moving straight to the left on the screen, the cursor would instead move left but also downwards at 15 degree angle (the change being consistent in all directions), resulting in a 15 degree counterclockwise rotation of the visual feedback space. Transformations of the visual space could be rotational, as described, or an inversion along a single horizontal or vertical axis. Regardless of the transformation, the participant would then need to adapt their manipulation of the input device in subsequent trials to match the cursor to the targets, hence: visuomotor adaptation. To this end, Cunningham (1989) in particular, found that when a rotation of varying degree or an inversion of the visual space was introduced to participants, the resulting error of moving the cursor to the target was greatest when the rotation was between 90 and 135 degrees (clockwise), but that inversions were sometimes found to produce error rates as high as the 90 and 135 degree rotations or as low as the 180 degree rotation which produced the lowest error rates, depending on the individual. We note, however, that there is no mention of a bias or preference for inversion being considered by Cunningham (1989). Previous training has been considered, which is of importance to this study, particularly when dealing with novices to first person camera controlled 3D virtual environments, as previous research suggests that prior visuomotor training, in certain contexts, may have an effect on new visuomotor learning (Krakauer et al, 2006).

The parallels to this study, which investigates a similar adaptation that occurs when users of a first person camera controlled 3D virtual environment are tasked with a different camera control y-axis mapping, and the previously cited works of researchers who have experimented with visuomotor adaptation are undeniable. It would be a rash judgment, however, to suggest that the results would be entirely predictable or similar as a result of these parallels. It is important to consider that many of the previously cited studies made use of a simple visual feedback device which amounted to a two dimensional representation of the movement made by the participant with the input device. None of the cited research involved a 3D virtual environment and none of the methods were designed to represent a first person camera perspective in such an environment. Additionally, many of the studies that are cited were conducted prior to the advent and prevalence of consumer video game consoles that popularized the first person shooter genre of video games reviewed earlier. Because, as stated earlier, video game technology has come to inform some of the more modern technology used in medicine (Jalink, et al., 2014a, 2014b, 2015; Rosser et al., 2017) or military applications (Oppold et al, 2012), there is also value in revisiting the phenomenon in an updated context. It is important to consider that in many of these previous studies, the movement task that is being asked of the participants is very small or short in nature. Participants are tasked with moving an input device in a single or smooth motion in one direction to move a cursor to a target. Some of the researchers do acknowledge this limitation (Krakauer et al, 2000; Miall et al, 2004), even noting it as an issue during the experiment that was addressed by instructing participants to commit to a movement trying not to correct it once a direction is committed. Despite this, it was noted that corrections were still made by participants (Krakauer et al, 2000; Miall et al, 2004). Other researchers looked at this as an opportunity and began investigating the nature of these corrections and what patterns emerged therein (Wigdor et al, 2006). Speaking to the actual physical movement required of the participants in the studies cited, Shadmehr and Mussa-Ivaldi (1994) chose to use a series of targets that did not require the participant to return to the middle of the visual space with each trial. This design does differ from the 'centre-out' style movement trials required of participants during the other studies cited. Cunningham and Welch (1994) experimented with a target 'tracking task' in which the target would continuously move in a sinusoidal wave-like path, of varying amplitude, providing a continuous path the participant would be tasked with following. Additionally, Shmeulof et al (2012) used a simple path in a similar context, but their research did not involve visuomotor adaptation, instead choosing to concentrate on the development of a novel motor-skill using similar equipment. Regardless, using single targets simply does not account for more complex movement required to perform something like following a path, following a moving target, or gesturing with the input device, which is why both a single target selection task as well as a target tracking task were tested in this study.

Methodological Review

Performance and Learning in Psychology

In the field of psychology, a working definition of learning had been established by the mid-20th century and while there were slight variations there was a general consensus that learning could be characterized in an organism by observing changes in association, i.e., how an organism perceives an object or stimulus, and the connection the organism then makes as a result of interacting with it. Stagner and Karwoski (1952) stated that "perception and behaviour are modified by experience; and this process of modification is labeled learning" (p. 248). Similarly, Munn (1962) defined learning as "the process of being modified, more or less, permanently, by what happens in the world around us, by what we do, or by what we observe" (p. 270). This definition of learning is often accompanied by the use and explanation of learning curves, which were utilized as a method of measuring and characterizing the process of learning—through association—in a quantitative way. Despite being called a learning curve, however, it is actually a plot of performance (Stagner & Kowroski, 1952). A learning curve will typically plot some measure of performance along the y-axis (eg. number of correct answers, time taken to complete a task, number of observable examples of a skill, or even a combined score), with some measure of time along the x-axis (ie. number of trials, hours, weeks, etc.). An easily described example of a learning curve from early psychological literature might illustrate the basic operant conditioning of a mouse during a visual discrimination task (Stagner & Kowroski, 1952). If the mouse is continually positively reinforced to identify one of two visually distinct items, a learning curve that plots the percentage of correct identifications made in each set of trials would increase over successive trial sets from a rate of 50% (due to chance) in the earlier trial sets to a much higher rate nearing 90% to 95%, as the mouse begins to achieve perfect or near perfect runs. Stagner and Kowroski (1952) state:

> The complete learning curve is S-shaped (See Figure 6)… one can get a positively accelerated curve if he stops at the right point; but the curve could not continue that way indefinitely… it must taper off and hit a ceiling somewhere… if our learning task is one where some prior improvement has taken place, our measures may start where the dotted line is drawn (p. 259).

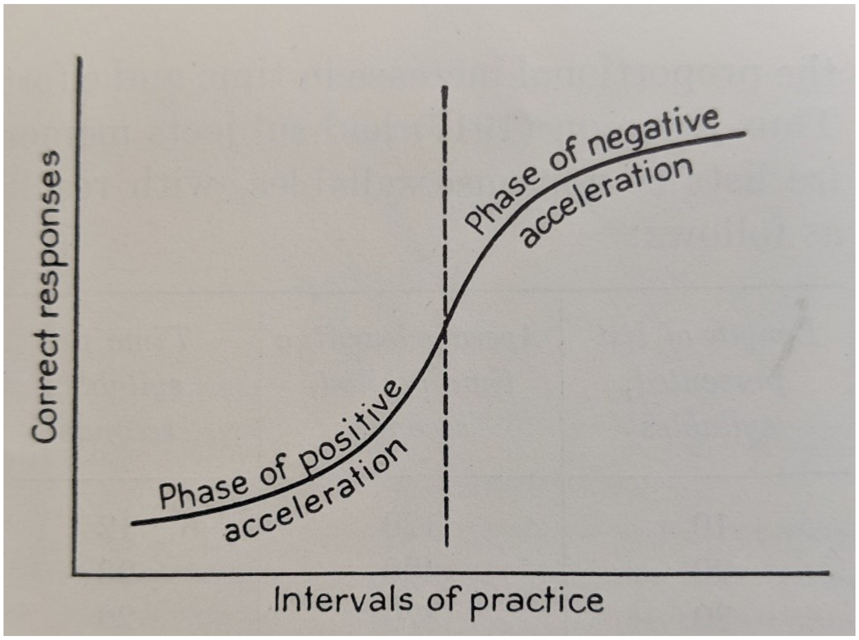


Figure 6. The S-shaped learning curve (Stagner & Kowroski, 1952, pg. 259)

Learning curves are characterized by two phases: a phase of positive acceleration, as the performance increases with successive intervals of practice, followed by a phase of negative acceleration, as a theoretical maximum is achieved. If, however, the learning curve is a plot of the error or decreasing unwanted/negative part of a skill development, the curve would be inverted and would contain a phase of negative acceleration followed by a phase of positive acceleration as the theoretical minimum error is achieved. An example of a typical learning curve can be seen in Figure 7, which plots the average completion rate across trainees working towards required satisfactory completion rates of upper GI endoscopy (95%) known as oesophago-gastro-duodenoscopy (OGD) (Ward et al, 2017, p. 1025). Figure 7 illustrates an example of an inverted learning curve, as it plots the total number of movements during a laparoscopic motorskill training simulation in a virtual environment, compared to a control group, where the total number of movements being minimized is a sign of greater proficiency (Crochet et al 2011, p. 1219).

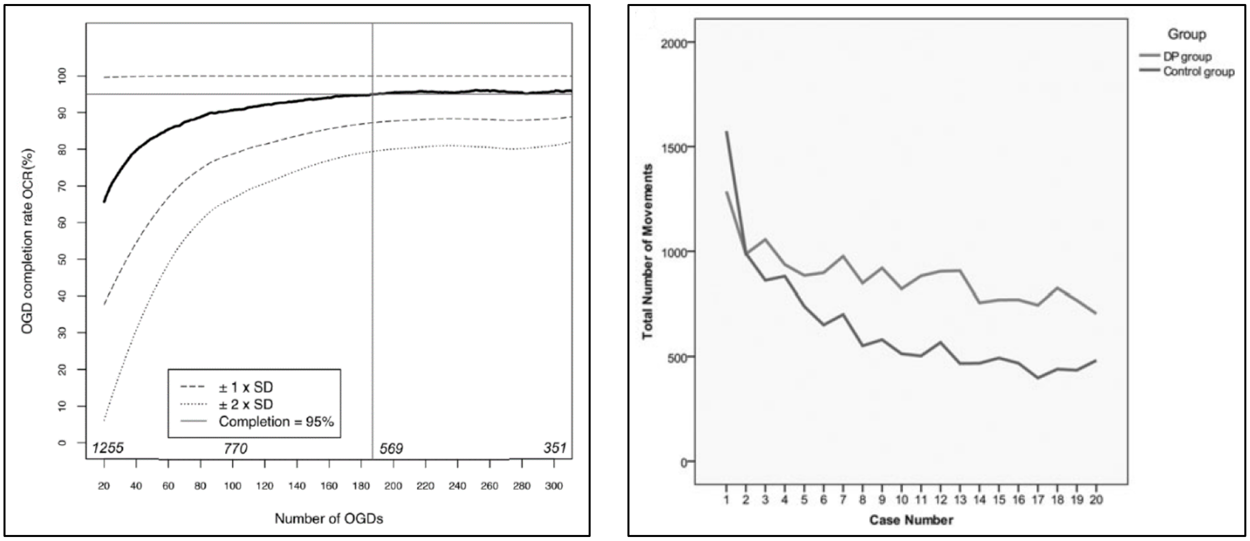


Figure 7. Examples of learning curves (left) Typical learning curve (Ward et al, 2017, p. 1025), (right) inverted style learning curve (Crochet et al 2011, p. 1219)

While the characteristics of a learning curve are somewhat consistent for skill development, it is the steepness of the curve and where in the training/practice cycle (x-axis) that the curve begins to climb, that is of interest to researchers as it allows for conclusions about the difficulty of the skill development to be made: A curve in which the initial acceleration in performance occurs in earlier trials could indicate an easily learned task, while a curve with an initial acceleration that occurs later in time could indicate the opposite. A curve with a less steep slope would indicate a skill that would require more trials to become proficient, or take a longer period of time, while a curve with a steeper slope would indicate the opposite. Plateaus in the curve may also appear, before the theoretical maximum or minimum, which can indicate conceptual hurdles that need to be overcome before performance can increase further. Learning curves are the most effective when they represent an average performance of multiple participants (Stagnar & Kowroski, 1952; Donner & Hardy, 2015; Ward et al, 2017), as it masks individual differences among participants, which could otherwise result in fluctuations in the learning curve plot, making it hard to interpret. To this end, learning curve theory and utilization has continued to evolve over time and has become accepted as theoretical norm for describing how a skill may be developed (Deliano, Tabelow, König, & Polzehl, 2016; Koedinger, Yudelson, & Pavlik, 2016). Learning curves have also seen considerable use in many practical fields outside of Education and Psychology, including: construction and industrial design (Jarkas, 2010; Jarkas & Horner 2011; Linton & Walsh 2013), marketing and management (Zangwill & Kantor, 1998; Lindsey & Neeley, 2010); medicine, particularly when describing the processes involved with surgical skill development (Blehar, Barton, & Gaspari, 2015; Crochet et al, 2011; Cologne, Zehetner, Liwaneg, Cash, Senagore, & Lipham, 2016; Robert et al, 2015; Balij, 2015; Papachristofi, Jenkins, & Sharples, 2016; Huang et al, 2016; Ward et al, 2017). Gofton, Papp, & Beaulé (2015) state, “as surgical techniques continue to evolve, surgeons will have to integrate new skills into their practice. A learning curve is associated with the integration of any new procedure” (p. 623). The rise of robotic-assisted surgical tools have made the importance of understanding learning curves increasingly important to researchers and practitioners (Foo & Law, 2015; Yamaguchi et al, 2015; Adayener, Okutucu, & Uygur, 2016), as well as simulations used for training (Rahm, Wieser, Wicki, Holenstein, Fucentese, & Gerber, 2016). The performance data produced by the participants of this study are presented in a learning curve style plot as part of the analysis. In this case, participant’s error, either when selecting a target or when tracking a target in a first person camera controlled 3D virtual environment, is plotted along the trials performed.

Performance Measurement in the Psychomotor Domain

Harrow’s (1973) goal in creating a model for the Taxonomy of the Psychomotor Domain was, as with Bloom’s (1956) original Taxonomies for the Cognitive and Affective domains, to provide a framework for which educational objectives could be produced. For example, in the category of manipulative movements, Harrow (1973) provides an example of an educational goal, “for pre-school children to improve their dexterity in manipulating their hands and fingers so that given a shoe string and a play shoe, ninety percent of children can decrease by two seconds the time taken to lace and tie the shoe on a before and after test” (p.112). Similarly, in the category of coordination activities, an example is outlined as, “first grade children develop eye-hand coordination as measured by each child’s ability to copy in distinguishable from at least ninety percent of the printed upper-case letters of the alphabet” (p. 127). Harrow does not stray from the established format of observable and measurable outcomes for measuring performance. However, because these are education goals in the grander sense, they are written in terms of a group of individuals as one might experience in a classroom rather than being written with respect to an individual student. That said, we can consider that the same principles could be applied to an individual. To this end, when considering this study, it would not be difficult to create similarly formatted goals with respect to the development or redevelopment of eye-hand coordination following a switch in y-axis camera controller mapping as measured by the study of a participant's ability to manipulate a controller to select or target and track a target in a first person camera controlled 3D environment.

Following its publication, Harrow’s (1973) Taxonomy of the Psychomotor Domain brought about an era of development with respect to measures of performance in the then newly defined domain. Of note are the development of (and subsequent updates to) standardized tests such as: the Peabody Developmental Motor Scales (PDMS-2; Folio & Fewell, 2000), the Bruininks-Oseretsky Test of Motor Proficiency (BOT-2; Bruininks & Bruininks, 2005), and the Beery-Buktenica Developmental Test of Visual-Motor Integration (Beery VMI; Beery, Buktenica, & Beery, 2010). The PDMS-2 was designed to measure the development of young children no older than seven years old, while the BOT-2 has been standardized for ages 4-22.

The Beery VMI is designed to be used at any age, though it is primarily intended as a tool for diagnosis of *deficiencies* related to Visual-Motor skills as the age of the individual being assessed increases past 14. In fact, all of the tests listed are utilized primarily in the educational field by professionals tasked with identifying and diagnosing deficiencies in development related to the psychomotor domain to some extent, making them extremely popular tool in the field of occupational therapy (Pearson, 2011).

Bearing this all in mind, some form of standardized test, appropriate for the age of the participants enrolled, was considered for this study; however, just as those previously described, many of the available tests selected only offer a diagnosis of deficiency or handicap in the individual with relation to psychomotor skills, and were omitted as options, as the potential benefit of the information provided by the test would be outweighed by the detriment related to the time it takes to administer the test cutting into the tasks required by the experimental design itself.

Performance Measurement and Visuomotor Adaptation

Dating back to the Visuomotor or Visual-Motor research of Stratton (1897a, 1897b), much of the experimentation of Visuomotor Adaptation has involved introducing a perturbation or modification of visual perception. In Stratton’s case, this was accomplished with a head mounted prism, which he wore without interruption for one week. While no specific performance measures were made, Stratton kept a diary of his experiences in which he made detailed notes and observations of the sensations he experienced. He noted that there was a constant feeling that his legs and arms were ‘fighting’ with his vision to move as intended. That said, since no specific measurements were made, the findings would be considered a qualitative case study. As the field progressed, as a result of Stratton’s findings piquing the interest of researchers in the developing field, more specific experimental design followed suit. Performance measures related to target selection are, by-in-large, the norm for visuomotor adaptation research. Input devices such as the digitizing tablet surfaces, manipulandum/robot arms, or joysticks mentioned earlier are manipulated by participants who view the movements of said devices on a feedback surface, usually an upright monitor. Participants are given an opportunity to practice with the 'default' mapping of the input device, until a predetermined numbers of trials has occurred, they have reached a certain level of performance dictated by the experimental design, or the participant indicated they are satisfied. Krakauer et al (2000) refer to these trials as "'familiarization' blocks… in which subjects moved to all targets in the relevant target set in the absence of any perturbations... and with continuous cursor feedback" (p. 8917). Sometimes called a 'preadaptation,' 'baseline,' or 'training' phase, while its name, length, and number of trials may differ with each experimental design, it is common to much of the modern research in the field (Abeele & Bock, 2001; Bedford, 1994; Bock, 1992; Cunningham & Pavel, 1991; Cunningham, 1989; Miall er al, 2004; Shadmehr & Mussa-Ivaldi, 1994; Smith et al, 2000; Wigdor et al, 2006). Once a perturbation of the input mapping to visual feedback is introduced, be it a rotational transformation or an inversion like those described earlier, the experimental portion of the study begins and performance measures are utilized while having the participant manipulate the input device to select a target in continual trials of varying length and quantity depending on the experimental design. Performance measures during the experimental phase include: Reaction time and performance or completion time, i.e., the time elapsed between the presentation of the target and movement of the participant, followed by the time taken to move from the start location to the desired target (Cunningham, 1989; Wigdor et al, 2006); and some form of Trajectory or Directional error, based on the angular deviation of the path taken compared to true direction of the intended target, usually calculated using a root-mean-squared (RMS) error (Abeele & Bock, 2001; Cunningham, 1989; Lillicrap, Moreno-Briseño, Diaz, Tweed, Troje, & Fernandez-Rutz, 2013; Miall et al, 2004; Shadmehr & Mussa-Ivaldi, 1994). The directional error, when plotted out, would often produce a curve of varying steepness like a learning curve in which the average error per trial would reduce quickly during early continuous trials and ultimately ‘flatten out’ at or near a level similar to the performance observed during the practice or familiarization runs.

Given the prevalence of error as the measure of performance in the research reviewed, this study did not look to stray from the norm and utilizes a similar form of error calculation to measure performance during the experimental task. Something to consider, however, is that the virtual environment that was developed/designed for the study is a first person camera controlled 3D virtual environment, which is different than the visual feedback devices described in much of the previous research. Rather than using an input device to manipulate a cursor on a 2D surface or screen, as described in the reviewed research, the participants of this study instead use an input device (controller) to pitch and rotate the camera to centre its view on a target that exist in a 3D virtual environment. While this is different, the targets are located in the virtual environment directly on top and next to one another so they effectively produce a 2D surface of visual feedback for the participant. The centre of the camera’s view is the cursor and, thus, the same measurements for trajectory or direction found in the reviewed research can still be utilized. The controllers available for modern video game consoles (like the XBox One controller selected for this study) are designed for handheld operation while viewing an upright monitor. While this may provide some difference in context, the setup of the virtual environment presented to the participant and the control device they were tasked with manipulating in this study is quite similar to the setups found in the reviewed research.

Performance measures in Educational technology

The following section provides examples, moving from historical to more recent, of how performance measures within the context of virtual environment have been used in research. Although technology has progressed, the measures have remained remarkably similar. For example, in as early as 1981, Jones, Kennedy, and Bittner began testing the effectiveness of using a video game for the ‘performance testing’ of US-Navy Enlisted participants. The study tasked participants with playing a portion of the ATARI 2600 video game Combat (Atari, 1977), namely the Air Combat portion of the game, which the researchers claimed, “had substantial face validity for many tasks of military interest,” (1981, p. 145). Using a standard ATARI 2600 video game console controller, participants were measured on their ability to control a virtual aircraft in a rudimentary virtual environment, firing missiles to destroy enemy aircraft within a defined period of time. Their performance was measured on a ‘hits per trial,’ or ‘hits per game,’ basis, which meets the definition of performance used earlier, as the hits were clearly measured, observable, characteristics during each trial/game. Similarly, in the late 1980’s, researchers at the University of Manchester, UK, compared students’ performance over a series of gameplay sessions playing a custom designed video game called Space Fortress to scores they achieved on a standardized IQ Test (Rabbit et al, 1989). Participants in their study were scored by the game automatically on their ability to navigate a spaceship in a virtual environment and destroy a fortress by aiming and firing missiles at it. Mané and Donchin (1989) would summarize Space Fortress’ achievements as a “tool for the study of complex skill and its acquisition” (p. 17). Players of the game were awarded points when the fortress was hit and eventually destroyed.

Points were removed when the player's spaceship was hit by the enemy's projectiles, or when the player attempted to fire missiles after their original supply of 100 had run out. As before, in the case of the Atari 2600 game Combat (Atari, 1977), participants' performance was measured on clearly observable characteristics, in similar tasks. However, the Space Fortress game added a subtractive element to the scoring for an observable characteristic that the participant was encouraged to avoid doing. Performance then, can be a measure of observable characteristics that are desired or undesired in the experimental design. This is supported by the learning curve theory reviewed previously.

A similar example of measuring performance can be found in the domain of cognitive load theory, where measuring performance by observable characteristics is important to the field and often utilized. As described by deLeeuw and Mayer (2008) and Sweller, Ayres and Katyuga (2011), cognitive load can be measured by introducing a secondary task to another primary task and checking reaction times on the secondary task. For example, observable characteristics being measured could be: the elapsed time from the start of a multimedia presentation to the point where a participant notices a change in its background colour which they indicate by pressing a button on a keyboard or handheld controller. A longer time for a participant to react to the secondary task, would indicate the primary task required higher levels of cognitive load on the part of the participant (deLeeuw & Mayer, 2008). Haji, Khan, Regehr, Drake, de Ribaupierre, and Dubrowski (2015) extended this idea in the very specific context of a simulation for surgical students who were asked to tie one handed knots around a wooden dowel while monitoring a screen that simulated a patient's heartbeat. If the simulated patient's heartbeat changed within a certain predetermined parameter, the participant was tasked with pushing a footpad. The software utilized in the study measured three observable characteristics within each trial: the number of times the heart rate changed, the number times the change was identified by the participant, and the reaction time to the change after it was presented to when it was identified (Haji et al, 2015). Also in the medical field, a series of concurrent studies by Jalink et al (2014,2015) and Rosser et al (2017) assessed the impact of video game playing on basic and advanced laparoscopic skills using a combination of commercially available and custom designed video games. The researchers utilized multiple observable measures of performance including the scores obtained in the two video games and the total time taken to complete specific standardized tasks using a robotic laparoscopic device.

There is a history of using very specific, observable, characteristics of a skill to measure performance while using commercially available or custom built educational technologies. Given the nature of this study, it was possible to select a set of performance measures related to the very specific characteristics of the skill. Two measures were selected as being most applicable for this study: accuracy and completion time. Accuracy is measured as the distance from a target where better performance is characterized by a lower score. Completion time per task is the elapsed time between the start of each task and the participant completing it, also characterized by a lower time indicating better performance.

Measuring Performance in Virtual Environments

Virtual environment research, though still relatively new in the field of Education, has seen substantial growth in recent years. As such, the measures of performance in these studies continues to evolve and change to meet the needs of the research. As it has been discussed earlier, the measures must be observable and measurable to be effective for analysis. A virtual environment could be set up to measure a cognitive process or skill, or a physical/psychomotor skill just the same. For example, in addition to research involving virtual environments reviewed earlier (Jones et al, 1981; Rabbit et al, 1989; Mané & Donchin, 1989), the research of Meng and Zhang (2014) evaluated way-finding performance during higher stress situations. They utilized performance measures of total time and total distance travelled when completing a task of evacuating a building in the virtual environment—both of which were objectively measured by the software. Similarly, Slone et al (2014) had participants perform a repeated measure wayfinding task in a virtual environment. Their research analyzed performance measure data in the form of non-optimal route counts (error) and additional time used above a minimal possible time (delay score), which was derived from a ‘perfect run’ established prior to testing. Together, the measures were used to determine the participant's performance in the virtual environment and were analyzed for how they progressed over the subsequent trials in different orientations of the environment. Bekele et al (2014), used performance measures to assess a virtual environment for facial affect recognition in adolescents on the autism spectrum compared to adolescents who were not on the spectrum, using simple measures of accuracy, response latency, and ratings of response confidence. All three variables were measured within a purpose built virtual environment that presented participants with a computer generated animation of a person creating a facial expression. This was followed by a list of responses the participant would select from to identify the expression as well as a Likert scale to indicate the confidence they had in the response. Participants were also timed by the software to record response latency for each trial. The net result was a data series that would be used to compare performance with respect to the three variables between the two groups of participants. Rogers, Bowman, and Oliver (2015) chose to use the built-in objective system of a commercially available FPS video game for their research. The video game had, itself, a system of variables involving the accuracy of the player when shooting targets, in addition to the correctness of being able to do what is asked of the player—within a time limit—which is all manifested in the games story-based levels or missions. The ability of the participant to play the game successfully, as it was intended to be played, was then used as a performance measure while they were exposed to different controller types and mappings while playing. Huegel, Celik, Israr, and O'Malley (2009) used a virtual environment to validate expertise-based performance measures of trajectory error and input frequency. The researchers stated that these measures capture the key skills of a specific target shooting task in a virtual environment using a joystick to control the shots. In essence, their measures do not differ too greatly from those used in previously mentioned research referring to accuracy. However, their analysis and validation of these measures in particular, were considered when determining which measures of performance were utilized in this study.

For clarity, the performance measures previously presented all provide examples where the virtual environment itself is being used for measurement and the measurement is itself integrated into the virtual environment. The goal is to use the virtual environment as a venue to facilitate performance measurements. The goal is not to evaluate the use of first person camera controlled virtual environments. The use of virtual environments in this domain has already been established as a viable option for teaching and learning in previous sections. In many cases, studies which look to measure the effectiveness of a treatment which utilizes a virtual environment will involve some form of external instrument. This is typically because the control treatment being compared does not utilize the virtual environment. A simple example of this distinction can be found in the research of de Castro, Bissaco, Panccioni, Rodrigues, and Domingues (2014) wherein their study measuring the effect of a virtual environment on the development of mathematical skills in children with dyscalculia compared to traditional methods and did, indeed, involve the use of a series of video games. All of the performance measures, however, were made using instruments outside of the virtual environment using a scholastic performance test. This is in contrast to the virtual environment being the venue in which the treatment would occur, as is the case of the research of Meng and Zenge (2014) who very specifically note that the effectiveness of virtual environments for way-finding research has been long since previously established, allowing their research to concentrate entirely on analysis of performance measures made while comparing different conditions within their purpose built virtual environment. This is also the case for this study. For this study, a particular and specific element involved in the use of a virtual environment is being analyzed—first person camera control y-axis mapping. All of the treatment levels exist within the context of the same virtual environment, so it is not only feasible but also desirable to select performance measures which can be observed and measured within the virtual environment itself.

Measures of Individual Differences affecting Performance and Learning

Throughout the history of performance and learning research, the development of methods to measure individual differences has been an ongoing process of finding, verifying, and refining procedures. In the broad field of psychology, individual differences in performance and learning are often credited to differing levels of ability, i.e., mental ability, which is used to describe “a person’s performance on some task that has a substantial information-processing component... when that person is trying to perform that task as well as possible… the exact nature of which is unfamiliar to them, but for which they have the necessary cognitive skills” (Cooper, 2010, p. 118-119). As a result of the individual differences, there can be observable and measurable differences in performance or ability. Jonassen and Grabowski’s (1993) *Handbook of Individual Differences* refers to such examples as aptitude-treatment interactions, offering the example of measuring intelligence in terms of IQ with a standardized IQ test, and achievement by way of a test of mathematics, for example, “following instruction in which the learners were given no remedial help” (p. 24). As scores on the IQ test increased, scores on the math test also increase—evidence of a positive correlation. Being aware of the potential for interactions from individual differences is of great importance to this study, as is made evident by the selection of pre and post tests used to measure individual differences among participants that have been confirmed in previous similar research as having an effect on performance in virtual environments.

Early research in the field of individual differences affecting performance and learning was spent primarily determining which abilities could be measured, and then, subsequently, creating and validating instruments to do so. Initially it was thought that a single factor of general ability could be derived from a series of tests of other abilities such as vocabulary, visualization, and mathematical ability among others (Spearman, 1904). Later it was theorized that a single general ability factor was not possible and that a list of *primary mental abilities* could be used to measure individual differences (Thurstone, 1938). This was supported and expanded with research which produced different lists of factors scales and subscales (Vernon, 1950; Horn & Cattell, 1966; Cattell, 1971; Ekstrom, French, & Harman, 1979; Hakstian & Cattell, 1978; Kline & Cooper 1984; Carroll, 1993). The Compressive Ability Battery (Hakstian & Cattell, 1975), for example, contained 20 primary ability tests, for abilities such as verbal ability, numerical ability, spatial ability and mechanical ability. Similarly, the Kit of Factor-Referenced Cognitive Tests (Ekstrom et al., 1979) contains two or more tests for each of 23 cognitive factors, such as: speed of closure, word fluency, induction, associative memory, logical reasoning, and spatial orientation. Spatial orientation is defined in the kit as “the ability to perceive spatial patterns or to maintain spatial orientation with respect to objects in space”

(Ekstrom et al., 1979, p. 67), and is measured using one of two tests: the card rotation test, or the cube comparison test (Ekstrom et al., 1976). As this study has a spatial component, a more recently developed measure of participants' spatial orientation aptitude developed by Hegarty and Waller (2004) was used to measure and control for any individual differences with respect to spatial aptitude effecting performance—please consult the method section for a description. Cooper (2010) notes that tests of mental ability or aptitude are different than tests of *attainment*, which are tests or measures of "how well individuals have absorbed knowledge or skills *that have been specifically taught"* (p. 118), this time offering the example of a simple geography test given to students, based on items sampled from a course syllabus. For this study, then, measures of specific mental abilities or aptitude were selected over measures of attainment.

Measures of Individual Differences that may Affect Performance in Virtual Environments

As was reviewed earlier, individual differences related to computer/video game experience (Barlett, Vowels, Shanteau, Crow, & Miller, 2009; Frey, Hartig, Ketzel, Zinkernagel, & Moosbrugger, 2006; Jalink et al, 2015; Jalink et al, 2014b; Mayer et al, 2013; Rosser et al, 2007; Sanchez, 2012; Smith & Du'Mont, 2009; Spence & Feng, 2010; Tsai et al, 2012; Walkowaik et al 2015), immersive tendencies (Frischmann et al, 2015; Walkowaik et al, 2015), presence (Wirth et al, 2007; Frischmann et al, 2015; Lyons, 2010; Skalski et al, 2011; Klimmt & Vorder, 2003; Witmer & Singer, 1998), and spatial ability (Santone, 2009; Shute, Ventura, & Ke, 2015; Spence & Feng, 2010), have been explored in virtual world research as affecting, or potentially affecting, performance in virtual environments. Computer/video game experience has been and can be measured in multiple ways. In some cases, self-reported questionnaires utilizing Likert scales containing questions like 'how often do you use a computer?' or 'while in high-school, how many hours did you play video games?' are implemented. (Barlett et al, 2009;

Mayer, Warmelink, and Bekebrede, 2013; Rosser et al, 2007; Smith & Du'Mont, 2009; Walkowiak et al, 2015). In other cases, the researchers have provided the computer experience by way of exposure to video games. In these cases participants are asked to play a video game—commercial or custom made—for a certain amount of time. The study then uses the video game play as a treatment level when researching the effect it has on the development of another skill (Barlett et al, 2009; Jalink et al, 2015; Jalink et al, 2014a; Sanchez, 2012; Smith & Du'Mont, 2009; Rosser et al, 2007; Waxberg et al, 2005). Another measurement that can complement the self-reported computer experience measures is a measure of exposure to computer software or video games specifically. This measure has been employed by Boechler et al (2008), which involved modified an existing test, the Magazine Title Recognition Test (Stanovich & West, 1989). In the Magazine Title Recognition Test participants are asked to identify 20 popular titles of books, magazines, or other print media that are mixed up along with 20 foils—fake, but believably named title—to account for guessing. Boechler et al (2008) modified the test by replacing magazine titles with popular software titles from different categories including video games, productivity software, academic software, mobile applications, and Web 2.0 application, with a similar proportion of 'software-sounding' foils to create a Software Recognition Test (Boechler Ingraham, Marin, & deJong, 2016; Boechler, Dragon, & Wasniewski 2014; Boechler, Carbonaro, Stroulia & Gutierrez, 2011). While a Software Recognition Test is itself not a measure of computer or video game experience, it is an objective measure of exposure, as opposed to a subjective (self-reported) measure of experience. For this study, then, the Software Recognition Test developed and utilized by Boechler et al (2008) would be further modified to narrow in on video game exposure and even more specifically first person camera controlled video game exposure. Ultimately, for this study, it was determined that a combination of the original SRT employed by Boechler et al (2008) and a number of FPS video games would provide an objective measure of both general computer exposure and specific FPS video game exposure. Because the original SRT contained a number of video games as part of its creation, coupled with the fact that many of the most popular video games are, already, FPS games, the modification was not onerous and would produce a single, objective, measurement of both specific first person camera controlled video game software exposure within a general computer exposure. This would then be coupled with a self-reported, Likert style, video game experience questionnaire to provide two individual difference points of data for each participant. Further details on the creation of the first person software recognition test and the video game experience questionnaire appear in the method section of this paper

Measuring individual differences in terms of immersive tendencies and presence, when accounting for the effects they may have on performance is also a consideration for this study, but the field is broad and some amount of specificity is required. Research related to virtual environments has found use in validated instruments such as the Presence Questionnaire and Immersive Tendencies Questionnaire developed by Witmer and Singer (1998) (Frischmann et al, 2015; Lyons, 2010; Walkowiak, 2015) or the Temple Presence Inventory developed by Lombard et al (2000), which specifically targets spatial presence (Skalski et al, 2011). These instruments are characterized by a series of factor referenced questionnaires which specifically target the desired ability or phenomena. Similarly, measuring spatial orientation abilities has been accomplished in virtual environment research utilizing standardized tests such as the Purdue Spatial Visualization Test (Guay, 1976), or the Spatial Orientation portion of the Kit of Factor Referenced Cognitive Tests (Ekstrom et al, 1976), (Sanchez, 2012; Santone, 2009). Both of these tests involve a similar set of tasks in which the participant is asked to mentally rotate an image and select, from a series of options, the same object rotated as described. For their part, Frishman et al (2015) argue that spatial ability and spatial orientation are not entirely the same thing, and preferred the use of the spatial orientation portion of the Guilford-Zimmerman Aptitude Survey (1948), arguing that:

> Rather than the conceptualized feeling of presence being focused on the object (e.g., avatar, vehicle) being moved through virtual space, it would be focused on the user's feeling of orientation *from within* the virtual space… to include this idea within the framework of its hypothesized relationship with inversion preference, it seems to be more apt to measure spatial orientation rather than more common spatial ability measurements of object rotation (p. 1793).

The Guilford-Zimmerman (1948) survey attempts to measure spatial orientation by way of presenting participants with a series of pairs of illustrations from a first person perspective looking off the bow of a boat. The perspectives are drawn to show a rotation of the boat that the participant is to imagine they are standing on. The participant is then asked to select from a series of diagrams, each showing a possible rotation of the boat. While the argument made by Frishman et al (2015) is sound, their study did not reveal any differences among participants and, thus, go on to suggest other spatial intelligence and cognitive models be considered in future study. It should also be noted that in the development of the Kit of Factor Referenced Cognitive Tests, Ekstrom et al (1976) noted that Zimmerman (1954) did follow-up the development of the Aptitude Survey with arguments that the spatial orientation measures in the survey were not entirely sufficient on their own, suggesting that a more complex mental ability may account for individual differences. The findings of Eyal and Tendick (2001) who explored the effect that spatial ability had on the performance of novice participants while tasked with manipulating a virtual laparoscope in a 3D virtual environment, found that all three of the standardized tests used in the study: Card Rotations Test (Ekstrom et al, 1976); Paper Folding Test (Ekstrom et al, 1976); and Object Perspective Taking Task (Kozhevnikov & Hegarty, 1999), had significant correlations with performance in the virtual environment. Hegerty and Waller (2004) would later further improve and validate their Object Perspective Taking Task as an accurate measure of spatial ability by creating a second, more reliable, revision. With all of these previous findings considered alongside the potential to require a measure of spatial ability for this study, there was solid support for some sort of standardized spatial ability test—orientation, perspective, or otherwise—to be used as a premeasure to account for the effect that individual differences among participants may have on performance in the subsequent experimental tasks. While no standardized test could be found that utilizes a virtual environment, this study implemented Hegarty and Waller's (2004) Object Perspective Taking Task, which is a standardized test of spatial ability and is further reviewed in the methods section of this paper.

Determining Individual Differences Related to Preference of Controller Mapping in First Person Camera Controlled Virtual Environments

Determining individual differences for camera control y-axis mapping preference in first person camera controller virtual environments is a particularly under researched element in the fields that have interest in performance and/or learning in 3D virtual environments. The work of Frischmann et al (2015) is one of the few exceptions. Participants of their study were asked if they could indicate if they always, sometimes, or never used an inverted y-axis controller mapping. This method of determining preference leaves the data open to a number of potential errors, which was noted by the author: namely, the degree to which the answer of 'sometimes' would be selected by participants because of their familiarity to different games that are not necessarily first person camera controlled games (ie. Flight simulators, where the control is meant to mimic the operation of an airplane yoke, rather than of a human-like avatar, and would be in the inverted mapping as a result). A further point of potential error is the participant's experience with first person camera controlled games. As was suggested earlier, many users have the potential to be aware of only one type of y-axis controller mapping by virtue of being exposed first to whatever setting is the default setting for the video game, simulator, serious game, etc enacted in the virtual environment. It also does not account for a situation where a previous user may have set the camera control y-axis mapping to the *alternate-from-default* setting, thus causing the participant to adopt the previous player's preference as default. Regardless, the issue with asking the participant outright leading to potential error stems from the reliance it has with the participant being familiar with the two mappings to begin with, which cannot be guaranteed. To this end, then, the development of a standardized test or adoption of a test, or check, used in popular commercial software to determine first person y-axis controller mapping preference in 3D virtual environments has the potential to be beneficial not only for the purposes of this study, but also the field in general.

While a review of methodology in relevant fields to this study revealed very little in the way of a standardized first person camera controlled y-axis mapping preference test or check, there are two avenues that may be explored in developing such a test. First, there is certainly value in looking to industry standards in popular media (eg. consumer video games) for such a test, and second to consider the adaptation of another test for a similar preferences (eg. handedness or dominant kicking foot). Handedness, sometimes referred to as laterality, can be measured using a scale known as the Edinburgh Inventory of Handedness (EHI) (Oldfield, 1971), which has become the defacto measurement of handedness from its inception (Fazio, Coenen, & Denny, 2012). The inventory of 10 items is presented to an individual, asking them to indicate preference of which hand they would prefer for a series of activities: writing, drawing, throwing, using scissors, brushing teeth, using a knife (without fork), using a spoon, brooming (upper hand), striking a match, or opening a box lid. The results are then collected and a score of handedness is calculated. The age and accuracy of the EHI has since been argued by Fazio et al (2012), who have gone on to suggest an improved measure: the Fazio Laterality Inventory (Fazio et al, 2013), which modernized some of the items, while also accounting for an individual's own preconceptions of their handedness and for any injuries or impairments the individual may have which would influence their preference. The Fazio Laterality Inventory includes the following items: writing, drawing, waving hello or goodbye, using a TV remote, snapping ones fingers, scratching an itchy nose, pointing at something in the distance, throwing, reaching to pick up an object, and using a hammer. However, using a computer mouse was not included because, as Fazio argued in the defense of the items in the inventory, “the universality of items was considered (eg. those who are incarcerated or elderly may not use a computer mouse)” (2013). It is also important to consider that computer mice are generally designed to be used right-handed, which is unlike a TV remote or hammer for example, or sports equipment where left-handed versions are readily available (eg. golf clubs or hockey sticks). While both indexes (Edinburgh, or Fazio) are still vulnerable to the issues of self-reporting, each measure’s aim is to provide researchers with the same thing: a score that can be compared to experimental results to determine if individual differences related to handedness may have an effect on a particular outcome. The difference between these inventories and a test or check for first person camera controlled y-axis mapping preference, is that the index relies on the individual already being able to self-identify a level of preference for each item and the items are everyday activities, which is unlike the use of a first person camera controlled 3D virtual environment, which is a potentially novel activity for many people.

Returning to the possibility of adapting an existing test or check, a somewhat more similar test or check for individual difference may be found in the popular activity of snowboarding. Snowboarding involves an individual’s legs to be bound via special boots and bindings to a piece of equipment (snowboard) which is designed to travel with one foot facing forward down a hill. While an expert snowboarder will travel with either foot forward and change multiple times during the activity as their skill increases, they will still have a dominant or forward facing foot. It is very important for a beginner's forward facing foot to be determined when preparing their equipment. Ideally, an individual could self-identify their forward facing foot by selecting their non-dominant foot when kicking a ball. However, that would, of course, require the individual to know which foot they prefer kicking with. To this end, then, there is a well-known check many snowboard equipment experts utilize: the ‘push-test’. The push-test is administered by having an individual stand still with both feet together while being told to focus their gaze at an item or portion on the far side of the room in which they are standing. The tester then gives a slight, unexpected push to the individual’s back near their shoulders so they must step forward to stop themselves from falling forward. The foot that stops their fall should be their forward facing foot (which is also, often, their non-dominant kicking foot) (Wikihow.com, 2017). It is important for the push-test, however, that the individual does not expect the push, as this may influence their reaction. As with handedness, where most people are right hand dominant, there is a clear natural bias that most individuals fall into: left foot facing forward. In fact, the left foot facing forward stance it is referred to in snowboarding circles as regular stance, while right foot forward stance is referred to as goofy stance, both of which are derived from

1960's surfer culture. Unlike handedness, however, the activity of snowboarding is somewhat novel and not an everyday activity or preference many are familiar with, so the choice to set up snowboard equipment for a beginner in particular is binary as there are only two options: left or right foot forward facing, rather than on a continuum. The push-test provides a very simple and quick way to determine individual differences related to preference.

Industry Standard for Determining Individual Differences for First Person Camera Controlled Y-Axis Preference

Again, failing to find examples in the academic literature for a simple, quick, 'snowboard foot push-test' *like* check for determining first person camera controlled y-axis mapping preference, we can also to look to industry standards and consumer products such as video games, or simulations for a solution. Returning to consumer video games, there is a test or check, developed by the designers of the previously mentioned video game Halo: Combat Evolved (Bungie, 2001). The designers of early games in the Halo series were presented with the challenge of determining player preference for y-axis mapping, after initial market testing had revealed that many players were either being influenced by previous experience from the default control mapping of previously popular PC first person shooter video games, or were simply unaware of the availability of a different setting (J Griesemer, personal communication, March 7, 2017). Thus, the designers set out to develop a snowboard push-test, of sorts, for the first person camera control y-axis mapping preference of their players, which would be presented in the game as one for the first tasks the player would experience. The development team was familiar with needing to quickly determine a player's preference for y-axis controller mapping, as they often had small test groups come in during early builds of the game; since a developer was running the test, however, they implemented a quick 'check' by handing the tester a controller and simply asking them to ‘look up,’ and watch the way the tester would manipulate the controller by either pushing forward or pulling back on the control stick (R Pagulayan, personal communication, July 27, 2017). Thus, the basis of the y-axis mapping preference check was established, which was then operationalized into the game and first implemented in Halo: Combat evolved (Bungie, 2001). It was reused, with minor modifications, in the sequel Halo 2 (Bungie, 2004) and repeated in subsequent titles of the series thereafter. The first implementation of the check in the Halo series tasked the player with approaching an ‘optical diagnostic station,’ where they must manipulate the controller to orient the camera to point at five different glowing lights on the screen, which are setup in a cross pattern with all of the flashing yellow lights in the player’s view when the task begins (see Figure 8). As the targeting reticle in the center of the screen meets each light, the light changes colour from flashing yellow to solid green. Once the player completes this task for the first time, a voice comes over the speaker system in the room saying, “Sir, I’m getting some calibration errors, I’m going to invert your looking pitch so you can see if you like it better that way.” The camera control y-axis mapping is then switched to an

Vertical looking is now inverted
Target each of the flashing lights
Saving...

Figure 8. Screenshot from Halo: Combat Evolved, during the look test for Camera control y-axis mapping preference (Bungie, 2001)

inverted y-axis mapping and a message, “vertical looking is now inverted,” is displayed on screen. The player is tasked with looking at the same 5 targets again and, once completed, the voice returns to ask, “is that better, or should I switch it back?” The player is then given the opportunity to change the y-axis controller mapping back to normal or leave it as inverted. Whichever the player chooses, the voice lets them know what their choice was, and lets them know that it can be changed again later if so desired. This portion of the game is all done within narrative context and is an example of how the developers identified that there was a need to let novice players be aware of the possibility to switch the mapping. It should be noted, however, that the experience of both mappings was forced on the player. The player was exposed to both the normal and inverted camera control y-axis mappings, whether they were already aware of their preference or not. The modification made when Bungie released the second game in the

Table 2.

Halo 2 (Bungie, 2004) Camera control y-axis mapping preference check logic

1st Sequence Commands		2nd Sequence Commands			1st Sequence Commands		2nd Sequence Commands		
Up	Down	Up	Down	Result	Up	Down	Up	Down	Result
Input by User/Player					Input by User/Player				
↑	↓	↑	↓	normal	↑	↑	↑	↓	normal
↑	↓	↓	↑	inverted	↑	↑	↓	↑	inverted
↑	↓	↑	↑	inverted*	↑	↑	↑	↑	inverted*
↑	↓	↓	↓	normal*	↑	↑	↓	↓	normal*
↓	↑	↑	↓	normal	↓	↓	↑	↓	normal
↓	↑	↓	↑	inverted	↓	↓	↓	↑	inverted
↓	↑	↑	↑	inverted*	↓	↓	↑	↑	inverted*
↓	↑	↓	↓	normal*	↓	↓	↓	↓	normal*

* Indicates that the second sequence inputs were inconsistent with either camera control y-axis mapping preference, so the software selected a mapping based on the second input in the second sequence only. In these cases an additional third sequence was presented to the user to confirm their preference.

Halo series, Halo 2 (2004), saw the developers refine the y-axis preference check slightly by making the experience more predictive, rather than simply exposing the player to both the normal and inverted y-axis controller mappings. When Halo 2 begins, the player is immediately asked to perform the check, rather than having them approach another ‘optical diagnostic station.’ This time the player also has a ring of only four targets, at the cardinal extremes of the screen to look at. The sequence is also more efficient: a voice instructs the player to simply “look up, at the top target.” At this point, though, the controller is mapped in such a way that regardless of the input the player makes (ie. pulls back on the control stick, or pushes forward), the camera will tilt upwards. When the targeting reticle meets the top target, the voice instructs the player to then look down at the bottom target, and again the control mapping is temporarily set to tilt downward regardless of input from the player. This first sequence is meant to act as a familiarization sequence. Both the inputs from the first and second sequence are recorded. If the player manipulates the controller in a manner consistent with the normal y-axis mapping, or inverted mapping, the voice simply says “ok, great” and the game progresses with the appropriate mapping. If, however, the player makes multiple inputs in different directions, or uses the same input for both commands, up and down, the game’s programming attempts to determine the mapping the player might use, based on the logic found in Table 2. The voice returns and suggests that “tracking looks sketchy, I'm going to run you through the full diagnostic” and proceeds to request the player look at all the targets on the screen, but now also provides the option to switch to an inverted y-axis camera an alternate control mapping, normal or inverted, and then back again, until the player is satisfied with the choice, while still being told that it can be changed later if desired. This refinement to the first person camera control y-axis control mapping preference check became the standard for the Halo series and continued through the recent titles of the series. According to the lead designer, the sequence was quite accurate, and was able to correctly determine the mapping that the player preferred 90% of the time, which the development team defined as any situation where the user did not later change the mapping while playing the game (J Griesemer, personal communication, March 7, 2017). Given the accuracy of this method, we implemented a similar first person camera controlled y-axis mapping preference check in to the procedure of this study. It was used to determine the participant's preference, whether they knew it or not, and was recorded so it could be used to setup the trials for baseline and adaptation performance in the tasks presented to the participant.

Review of Research Approach and Design

As Keppel (1991) states, "the basic requirements of an experiment are simple: differential treatments are administered to different groups of subjects (or to the same subjects in different orders), and performance on some response measures is observed and recorded following the administration of the treatments" (p. 5). Before describing the design and results of the study, a review of research design follows. There are a number of dichotomies in research design that must be considered: theoretical vs. applied, laboratory vs. field, participant report vs. researcher observation, quantitative vs. qualitative (philosophical), objective vs. subjective (data and collection), and statistical vs. descriptive (analysis) (Gliner, Morgan, & Leech, 2011). This study, then, has an applied, laboratory, researcher observed, quantitative, objective, statistically analyzed design. The next consideration is the research type or approach to be utilized. A randomized experimental approach looks to make comparisons across groups and has random assignment of participants to all elements (groups, treatments/conditions etc.) of the study, while a quasi-experimental approach has an active independent variable, but the group assignment is no longer randomized. These specific approaches are considered to be experimental research general approach types (Gliner et al, 2011). A comparative approach looks to make comparisons between groups on a dependent variable, but the groups are based on an attribute independent variable (ie. gender) and are compared to one another, while an associative approach looks to search for connections within a series of continuous variables for the same group of participants. These specific approaches are considered to be nonexperimental research general types (Gliner et al, 2011). Only a purely descriptive approach remains, which refers to research questions that use only descriptive inferential statistics (Gliner et al, 2011). This study, based on research questions that will be outlined later, takes a primarily quasi-experimental approach. We are dealing with an active independent variable—the participant's natural preference for first person camera control y-axis mapping—which distinguishes it from any approach that requires randomization.

Method

Research Questions

Primary Question.

In first person camera controlled 3D virtual environments, what is the effect of forcing camera control y-axis mapping to an individual's nonpreferred mapping on performance?

Secondary Question

In first person camera controlled 3D virtual environments, is there a difference in the performance between those who prefer normal or inverted camera control y-axis mapping, while using a preferred or nonpreferred mapping?

Participants

Participants for this study were recruited from the Faculty of Education's Department of Educational Psychology Participant Pool at the University of Alberta. Enrollment in the pool is voluntary for students who are enrolled in select undergraduate courses in the same department.

The sample group included 156 undergraduate students, between the ages of 18 and 55, 139 of which were under the age of 25. The homogenous nature of the participants is noted, and understood to be a limitation of this study. There is, however, an advantage that a relatively similar sample can provide, namely reduced subject variability in general (Keppel, 1991). Participants were not pre-screened or excluded for any reason other than their ability to interact with and manipulate the equipment being used. Participants were told during the sign-up process for the participant pool that they would be required to have normal or corrected to normal vision, and should be able to hold and manipulate a handheld device such as a video game controller. Ethical guidelines for research were adhered to as this study was subject to review and approval following protocol outlined by the University of Alberta Research Ethics Office. Ethics approval was obtained prior to any interaction with human participants.

Materials

Participants completed a number of different tests to establish a baseline of ability with respect to individual differences. They also performed a simple check to determine which first person camera control y-axis controller mapping preference the participant had, whether they were aware of the phenomenon or not.

To measure spatial ability, Hegarty and Waller's (2004) Object Perspective Taking Task was utilized. This test consists of 12 items, that each contains a configuration of seven easily distinguishable objects drawn on the top half of a standard letter sized sheet of paper (8.5" x 11"). The participant is then asked to imagine being at the position of one object in the display (the station point) facing another object (defining their imagined perspective within the array) and are asked to indicate the direction to a third (target) object. The bottom half of the page shows a picture of a circle, in which the imagined station point (eg. the stop sign) is drawn in the

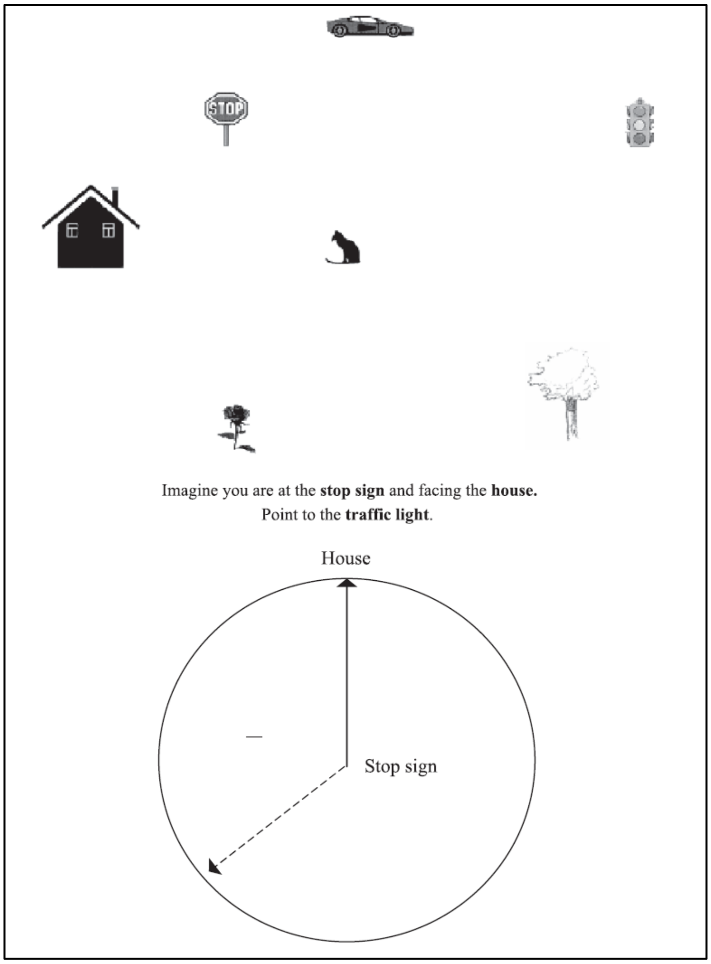
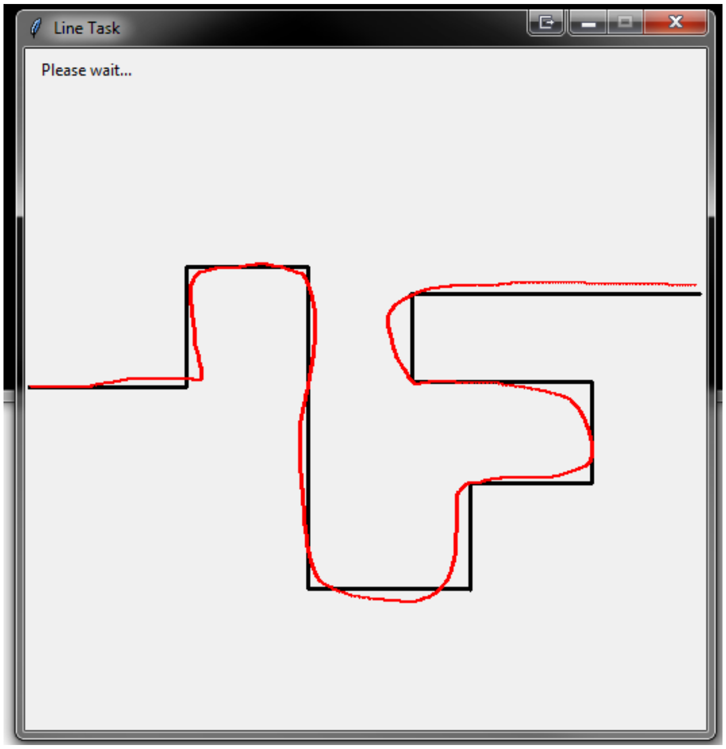


Figure 9. Sample Item from Object Perspective Taking Task. Hegarty and Waller (2004)

center of the circle, and the imagined heading (eg. direction to the house) is drawn as an arrow pointing vertically up. The task is to draw another arrow from the center of the circle to the edge of the circle indicating the direction to the target object (eg. the traffic light), as in Figure 9 (Hegarty & Waller, 2004). As the test protocol dictates, participants were instructed to complete as many items as possible within five minutes. Items are scored by comparing the line drawn by the participant to a quadrant of the circle which represents a correct response allowing the participant to be correct without being exactly precise.

To measure Computer Experience, a modified version of Boechler et al's (2014) Computer Experience Questionnaire was administered on a computer in the form of a digital survey. The questionnaire contains two parts. First, a series of self-reporting styled question related to video game use at four different times in their academic careers. For example, the question would read ‘please indicate how much time you spent playing VIDEO GAMES, on average, PER WEEK,’ which is matched to a grid with ‘in recent weeks,’ ‘while in high school,’ while in junior high school,’ and ‘while in elementary school’ on separate rows. Across the top of the grid, the following options are available: ‘not at all,’ 1-3 hrs,’ 4-6 hrs,’ ‘7-9 hrs,’ or ‘10 or more hrs.’ The next part of the questionnaire is an updated Software Recognition Test (SRT), first utilized by Boechler, Leenaars, and Levner, (2008), which has been used to measure a person’s previous exposure to computer software to predict a general ability related to computer software. The SRT is a modified version of Stanovich and West’s (1989) Magazine Title Recognition Test (MRT) and Author Recognition Test (ART), which has been shown to measures a general print and literature exposure to predict spelling ability, word recognition, and cultural literacy to a high degree of reliability (Cronbach’s Alpha of 0.84 for MRT and 0.85 for ART). The SRT, like the MRT, consists of software titles and an instruction that the participant identify any that they recognize. The items themselves are composed of five groups of four of the most popular titles currently available in the following categories: video games, Web 2.0 websites, mobile phone apps, productivity tools or apps, and academic or professional tools or apps, for a total of 20 titles. This is then matched, in each category, with 20 fake titles, that are believably named to act as foils to account for a participant selecting all of the titles to appear very experienced. The SRT is scored as total number of real titles identified, minus the total number of foils identified. The range in possible scores then is -20 to 20. To more accurately gather a measurement of participants’ exposure to first person perspective camera controlled software, particularly First-Person Shooter (FPS) video games, a further modification of the previously described SRT was developed for this study. The same format was used: 40 titles, 20 of which are real and 20 are fake but real sounding. However, in this case, 10 of the 20 real titles was derived from a list of the top rated FPS games (Turner, 2017), approximately 1/3rd of which were available exclusively on home video game consoles, 1/3rd of which were available exclusively as Personal Computer (PC) software, and the final 1/3rd available for both. The remaining 10 titles were taken proportionately from each of the existing categories of the updated SRT. Since there was a potential point of crossover with the updated SRT containing video games as a portion of its titles that could also be very popular FPS video games, adjustments were made to ensure there was no overlap. Thus, the version of the SRT used for this study is referred to as Software/FPS Recognition Test (FPSRT), though it is scored in the same way as the SRT. The FPSRT used for this study yielded a similar level of reliability to the MRT and ART (Stanovich & West, 1989) on which it was based—Cronbach's alpha of 0.86. To ensure that there was is no time limit for the Computer Experience Questionnaire, as well as to prevent the content from the FPSRT portion of the questionnaire from informing participants as to what sort of tasks they were asked to perform, it was administered after the experimental tasks.

To test Eye-Hand Coordination, as it is described in the psychomotor domain, but updated for digital devices, a newly developed Digital Eye-Hand Coordination test was utilized. The Digital Eye-Hand Coordination Test consisted of seven test items, in which the participant is presented (on a computer screen) with a black line drawn from the left edge to the right edge. The instruction on screen state that the participant must trace the line with the computer mouse from left to right, in its entirety, as close as possible to the target line. The task begins with four familiarization trials that are not measured. They contain a target line that is a straight line, a line with two corners, and two angled lines with two corners each. This is followed by two sets of three trials, first a set of three trials of horizontal and vertical lines with square corners, followed by a set of three trials that contain lines at different angles linked by acute, square, and obtuse angles. Each set of three is randomized within the set. The trials are scored by calculating the Fréchet distance, which is a mathematical measure of similarity between curves that takes into account the location and ordering of the points along the two curves, i.e., the target line and the line drawn by the participant (see Figure 10). A perfectly traced line will result in a Fréchet distance of 0. This test was developed using code derived from an open source Python script (Bareiss, 2014) obtained from Github.com, which is itself based on an algorithm designed by Eiter and Mannila (1994). The score assigned to each participant for the test is the mean average across the six measured trials. There is no time limit associated with this test.



Please wait...

Figure 10. Sample Item from Digital Eye-Hand Coordination Test

Finally, the participants completed a first person camera controlled y-Axis mapping preference check. This check is based entirely on the design of the check for preference made popular in the Halo video game series previously explained. The participant was provided a standard XBox One controller, connected to a computer. On screen they were presented with a 3D virtual environment that is viewed from the first person camera perspective, created using the Unreal 4 video game development engine (Epic Games, 2014). The camera view starts level with the horizon and the environment contains a target in the form of a red circle that is immediately above the crosshair/target reticle in the middle of the screen. The instruction printed on the screen states, “using the controller’s RIGHT STICK, please LOOK UP to the Red Dot.” The controller is then mapped to pitch the camera up whether the participant pushes forward or pulls back on the right analog stick. When the target reticle reaches the red dot target, it changes to green and the instruction changes to, “thank you.” The red dot target then changes position to immediately below the current camera position and the instruction changes to “Using the controller’s RIGHT STICK, please LOOK DOWN to the Red Dot.” The mapping is now switched to pitching the camera down, again, regardless of the input by the participant. Once the red dot target is reached, it changes to green and the instruction reads “thank you.” The camera is, at this point, roughly back to the starting point. The sequence of looking up then down at the red dot is repeated one more time in exactly the same format. Once completed, the inputs for each of the four movements are recorded and based on the same table of results used by the Halo series provided earlier (see Table 2), the participant’s preference for camera control y-axis mapping was determined and recorded. The result of the preference check was also saved and utilized for setup during the experimental tasks that followed in the virtual environment.

The experimental design for this study is based on the design employed by Miall et al (2004), in which blocks of trials are used in immediate succession of one another with different perturbations being added or removed for each trial block. There are two experimental tasks that were tested: a Target Selecting Task, and a Target Following Task. Both tasks were administered in a 3D virtual environment, created using the Unreal Engine 4 (Epic Games, 2015) video game engine which participants interacted with using a standard XBox One controller.

The Target Selection Task virtual environment contains eight possible targets that the participant must move the view of the camera to centre on, using a targeting reticle in the centre of the camera view as a reference. Four of the possible target locations are directly up, left, down, or right of the starting position, referred to as, ‘top,’ ‘left,’ ‘bottom,’ and ‘right,’ respectively. The remaining four target locations are on diagonals between the first four, equidistant from the centre of the screen, referred to as ‘top-left,’ ‘top-right,’ ‘bottom-left,’ and ‘bottom-right’. The targets appear in the environment such that only one is on screen at a time. A

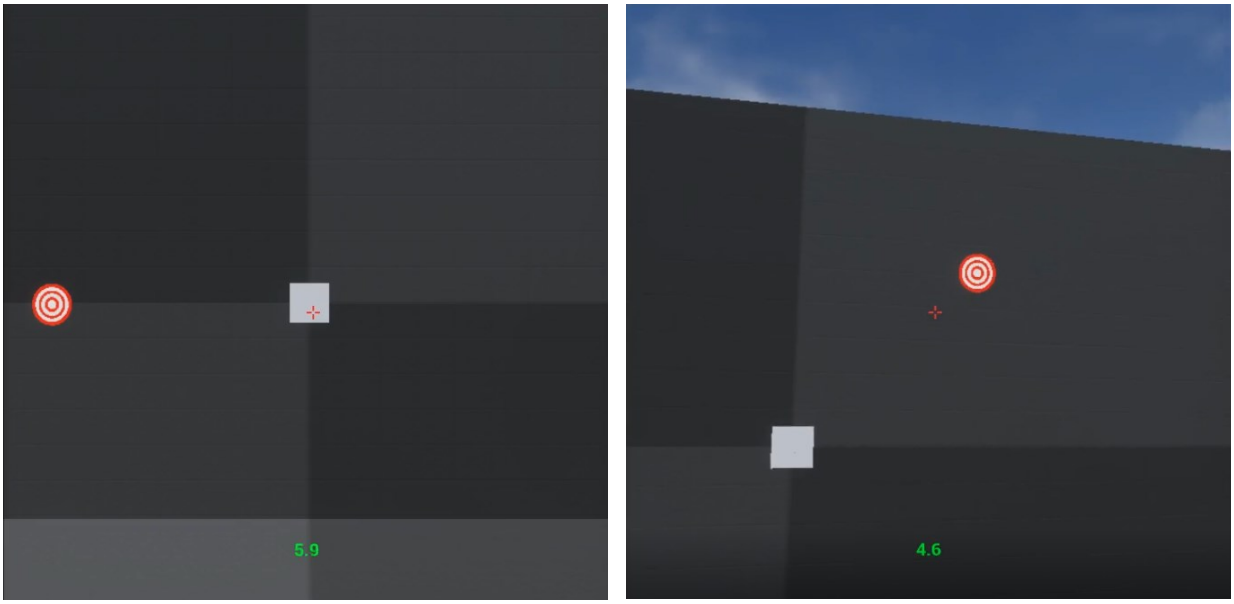


Figure 11 Examples of selection task trial, 'left' target and top-right target in progress.

box hovering in the environment, indicating the centre of where the targets may be located and referred to as a centreing box, is used as a guide to reset the view between trials. A trial consists of the participant being instructed to start with the targeting reticle in the centreing box. Then, following the appearance of one of the targets, the participant must select it by moving the camera view with the controller such that the targeting reticle is as close to the centre of the target and pull the right trigger of the XBox One controller (see Figure 11). The target disappears once selected and the participant must return the target reticle/camera view to the centreing box. As with the research of Miall et al (2004) twelve trials are repeated, in quick succession, to constitute a trial block, in a previously selected random series to ensure that each target appears at least once in each block. To produce a sense of urgency, as well as to standardize the time taken for each trial, there is a limit of six seconds from when the target appears to when the participant must select it. The time is shown counting down on the screen as each trial is completed. This is done to control for a possible co-variate of time per trial, as well as to ensure all of the trials could be completed in the time allotted by the participant pool for the study. Before starting any of the experimental trial blocks, to allow the participant to familiarize themselves with the procedure, instructions are displayed while a pre-recorded video demonstrating the task is shown. The participant then indicates their readiness by pressing a button on the controller to start the trial block. The first trial block of the Target Selection Task is setup such that the camera control y-axis mapping of the controller is matched to the participant’s preferred y-axis mapping which was determined by the previously completed y-axis preference test. This block establishes a baseline of performance for the participant. This is followed, later, by a trial block in which the camera control y-axis controller mapping is set to the opposite of the previous trial block—mismatched. In this trial block, visuomotor adaptation takes place. Two performance measures are collected per trial: accuracy, which is measured as the Euclidian distance from where the participants selects the target to the centre of the target; and time, which is the elapsed time in seconds between the target appearing and the participant selecting it. If the participant 'timed out,' the maximum time was recorded along with the location of the targeting reticle when six seconds elapsed. These results are then used in subsequent analysis to produce a learning curve for the participant in each trial block.

The Target Following Task follows a similar design to the Target Selection Task. The same 3D virtual environment is utilized and the participant continues to interact with it using the same standard XBox One Controller. For this task, however, the target does not appear in a single location. Rather, the target appears immediately in the center of the screen, within the centering box, and begins to move about the screen in a previously determined path with random points. (See Figure 12) Each path was created using a random number generator that would produce a point in the environment that was a minimum distance away such that equal length

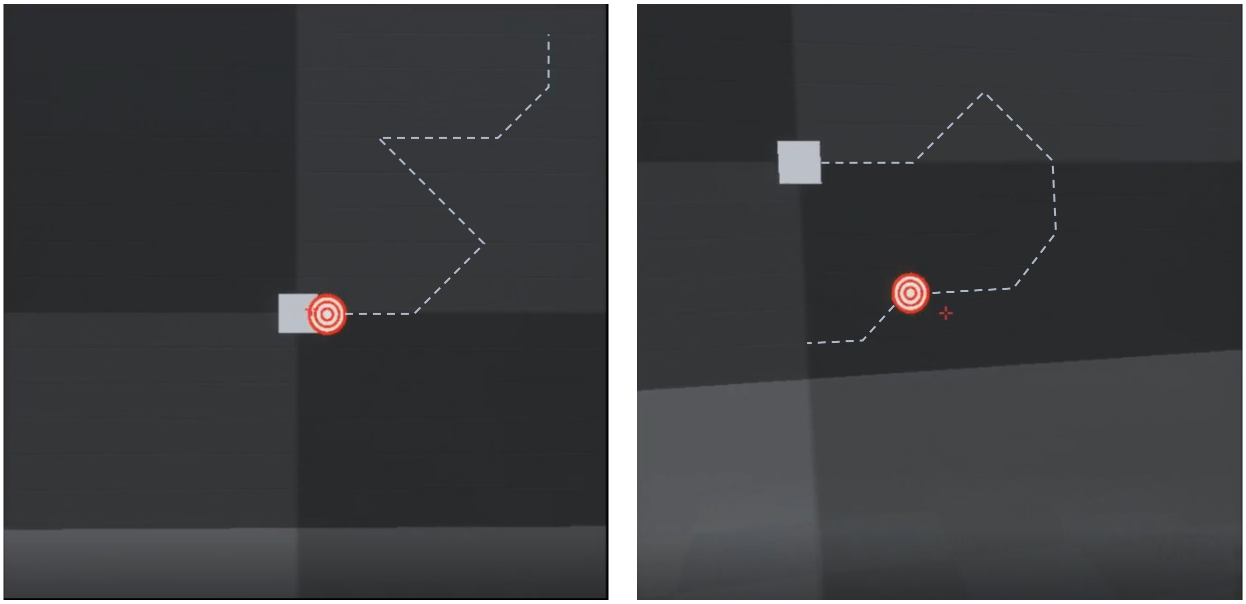


Figure 12. Sample trials of target following task- trial in progress (dashed line indicates path of travel for target)

paths were created for each trial. The participant is required to track the target as near to its centre as possible for the duration of its path of travel. The rate at which the target moves is roughly equal to half that of what the camera is capable of, which is done to allow a participant to ‘catch up’ to the target should they move in a wrong direction away from the target as a result of making a wrong input. As with the Target Selection Task, there are two blocks of twelve trials, the first of which is setup with y-axis mapping matched to the participant’s preference and then mismatched for the second block. Again, each trial is recorded but in this case the participant’s path is compared to the target path and a Fréchet distance (a mathematical measure of the closeness of two curves) is calculated, ultimately constituting the accuracy measurement. Unlike the Target Selection Task, however, the time taken to complete each trial during the Target Following Task is irrelevant as the target moves across the same distance at the same rate and thus the same amount of time for all trials. Once all of the trials were completed, the results were then used in subsequent analysis to produce a learning curve for the participant, taking into account performance in each trial block.

Each participant was exposed to both the Target Selection Task and the Target Following Task in both the mismatched and matched to y-axis mapping preference conditions, though not in that particular order (see Procedure). The participants were told in the study preamble that they would be required to complete four tasks, which, for the purpose of this document, are synonymous with trial blocks and are distinguished only for ease of language to the participant. For clarity, each task/trial block was titled one through four on screen during the study, though no mention of the controller mapping is made so the participant is not aware of when they are in the matched or mismatched condition. Between tasks, in addition to being shown instructions on what is required in each, the participant was asked to confirm when they were ready by pressing a button on the controller that is indicated on the screen, which clears the instructions and demo video for that task before the trials began.

Procedures

Upon arrival, and after completing a consent to participate form, participants completed a pen and paper version of the Objective Perspective Taking Task, followed by the Digital Eye-Hand Coordination Test administered individually on a computer. The participants were reassured that their performance on the two tasks had no bearing on their ability to complete or participate in the remainder of the study (nor was it a judgment of their general abilities otherwise). Following this, the participants were instructed to take hold of the XBox One Controller on the desk, at which point, when they were ready, they completed the first person perspective camera controlled y-axis mapping preference check, which determined the y-axis mapping—inverted or normal—the participant preferred. The results of the check were not communicated to the participants, though it was recorded by the software, as it was used in the subsequent experimental tasks that followed immediately. The program then used the result of the preference check to set up the y-axis controller mappings of the Target Selecting Task and then the Target Following Task, which occurred in the following order. Target Selection Task – matched condition, Target Following Task – matched condition, Target Selection Task – mismatched condition, and finally Target Following Task – mismatched condition. The reason for combining the Target Selection and Target Following trial blocks by condition is because pilot testing for the study with novice users revealed that the motor skill requirements for the Target Following Task were so much greater than the Target Selection Task, that reversing the order produced performance measure results on the Target Following Task that were extremely low and inconsistent, containing many trials with results that were outliers, making the data for an individual effectively unusable. While this could be seen as a potential source of error due to a practice effect, it was determined that the practice obtained during the Target Selection Task was ultimately relied upon by the study, so that the participants could actually perform the Target Following Task trials in a way that performance could be measured. Once completed, the participants were be presented with the Computer Experience Questionnaire, containing the First Person Software Recognition Test (FPSRT). These two elements were preferred to be administered after the experimental task, as their contents, particularly the FPSRT, could have informed and primed the participant to the experimental tasks. This sequence constitutes the entirety of the participation required of the individual and was designed to take no more than one hour total. In practice, however, the majority of participants completed the entire exercise in under 40 minutes.

Sample Size and Power

During the preparation phase of this study, before any participants were run through the experimental procedure, the researcher had predicted that a two-way repeated measures ANCOVA would be the desired form of analysis for the design. Subsequently, it was determined that in order to obtain a minimum power level of .80 or higher—normally controlled through appropriate sample sizes—as Keppel (1991) strongly suggests, a power analysis was conducted in G*Power (Faul et al. 2008) for a repeated measures design with two levels, five covariates, and two dependent variables using an alpha of 0.05, and a small effect size ($f^2 = 0.10$). The result of the analysis was a minimum sample size of 72 participants. Therefore, the sample size of 139 participants obtained was more than what was determined to be required. When determining the effect of y-axis preference on performance, the secondary research question, the number of groups is increased to four and, with the same assumptions, an analysis in G*Power predetermined a minimum sample size of, again, 72 participants. However, this would require half of the participants to be equally distributed in the two y-axis preference groups (those who prefer inverted and those who prefer normal y-axis mapping) for each condition. With this in mind, using previous research by Frischmann et al. (2015) as a guide, 10-15% of the population can be expected to prefer the inverted mapping. Therefore, a sample size of 240+ participants would need to be obtained, to ensure there were equal group sizes. Indeed, the sample obtained of 139 participants, limited by the participant pool quotas, was not sufficient. Moreover, only 11 participants were determined to prefer the inverted mapping, following the results of the preference check portion of the study procedure. Following data collection, and after looking more closely at the raw data when it was compiled, it determined that a different form of analysis, a hierarchical linear model would be preferred to the previous analysis chosen during the preparation phase.

Research Design and Statistical Analysis

The study that was executed is a quasi-experimental approach, using a repeated measures design (Keppel 1991), with performance measures related to first person camera controlled tasks in a 3D virtual environment as the response variables. The independent or condition variable is the matched or mismatched y-axis control mapping setup to preference of the participant. Specific response variables common to all four tasks/trial blocks are accuracy, which is a generally accepted measure of visuomotor and motor skill performance (Shmuelof, Krakauer and Mazzoni, 2012), In this study it is measured as the distance (specifically, the Euclidean distance) from each target in a trial as well as time elapsed to complete each trial during the Target Selection Task, and Fréchet distance for the duration of each trial during the Target Follow Task.

This study utilized a repeated measures design, in the form of hierarchical linear modeling (HLM) or multilevel modeling (MLM) analysis. The object of repeated measures designs is to model within-subject variance (Garson, 2013) e.g., what factors influence people's performances over multiple attempts: As Garson (2013) states:

> What is ‘within’ a subject is, of course, the series of measurements taken over time for a given unit of analysis (typically an individual subject). Each subject will have multiple rows of data corresponding to multiple observation times. In terms of multilevel analysis, level 1 is within-subjects (for the variance among repeated measures for given individuals, on the average) and level 2 is between-subjects, with the observation unit (usually the individual) being a grouping variable for the measures (p 18).

Multilevel analysis models an individual participant’s score at each time point by taking account of both time point specific factors (i.e., level 1 within subject factors) and individual specific factors (level 2 between subject factors). For example, a student's performance at a particular time point depends on his mood at that time point (within subject factor) and his general ability (between subject factor), which is constant across time points. Multilevel analysis models the example by regressing performance on mood for every student. This means each student's performances are modeled by a regression line. The slope of the regression line reflects how mood influences the student's performance, and the intercept of the regression line reflects the student's general ability. In the simplest case, mood affects performance the same way for all students (i.e., same slopes), and students only differ in their general abilities (i.e., different intercepts). This model informed the design for this study, as it is extended to the hypothesis that matching y-axis mapping to a participant’s preference effects performance (the slope of regression) and is moderated by the participant’s abilities (intercept of the regression line), which informs the different levels of the hierarchical linear model analysis—level 1 as trial/task specific within subjects factors, and level 2 as participant specific between subject factors.

There are two levels estimated in this hierarchical linear model (HLM) analysis. Task/trial (level 1) nested within participants (level 2). Level 1 variables included the performance indicators for all 12 trials in both conditions, matching and mismatched, and in the case of determining the effect of preference on performance, the preference of camera control y-axis mapping, inverted or normal. Participant-level variables included the covariates related to previous experience and exposure with video games in general and First Person Shooter (FPS) games specifically which are self-reported and measured respectively. This is in addition to eye-hand coordination, spatial ability, and again in the case of the secondary research question, the participant's y-axis camera control preference. A dummy variable, *d*, was included at the task/trial level for each trial. All of the variables were grand mean centered at both levels in all analyses. The statistical analysis software Mplus (Muthén & Muthén, 2012) was used to run the HLM analysis, with an alpha level of 0.05. The default estimator used by the software is maximum likelihood robust standard error (MLR), which estimates with standard errors and a chi-square test statistic (when applicable) that are robust to non-normality and non-independence of observations. Learning curve theory, previously reviewed, predicted that performance would begin with an initially negative slope that would increase as the trial number increased. Initial inspection of the raw data confirmed that the relationship between performance and trial number exhibited characteristics similar to a typical inverted learning curve, previously described (see Figure 7).

Effect of Mismatch from Preferred Camera Control Y-Axis Mapping

To determine the effect of forcing a non-preferred y-axis controller mapping has on performance, Level 1 of the model is either

Target Selection Task

$$y_{ij} = \beta_0 + \beta_1(match) + \sum_{i=2}^{12} \beta_i \cdot d_i + \sum_{k=13}^{23} \beta_k(int)_k + \beta_{24}(time) + \varepsilon_{ij}$$

Target Follow Task

$$y_{ij} = \beta_0 + \beta_1(match) + \sum_{i=2}^{12} \beta_i \cdot d_i + \sum_{k=13}^{23} \beta_k(int)_k + \varepsilon_{ij}$$

respectively, where y_{ij} is the performance of the jth participant on the ith trial based on the predictors (β_n); *match* indicates whether or not the y-axis mapping was matched or mismatched to the participant's preference; *d* is the dummy code for the ith trial; *int* is the interaction between *trial* and *match*; *time* is the elapsed time when completing each trial (for Target Selection Task only); and ε_{ij} represents the residual error term for participant j on the ith trial and is assumed to be normally distributed with a mean of 0.

As Keppel (1991) states, "unfortunately the major source of error variance in the behavioral sciences is that contributed by individual differences" (p. 71). Thus, possible covariates informed by the existing literature were also measured including: spatial ability, previous experience, and eye-hand coordination, so as to mitigate individual differences as a source of potential error and to control for those relationships or effects on the primary performance measures. In the hierarchical linear model, the covariates represent the between-subjects differences that could moderate the level 1 differences; therefore, Level 2 of the model is

$$\beta_0 = \gamma_{00} + \gamma_{01}(Spatial) + \gamma_{02}(FPSRT) + \gamma_{03}(VGExp) + \gamma_{04}(EyeHand) + \gamma_{05}(Age) + \mu_{0j}$$

for both tasks to determine the predictor for the participant's initial experience and ability. *Spatial* is the score the participant obtained on the spatial ability pre-measure; *FPSRT* is the participants previous exposure with first person camera controlled video games as measured by the modified Software Recognition Test; *VGExp* is the participant's self reported experience playing video games; *EyeHand* is the average score the participant obtained on the Digital Eye-Hand Coordination pre-measure; *Age* refers to the participant's age at the time of the study; and μ_{0j} is the Level 2 random person effect for the jth participant.

Effect of Camera Control Y-Axis Mapping Preference

Determining the effect of individual preference for camera control y-axis mapping on performance, which is the secondary research question, relies on a similar model to the previous primary analysis but introduces a new interaction predictor; therefore, Level 1 of the model for the secondary question is either

Target Selection Task

$$y_{ij} = \beta_0 + \beta_1(match) + \sum_{i=2}^{12} \beta_i \cdot d_i + \sum_{k=13}^{23} \beta_k(int)_k + \beta_{24}(time) + \beta_{25}[int(match \cdot pref)] + \varepsilon_{ij}$$

Target Following Task

$$y_{ij} = \beta_0 + \beta_1(match) + \sum_{i=2}^{12} \beta_i \cdot d_i + \sum_{k=13}^{23} \beta_k(int)_k + \beta_{24}[int(match \cdot pref)] + \varepsilon_{ij}$$

where all of the previous descriptions of the variables remain the same, with the addition of a predictor indicating the interaction of: *match,* whether or not the y-axis controller was matched to the participant's preference or not; and *pref,* the participant's preference for either normal or inverted y-axis mapping. Similarly, Level 2 of the model is

$$\beta_0 = \gamma_{00} + \gamma_{01}(Spatial) + \gamma_{02}(FPSRT) + \gamma_{03}(VGExp) + \gamma_{04}(EyeHand) + \gamma_{05}(Age) + \gamma_{06}(Pref) + \mu_{0j}$$

again, adding *Pref*, the participant's preference for camera control y-axis mapping as determined by the preference check, to the previous Level 2 model for the primary analysis.

Results

Effect of Mismatch from Preferred Camera Control Y-Axis Mapping

Hierarchical linear modeling (HLM) was used to statistically analyze a data structure where task/trial (level-1) performance was moderated by participant (level-2) covariates related to previous experience and ability on two different tasks in a first person camera controlled 3D virtual environments: target selection and target following. Of specific interest was the relationship between the performance (level-1 outcome variable) and the match or mismatch to preferred camera control y-axis mapping (level-1 predictor variable).

Target Selection Task

For the target selection task the model revealed an intra-class correlation (ICC) of 0.128. Thus, approximately 13% of the variance was determined to be between participants (level-2) and the remaining 87% of the variance in accuracy as performance scores is within trials (level-1). After controlling for the time taken to complete each trial as well as other (level-2) covariates (see Table 3), the main effect of the matching condition, i.e., whether or not the participant was forced to use their preferred or non-preferred y-axis mapping, was found to be not significantly different (β = -2.806, p = 0.777). See Table 4 for descriptive statistics for each trial, as well as Figure 13 for a plot of the learning curve using the adjusted means. A linear trend analysis

Table 3.

Target selection task (accuracy) participant level predictor summary.

Covariate	Predictor	Coefficient	*p*
Spatial Ability	*Spatial* (γ_{01})	-0.653	0.366
Previous Video Game Exposure	*FPSRT* (γ_{02})	-0.954	0.413
Self-Reported Video Game Experience	*VGExp* (γ_{03})	-1.412	0.119
Eye-Hand Coordination	*EyeHand* (γ_{04})	0.396	0.273
Age	*Age* (γ_{05})	0.565	0.212
Residual Variance	$\sigma^2_{\mu_{0j}}$	455.956	0.030*

*$p < .05$

Table 4.

Descriptive statistics for target selection task performance variable (accuracy): as distance from target, in virtual cm. N=139

	Matched			Mismatched		
Trial	*M*	*SD*	adj *M*	*M*	*SD*	adj *M*
1	50.807	94.038	48.000	44.599	84.278	45.194
2	42.475	87.850	42.818	34.227	57.748	35.418
3	37.463	72.805	36.935	46.870	107.839	50.535
4	40.651	91.826	39.862	37.076	61.827	39.866
5	25.173	56.724	24.712	28.306	46.191	32.504
6	26.395	50.864	26.290	20.734	15.253	20.459
7	23.439	48.802	23.265	20.757	23.194	20.598
8	24.696	49.709	24.319	35.377	42.369	36.397
9	29.032	57.635	28.760	33.854	58.394	35.394
10	26.096	53.404	25.615	34.716	59.226	34.318
11	32.236	66.100	31.735	34.792	55.368	35.234
12	27.848	63.450	27.722	31.689	37.324	31.572

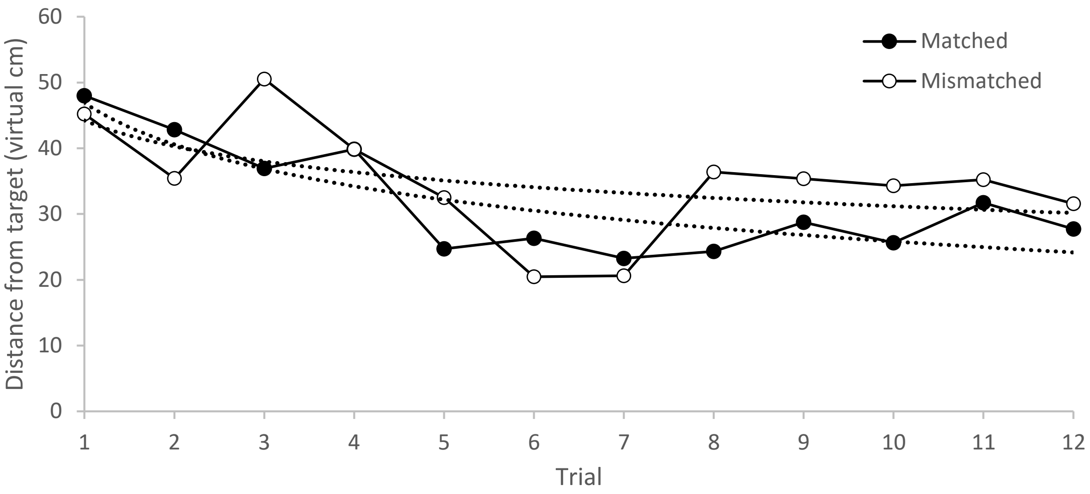


Figure 13. Target selection task performance (as accuracy) learning curves, for each condition of matching to y-axis camera control preference

revealed there was no significant interaction effect ($\beta = 0.0632$, $p = 0.428$) between the matching condition and the trials. A further comparison of the difference in accuracy for each trial across each condition revealed that only one trial—the eighth trial—was significantly different ($\beta = 12.077$, $p = 0.028$), confirming that the main effect was consistent for all but one trial. These results indicate that during a target selection task in a first person camera controlled 3D virtual environment, there is no effect when forcing the y-axis mapping to an individual's non-preferred mapping on performance with respect to accuracy. Participants are able to select targets to a similar level of accuracy regardless of the y-axis mapping they are using.

During the process of analyzing performance during the target selection task with respect to accuracy, an additional analysis was performed using the same model, but substituting the time taken to complete each trial, rather than accuracy, as an alternate measure of performance. Both response time and accuracy are generally accepted measures of performance in virtual environment research (Slone et al, 2014; Bekele et al, 2014). For the target selection task, with respect to response time, the model revealed an intra-class correlation (ICC) of 0.314.

Thus, approximately 31% of the variance is between participants (level-2) and the remaining 69% of the variance in performance scores is within trials (level-1). After controlling for (level-2) covariates (see Table 5), the main effect of the matching condition was found to be significantly different (β = -0.469, p = 0.007). See Table 6 for descriptive statistics for each trial, as well as Figure 14 for a plot of the learning curve using the adjusted means. A linear trend analysis revealed there was no significant interaction effect (β = 0.516, p = 0.052) between the matching condition and the trials. A further comparison of the difference in response time for each trial across each condition revealed that all but two trials—trial 5 (β = -0.099, p = 0.488), and trial 10 (β = -0.189, p = 0.119)—were significantly different, confirming that the main effect was relatively consistent for the majority of trials using an alpha level of 0.05. These results indicate that during a target selection task in a first person camera controlled 3D virtual environment, while there is no effect on accuracy, there is a significant positive effect on response time which equates to a negative effect when forcing the y-axis camera control to an individual's non-preferred mapping on performance. Participants are generally slower to select targets when they are forced to use their non-preferred y-axis mapping.

Table 5.

Target selection task (response time) participant level predictor summary.

Covariate	Predictor	Coefficient	*p*
Spatial Ability	*Spatial* (γ_{01})	-0.034	0.087
Previous Video Game Exposure	*FPSRT* (γ_{02})	-0.047	0.041*
Self-Reported Video Game Experience	*VGExp* (γ_{03})	-0.021	0.080
Eye-Hand Coordination	*EyeHand* (γ_{04})	-0.035	0.032*
Age	*Age* (γ_{05})	0.03	0.021*
Residual Variance	$\sigma^2_{\mu_{0j}}$	0.516	0.000*

*p < .05

Table 6.

Descriptive statistics for target selection task performance variable (response time):as time, in seconds, N=139

	Matched			Mismatched		
Trial	M	SD	adj M	M	SD	adj M
1	3.586	1.744	3.604	4.092	1.232	4.073
2	2.889	1.674	2.868	3.747	1.345	3.778
3	3.054	1.514	3.068	3.653	1.452	3.666
4	2.802	1.431	2.821	3.640	1.431	3.647
5	2.720	1.322	2.739	2.630	1.235	2.640
6	3.087	1.473	3.113	2.686	1.010	2.702
7	2.368	1.377	2.404	2.730	1.130	2.724
8	2.857	1.310	2.885	3.899	1.409	3.888
9	2.820	1.399	2.829	3.543	1.355	3.562
10	2.662	1.250	2.679	2.467	1.157	2.490
11	2.570	1.258	2.606	3.534	1.323	3.530
12	2.146	1.246	2.166	3.512	1.383	3.450

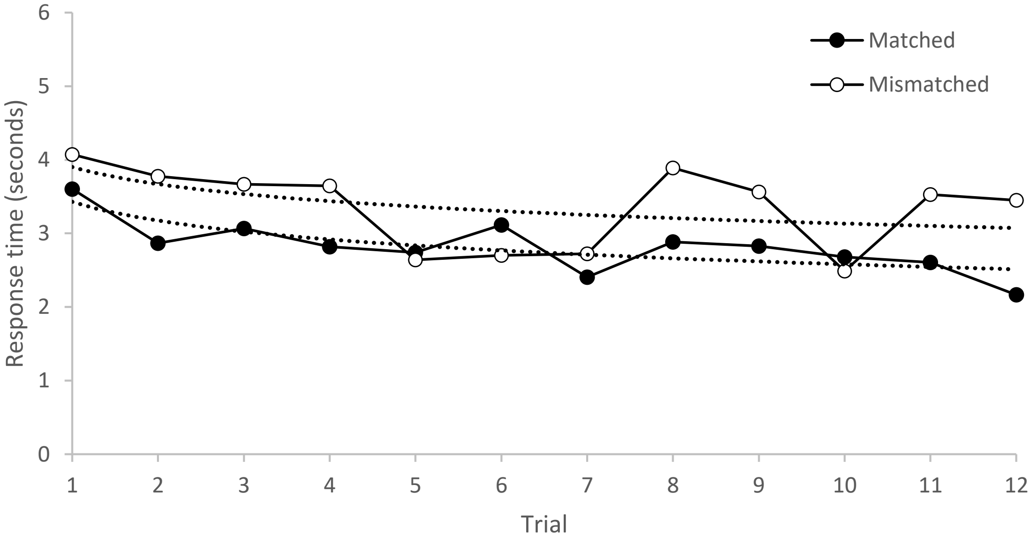


Figure 14. Target selection task performance (as response time) learning curves, for each condition of matching to y-axis camera control preference

Target Following Task

For the target following task the model revealed an intra-class correlation (ICC) of 0.156. Thus, 16% of the variance is between participants (level-2) and the remaining 84% of the variance in performance scores is within trials (level-1). After controlling for covariates (see Table 7), the main effect of the matching condition was found to be significantly different (β = 151.388, $p < 0.000$). See Table 8 for a descriptive statistic for each trial, as well a plot of the learning curve using the adjusted means (see Figure 15). A linear trend analysis revealed there was no significant interaction effect ($\beta = -1.350$, $p = 0.103$) between the matching condition and the trials. A further comparison of the difference in performance for each trial across each condition revealed that all of the trials were significantly different using an alpha level of 0.05, confirming that the main effect was consistent for all trials. This result indicates that during a target following task in a first person camera controlled 3D virtual environment, there is a positive effect on the accuracy error which equates to an overall negative effect when forcing the y-axis mapping to an individual's non-preferred mapping on performance. Participants are able to track a target's movement with the camera more accurately when they are able to use their preferred y-axis mapping.

Post Hoc Trial Analysis

A closer visual inspection of the learning curves for the response time variable during the target selection task revealed that trials with decreases in response time were observable, though not statistically significantly different from the other trials, particularly during the mismatched condition (trials 5, 6, 7, and 10). A review of recordings from the pilot data of the study, revealed that the targets for these trials appeared in the top, left, right, and bottom locations only, as opposed the top-right, top-left, bottom-right, or bottom-left locations. In order to quantify this

Table 7.

Target following task (accuracy) participant level predictor summary

Covariate	Predictor	Coefficient	*p*
Spatial Ability	*Spatial* (γ_{01})	-2.992	0.002*
Previous Video Game Exposure	*FPSRT* (γ_{02})	-4.132	0.000*
Self-Reported Video Game Experience	*VGExp* (γ_{03})	-4.211	0.000*
Eye-Hand Coordination	*EyeHand* (γ_{04})	0.374	0.524
Age	*Age* (γ_{05})	1.868	0.030*
Residual Variance	$\sigma^2_{\mu_{0j}}$	1047.770	0.000*

*$p < .05$

Table 8.

Descriptive statistics for target following task performance variable (accuracy): as Fréchet distance compared to target path, in virtual cm, N=139

	Matched			Mismatched		
Trial	*M*	*SD*	adj *M*	*M*	*SD*	adj *M*
1	106.156	115.956	108.644	257.614	138.000	260.032
2	102.607	73.099	102.014	245.808	115.681	246.737
3	108.939	80.804	109.059	163.656	96.724	164.651
4	92.336	74.405	91.872	242.939	145.378	244.611
5	103.140	55.441	103.551	231.099	122.264	231.076
6	81.215	52.354	82.012	211.450	154.555	213.477
7	94.237	45.432	94.999	210.327	104.791	211.194
8	97.071	56.549	98.073	207.596	116.854	211.262
9	105.661	62.734	105.409	204.907	139.951	206.242
10	86.844	44.510	86.979	218.962	122.332	220.497
11	93.890	46.590	93.979	195.682	108.022	196.663
12	86.601	68.099	86.592	220.913	126.836	225.350

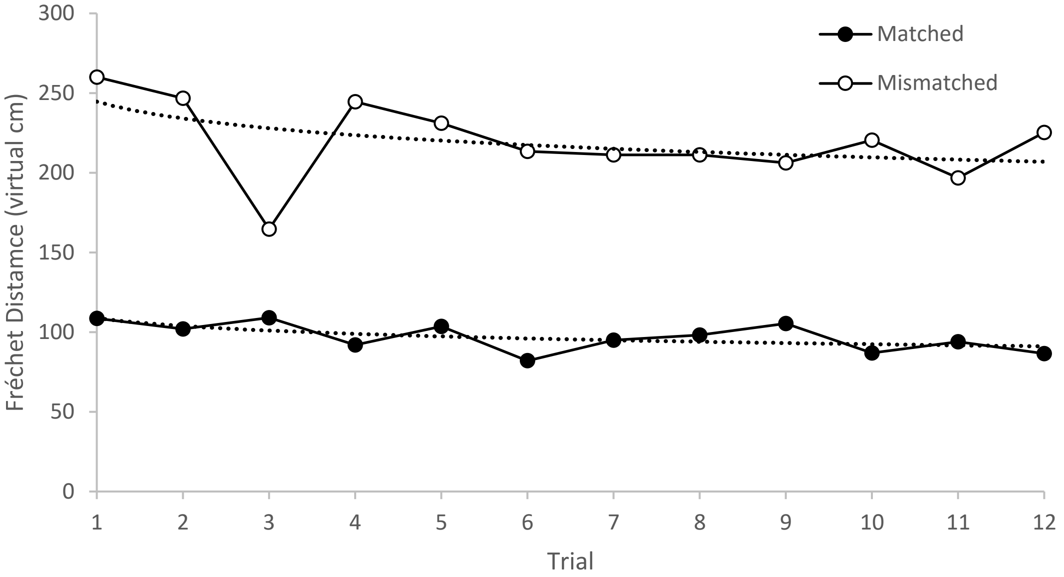


Figure 15. Target following task performance (as accuracy) learning curves, for each condition of matching to y-axis camera control preference

phenomenon, the trials for both conditions were coded with a label indicating whether or not the trial was on an angle or straight up and down (non-angled) to the centering box. A further analysis was completed, using the same model as the response time analysis for the target selection task, revealing that for non-angled trials, there was a significant negative linear relationship (β = -0.084, p < 0.000) between trial and response time. As trial increased, response time decreased, equating to improved performance. However, for angled trials, the negative relationship between trial and time was weaker (β =-0.080 + 0.024 = -0.056), meaning participants improved less on the angled trials. This result indicates that the angled trials were more difficult (slower response time) for participants to complete than the non-angled trials, in particular they were the most difficult when participants were forced to use their non-preferred y-axis mapping.

Effect of Camera Control Y-Axis Mapping Preference

Hierarchical linear modeling (HLM) was used to statistically analyze a data structure where task/trial (level-1) performance was moderated by participant (level-2) covariates related to previous experience and ability on two different tasks in a first person camera controlled 3D virtual environment: target selection and target following. Of specific interest was the relationship between the perfromance (level-1 outcome variable) and the match or mismatch to preferred y-axis mapping (level 1 predictor variable) and the participant's y-axis mapping preference (level-2 predictor variable). Unfortunately, the sample population contained a mismatched number of participants who preferred each y-axis mapping—128 who preferred the normal mapping and the remaining 11 who preferred the inverted mapping. This was to be expected, based on previous research reviewed (Frischmann et all, 2015), but is also understood to be a limitation of the following analysis.

Target Selection Task

For the target selection task, using distance to target as the measure of performance, the model revealed that camera control y-axis preference—normal or inverted—was not a significant predictor of performance ($\gamma = -3.223$, $p = 0.379$). An interaction between the matching condition and y-axis mapping preference was not found to be significant ($\beta = -0.110$, $p < 0.057$). A table of descriptive statistics for each condition and y-axis preference was produced (see Table 9; Figures 16, 17). A Post Hoc analysis was completed to determine the main effect of y-axis preference on performance in each condition. The analysis revealed that when participants were allowed to use their preferred y-axis mapping (matched condition), those who preferred the normal mapping did not perform significantly better or worse than those who preferred the inverted mapping ($\beta = 5.391$, $p = 0.398$). A further comparison of the difference in accuracy for each trial across each preference revealed that all of the trials were significantly different using an alpha level of 0.05, confirming that the main effect was consistent across all trials. When participants were forced to use their non-preferred y-axis mapping (mismatched condition) those who preferred the normal mapping performed significantly worse than those who preferred inverted (β = -11.771, p = 0.007). A further comparison of the difference in accuracy for each trial across each preference revealed that all of the trials were not significantly different using an alpha level of 0.05, confirming that the main effect was consistent across the majority of trials with the exception of trials 3, 9, and 11. These results indicate that during a target following task in a first person camera controlled 3D virtual environment, there is a significant difference in performance between those who prefer normal or inverted y-axis mapping only when they are forced to use their non-preferred mapping: those who prefer the normal mapping perform worse than those who prefer the inverted mapping, though this is not consistent across all trials. This is not true when participants are able to use their preferred mapping, in which case performance is not significantly different. Participants were able to select a target to a similar degree of accuracy when they are able to use they preferred y-axis mapping, but when forced to use their non-preferred mapping, those who prefer the inverted mapping are less accurate.

As with the primary question analysis the same process of substituting response time for accuracy into the model was undertaken with the following results. For the target selection task, using response time as a measure of performance, the model revealed that camera control y-axis preference was not a significant predictor of performance (γ = -0.189, p = 0.215). An interaction between the matching condition and y-axis mapping preference was significant (β = when participants were allowed to use their preferred y-axis mapping (matched condition), those who preferred the normal mapping performed significantly better than those who preferred the

Table 9.

Descriptive statistics for target selection task performance variable (accuracy) by each camera control y-axis mapping preference: as distance to target, in virtual cm.

	Normal Camera Control Y-Axis Mapping (N = 128)						Inverted Camera Control Y-Axis Mapping (N = 11)					
	Matched			Mismatched			Matched			Mismatched		
Trial	*M*	*SD*	adj *M*	*M*	*SD*	adj *M*	*M*	*SD*	adj *M*	*M*	*SD*	adj *M*
1	48.053	91.788	47.341	45.732	86.270	46.086	70.864	107.962	42.930	26.970	19.460	40.936
2	42.206	88.167	42.206	35.930	60.272	35.930	50.141	76.124	50.141	29.243	14.038	29.243
3	37.229	74.503	37.229	53.221	122.157	53.220	33.393	24.865	33.393	18.293	10.186	18.293
4	38.918	88.012	38.918	41.362	68.749	41.362	51.172	122.855	51.172	21.893	19.544	21.893
5	25.102	58.190	25.101	32.957	70.850	32.955	20.016	11.469	20.016	27.048	19.161	27.048
6	25.704	50.415	25.702	20.878	15.460	20.876	33.329	49.279	33.329	15.427	9.932	15.427
7	23.635	49.919	23.634	21.004	23.659	21.002	18.818	15.958	18.818	15.720	10.305	15.720
8	23.565	50.625	23.564	37.570	45.916	37.568	33.342	22.712	33.342	22.287	15.984	22.286
9	29.126	59.100	29.125	36.804	63.830	36.803	24.354	13.351	24.354	18.448	12.969	18.448
10	23.291	46.696	23.290	34.734	60.586	34.733	53.498	99.982	53.498	29.314	19.449	29.314
11	32.297	67.795	32.296	36.373	57.614	36.371	24.973	12.999	24.973	21.546	17.124	21.546
12	28.404	65.080	28.403	31.361	36.997	31.360	19.520	14.898	19.520	34.069	37.758	34.068

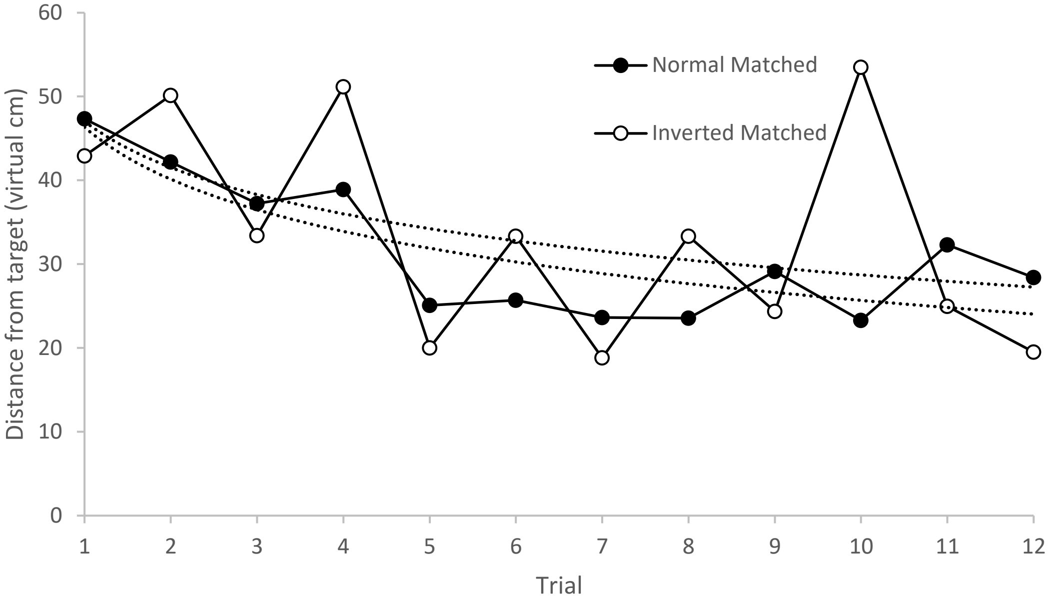


Figure 16. Target selection task performance (as accuracy) when matched to preference learning curves, for each camera control y-axis mapping preference.

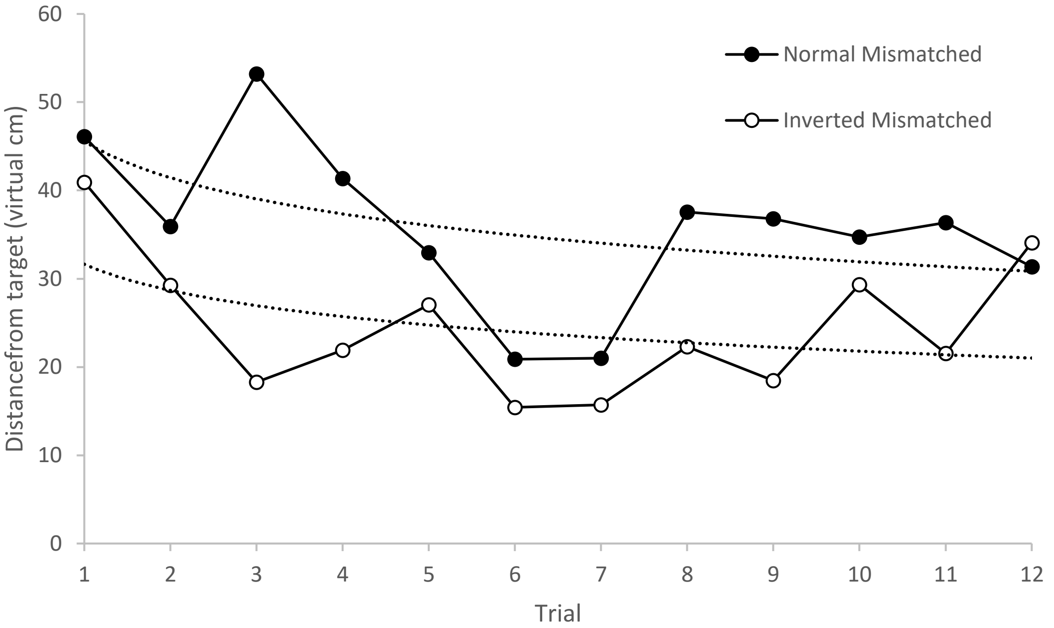


Figure 17. Target selection task performance (as accuracy) when mismatched to preference learning curves, for each camera control y-axis mapping preference.

inverted mapping ($\beta = 0.940$, $p < 0.000$). A further comparison of the difference in accuracy for each trial across each preference revealed that all of the trials were significantly different using an alpha level of 0.05, confirming that the main effect was consistent across all trials. When participants were forced to use their non-preferred y-axis mapping (mismatched condition) those who preferred the normal mapping performed significantly worse than those who preferred inverted ($\beta = 1.320$, $p < 0.000$). A table of descriptive statistics for each condition and y-axis preference was produced (see Table 10; Figures 18, 19). A further comparison of the difference in accuracy for each trial across each preference revealed that all of the trials were significantly different using an alpha level of 0.05, confirming that the main effect was consistent across the majority of trials with the exception of trials 6 and 10. These results indicate that during a target following task in a first person camera controlled 3D virtual environment, there is a significant difference in performance when considering response time between those who prefer normal or inverted y-axis mapping. When they use their preferred or non-preferred mapping, those who prefer the normal mapping perform significantly better while in the matched condition, while those who prefer the inverted mapping perform significantly better during the mismatched condition. When participants used their preferred y-axis mapping, those who prefer the inverted y-axis mapping were slower to select a target; but, when forced to used their non-preferred mapping, those who preferred the normal mapping were slower to select the target.

Target Following Task

For the target following task, using Fréchet distance as a measure of accuracy, the model revealed that camera control y-axis preference—normal or inverted—was not a significant predictor of performance ($\gamma = -8.739$, $p = 0.349$). An interaction between the matching

Table 10.

Descriptive statistics for target selection task performance variable (response time) for each camera control y-axis mapping preference: elapsed time, in seconds.

	Normal Camera Control Y-Axis Mapping (N = 128)						Inverted Camera Control Y-Axis Mapping (N = 11)					
	Matched			Mismatched			Matched			Mismatched		
Trial	*M*	*SD*	adj *M*	*M*	*SD*	adj *M*	*M*	*SD*	adj *M*	*M*	*SD*	adj *M*
1	3.442	1.694	3.442	4.196	1.169	4.196	5.552	1.161	5.509	2.610	0.998	2.631
2	2.822	1.680	2.822	3.915	1.285	3.915	3.419	1.329	3.420	2.137	1.088	2.138
3	2.942	1.517	2.943	3.783	1.450	3.784	4.588	0.858	4.588	2.288	1.075	2.288
4	2.858	1.495	2.858	3.799	1.383	3.799	2.382	0.702	2.382	1.837	0.610	1.837
5	2.758	1.393	2.758	2.713	1.258	2.714	2.512	0.720	2.512	1.755	0.963	1.755
6	2.989	1.442	2.989	2.731	1.042	2.731	4.606	1.465	4.606	2.368	0.953	2.369
7	2.380	1.436	2.379	2.775	1.118	2.774	2.706	1.185	2.706	2.128	0.851	2.129
8	2.775	1.303	2.775	4.040	1.347	4.041	4.218	1.038	4.218	2.075	1.014	2.075
9	2.752	1.417	2.752	3.695	1.311	3.696	3.764	0.947	3.765	1.981	1.005	1.982
10	2.568	1.211	2.569	2.546	1.183	2.547	4.009	1.082	4.009	1.824	1.006	1.824
11	2.515	1.265	2.515	3.653	1.306	3.653	3.711	1.179	3.711	2.080	1.159	2.080
12	2.168	1.309	2.168	3.585	1.315	3.585	2.148	0.653	2.148	1.843	0.952	1.843

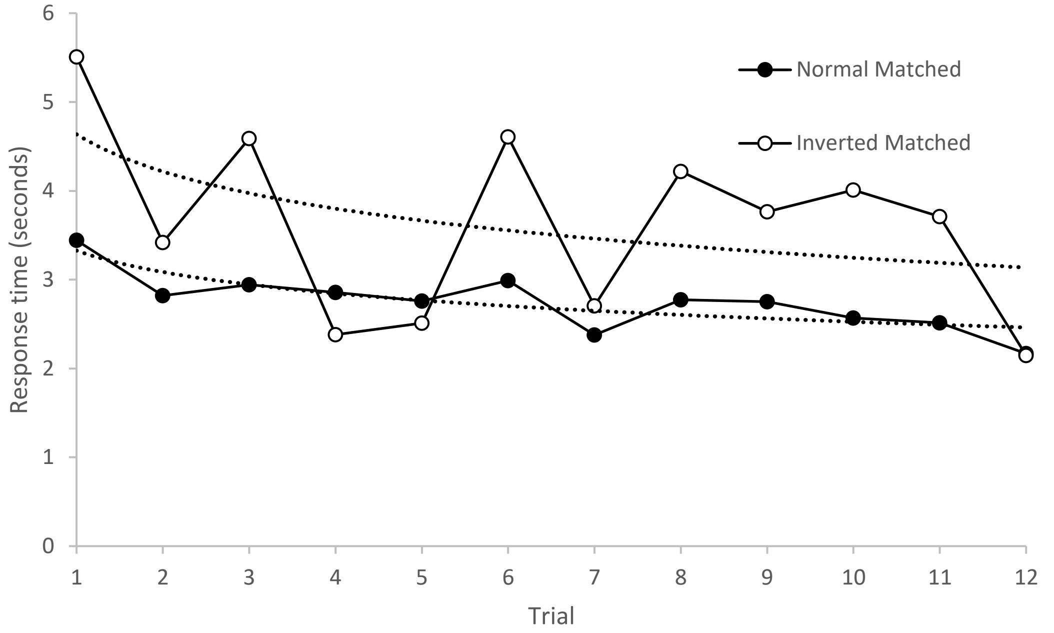


Figure 18. Target selection task performance (as response time) when matched to preference, learning curves for each camera control y-axis mapping preference.

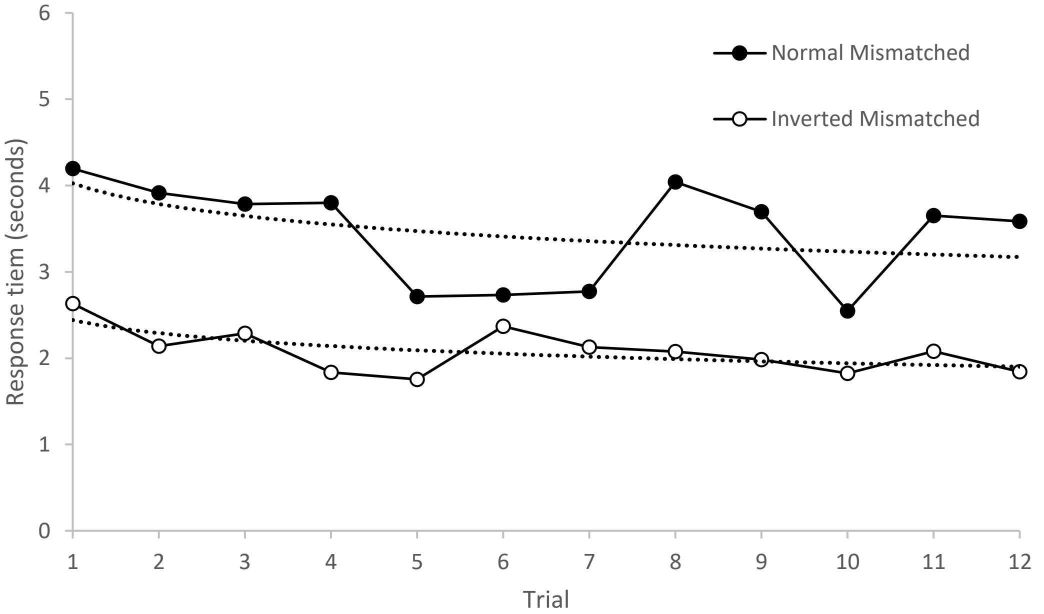


Figure 19. Target selection task performance (as response time) when mismatched to preference, learning curves for each camera control y-axis mapping preference,

condition and y-axis preference was significant ($\beta = -238.804$, $p < 0.000$). A table of descriptive statistics for each condition and y-axis preference was produced (see Table 11; Figures 20, 21). A Post Hoc analysis was completed to determine the main effect of y-axis preference on performance in each condition. The analysis revealed that when participants were allowed to use their preferred y-axis mapping (matched condition), those who preferred the normal mapping performed significantly better than those who preferred the inverted mapping ($\beta = 110.960$, $p < 0.000$). A further comparison of the difference in accuracy for each trial across each preference revealed that all of the trials were significantly different using an alpha level of 0.05, confirming that the main effect was consistent across all trials. When participants were forced to use their non-preferred y-axis mapping (mismatched condition) those who preferred the normal mapping performed significantly worse than those who preferred inverted ($\beta = -128.606$, $p < 0.000$). A further comparison of the difference in accuracy for each trial across each preference revealed that all of the trials were significantly different using an alpha level of 0.05, confirming, again, that the main effect was consistent across all trials. These results indicate that during a target following task in a first person camera controlled 3D virtual environment, there is a significant difference in performance between those who prefer normal or inverted y-axis mapping. When they use their preferred or non-preferred mapping, those who prefer the normal mapping perform significantly better during the matched condition, while those who prefer the inverted mapping perform significantly better during the mismatched condition. When participants used their preferred y-axis mapping, those who prefer the inverted y-axis mapping were able to track a moving target less accurately; but, when forced to used their non-preferred mapping, those who preferred the normal mapping were less accurate.

Table 11.

Descriptive statistics for target follow task performance variable (accuracy) for each camera control y-axis mapping preference: Fréchet distance compared to target path, in virtual cm.

	Normal Camera Control Y-Axis Mapping (N = 128)						Inverted Camera Control Y-Axis Mapping (N = 11)					
	Matched			Mismatched			Matched			Mismatched		
Trial	*M*	*SD*	adj *M*	*M*	*SD*	adj *M*	*M*	*SD*	adj *M*	*M*	*SD*	adj *M*
1	99.394	115.081	101.875	273.219	135.009	271.979	185.128	70.530	183.466	119.052	101.720	119.884
2	92.356	60.329	92.356	258.808	110.873	258.808	217.918	101.708	217.919	101.902	47.504	101.903
3	98.274	60.267	98.274	171.713	96.113	171.714	238.477	150.690	238.478	79.906	38.076	79.908
4	82.027	60.833	82.028	256.208	145.599	256.209	210.001	106.999	210.002	105.439	68.066	105.441
5	94.300	35.913	94.301	243.269	118.310	243.271	214.566	104.965	214.567	84.769	33.463	84.770
6	74.264	40.325	74.264	224.753	157.935	224.754	175.002	86.796	175.003	78.181	23.498	78.183
7	88.895	38.302	88.895	215.426	107.218	215.427	168.244	62.610	168.244	160.400	70.965	160.400
8	89.569	41.510	89.569	222.210	119.094	222.211	200.119	106.102	200.120	79.878	18.619	79.880
9	100.305	58.362	100.305	217.674	138.997	217.675	166.677	73.806	166.678	69.084	32.035	69.085
10	79.093	26.559	79.093	231.077	121.127	231.077	181.614	90.439	181.615	93.550	36.043	93.551
11	86.394	29.100	86.393	205.631	106.541	205.630	184.998	95.977	184.998	89.046	31.863	89.047
12	76.499	31.410	76.499	235.577	141.197	235.577	207.709	184.037	207.710	102.636	34.798	102.637

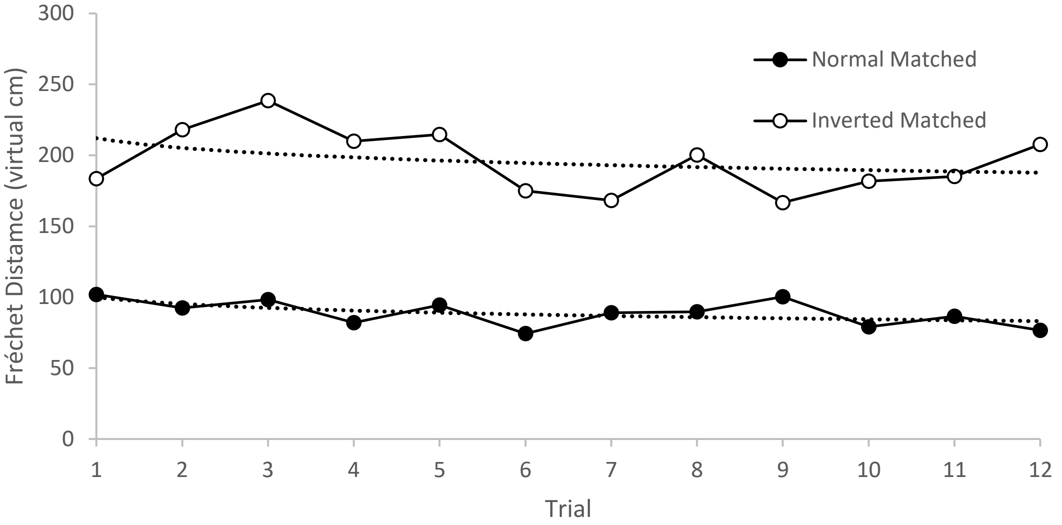


Figure 20. Target following task performance (as accuracy) when matched to preference, learning curves for each camera control y-axis mapping preference.

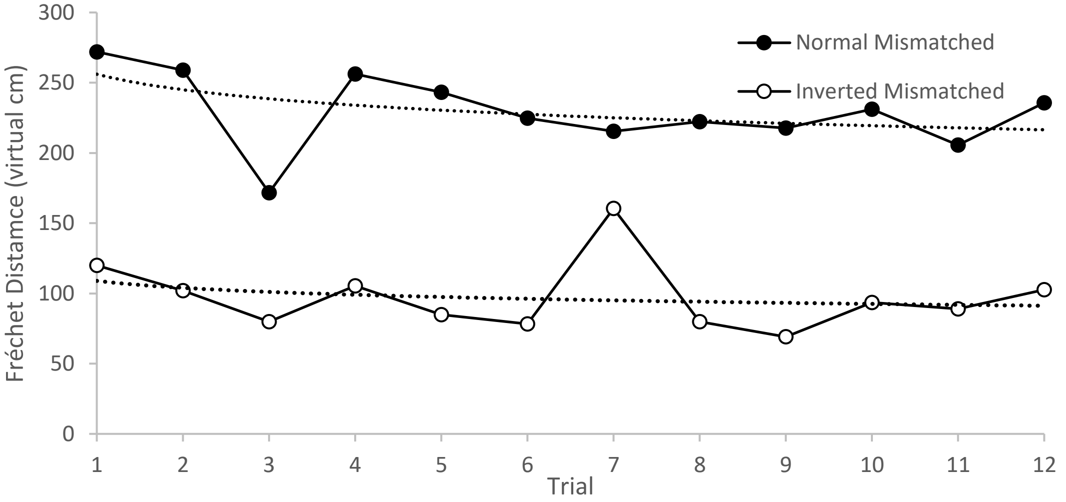


Figure 21. Target following task performance (as accuracy) when mismatched to preference, learning curves for each camera control y-axis mapping preference,.

Discussion

The results of this study have provided some insight into the phenomenon of first person camera control y-axis mapping preference and the performance that can be expected of an individual when a mismatch to preference is present. The study also raises some additional questions which warrant considering for future research.

Research Questions

Speaking to the primary research question: In first person camera controlled 3D virtual environments, what is the effect of forcing y-axis mapping to an individual's non-preferred mapping on performance? The results indicated that in one of the two experimental tasks performed during this study—target following—participants exhibited performance significantly worse when forced to use their non-preferred y-axis mapping compared to when they were able to use their preferred mapping, after controlling for previous experience, age, and spatial ability. Participants were at least two times less accurate when following a target's path when they were forced to use their non-preferred y-axis mapping. This finding was not true with respect to accuracy during the target selection task. During the target selection task, participants, on average, were able to select the target with no significant difference when forced to use their non-preferred y-axis mapping than using their preferred mapping. This could indicate a difference in adaptation ability depending on the type of first person camera movement required by the task—target selection or target following. However, when considering the time taken to complete each target selection trial, the participants were able to respond more quickly, on the order of half a second faster across trials, when using their preferred y-axis mapping. Participants were able to select the target to the same degree of accuracy while being forced to use a non-preferred y-axis mapping but were unable to select the target as quickly, therefore exhibiting a level of performance decrease overall.

When reviewing the results of this study with respect to the secondary research question—in first person camera controlled 3D virtual environments, is there a difference in the performance between those who prefer normal or inverted camera control camera control mapping, when they use their preferred or non-preferred mapping?—the results indicate that there is a difference in performance experienced by participants who prefer either normal or inverted y-axis mapping. The nature of the difference in performance, however, is revealed to be reversed levels of performance based on y-axis mapping preference. Those who prefer the normal mapping exhibit a difference in performance when forced to use their non-preferred mapping consistent with the findings of the main research question, i.e., worse performance while mismatched to y-axis mapping preference. Conversely, those who prefer the inverted mapping exhibit a difference in performance that is opposite to the findings of the first research question, i.e., worse performance when matched to y-axis mapping preference. Moreover, an analysis of the adjusted means reveals that the level of performance achieved by each group in each of the experimental conditions (match to preference) mirrors each other. It is noted, however, that these results are limited due to the much smaller number of participants who were found to prefer the inverted y-axis mapping and should be considered preliminary until further research can be done with a balanced sample. Thus, to explain any reasoning for these results would be an exercise in speculation. The results may well support the research of Frischmann et all (2015), who state that when formulating a study of this phenomenon, potentially every possible sample could be contaminated by the fact that the normal y-axis mapping is the default mapping in the vast majority of situations where an option to choose the mapping exist. The participants who were determined to prefer the normal mapping by the preference check, but may well have preferred the inverted mapping, may have be influenced by the nature of the normal mapping often being the default mapping in their previous exposure to first person camera controlled 3D environments. What can be inferred from this mirroring of performance results, however, is that they were also able to perform similarly to their normal mapping counterparts. Perhaps if they were able to use their preferred y-axis mapping for a longer period of time, the results would indicate a true difference between those who prefer either mapping.

Learning Curves and Adaptation

Throughout the process of designing this study, much consideration was made regarding learning curve theory and what the performance data of the experimental tasks would look like when average performance of participants' data was plotted on a curve. A number of learning curves were created for this study (see Figures, 13, 14, 15): two target selection curves, one for accuracy and one for response time; and one for target following in each condition, matched or mismatched to y-axis mapping preference. These curves were then created with the results separated for participant's camera control y-axis preference (see Figures 16, 17, 18, 19, 20, 21).

Target Selection Task

The learning curves for the target selection tasks exhibited characteristics of a typical inverted learning curve as described by Stagner and Kowroski (1952), which is consistent with similar learning curves that measure error or some other negative element of a task. In this case, the measure is distance from target at time of selection. As the trials progressed, for both matching conditions, the distance from the target when a selection is made, as well as the response time to make the selection, is decreasing. For the accuracy performance measure, the intercept of the two curves is similar but the rate at which the slope increases and flattens out is less in the mismatched condition than in the matched. This would suggest that the participants were unable to reach the same level of accuracy when forced to use their non-preferred y-axis mapping and were not able to completely adapt to the perturbation; however, the results do not indicate that this difference is significant. What is unclear is if the participants would ever be able to perform as well when being forced to use their non-preferred mapping, as they would when allowed to use their preferred mapping. A longitudinal study would need to be considered to answer this question. For the response time performance measure, the two curves do not have a similar intercept with a difference that amounts to roughly half a second across trials. While the curves for each condition were found to be otherwise similar in a trend analysis, neither of the response time curves have as steep of an initial slope as the accuracy measure curves. This can be explained by the six second cap put on each trial. Had there been no time limit, and participants were required to finish each trial completely, it is possible the initial slope for the response time performance measures may have been steeper.

Target Following Task

Learning curves plotted for the target following task also exhibited characteristics of a typical inverted learning curve as described by Stagner and Kowroski (1952), though less pronounced than the target selection task. As was determined during the analysis of results, there was a significant interaction between the number of trials and the matching to y-axis mapping preference, meaning that when forced to use their non-preferred mapping (mismatched condition) participants would experience both a more negative slope of performance across trials to begin with as well as a greater rate of increase in slope as the trials continued, compared to when they were able to use their preferred mapping (matched condition). This is to be expected as the intercept (ie. initial performance) during the mismatched condition was significantly higher than the matched condition because of the adaptation to the perturbation the mismatch requires of the participant during the earlier trials. As trials continued in the mismatched condition, however, participant’s performance learning curves seem to plateau at a level of performance that may suggest they would not ever reach a level of performance equal to or greater than the performance exhibited when they were allowed to use their preferred y-axis mapping (matched condition).

Implications

As was suggested in the introduction to this research, the implications for the findings of this study may have help to influence the development practices of first person 3D virtual environments that are used in the field of education taking the form of serious games, virtual simulations, or video games that are used in digital game based learning. It may also inform the development of tools used in remote controlled robotics whether they are utilized for search and rescue, construction, or medicine. The results of this study support, to some extent, the need for the continued inclusion of y-axis mapping to be selectable by the user in first person camera controlled 3D virtual environments. In particular, for tasks where it is either required or desired that greater performance, e.g., a more precise level of control of movement accuracy, be exhibited during the path of the camera's travel, then the option to switch the y-axis mapping such that it matches the user preference is strongly encouraged and supported by this research. It may also be extended to suggest that users themselves become familiar with the phenomenon of preference with respect to y-axis mapping in first person camera controlled 3D virtual environments (or similar tools), to ensure that they are using the mapping that matches their preference to ensure the best performance outcomes are possible. Failing to provide the option to set the mapping to a user's preference or users accepting the mapping provided by the software or tool may or may not be detrimental. The results of this study suggest that if the software defaults or only allows for the normal mapping, performance is not likely to be affected. If the software defaults to an inverted mapping, many users will find a performance benefit if they are given the opportunity to change it to a normal mapping. If, however, the software is setup to only use an inverted mapping, the results indicate that many users will experience lower levels of performance in the environment, with respect to accuracy and task completion time. This potential for reduced performance may also be extended to harm the learning potential of virtual environments or tools used in the field of education and could even cause unnecessary damage/injury as a result of inaccuracy when a user is operating a tool that utilizes a first person camera control-like method and is forced to use their non-preferred mapping..

Limitations

As with any research design, there are limitations to the findings based on the design, the results, or both. The largest limitation remains the unequal/small number of participants who were found to prefer the inverted y-axis camera controlling mapping. However, as was stated, this is generally unavoidable as the rate in which those who prefer the inverted mapping seem to hover around the 10-15% margin. Regardless, the results of the second research question in this study and any other future study will be subject to this limitation without a much larger sample population, or a recruitments method that targets the minority preference to balance the study.

As was mentioned earlier, the sample set present for this study being relatively homogenous in terms of age, experience, and possibly anything else not expressly measured as a result of being selected from a participant pool provided to the researcher by a single department in the Faculty of Education at a single university. This homogeneity of sample is somewhat overcome by measuring and accounting for the covariates included in the model of analysis used by this study but a more diverse sample would clearly allow the research team to ensure the results are consistent with a greater population.

Additionally, while it was suggested in the introduction and again when discussing the implications of this study on real life applications such as those found in robotics, search and rescue, construction, and medicine, etc, it is important to note that all of the experimental tasks utilized by this experimental design involved a purpose built 3D virtual environment. Specific research into the effects of this phenomenon on physical real-world hardware should be informed by the results of this study but direct links would require further research to confirm.

With respect to pre-measures and covariates, the researcher also notes that the measure of eye-hand coordination developed for this study, the digital eye-hand coordination test, was not found to be a significant predictor for many of the performance measures. This may indicate that either the task itself requires further study to further determine its validity, or that eye-hand coordination, indeed, has no effect on performance in a first person camera controlled 3D virtual environment. Similarly, the camera control y-axis mapping preference check developed for use in this study is not a standardized test. It is based on a similar test utilized by the Halo video game series (Bungie, 2001, 2004), where it was found by the developers to be very effective for helping players of the video game to determine their mapping preference, but there has not been any research done on its validity or reliability. The developers, for their part, claim that the test is accurate at determining y-axis mapping preference “roughly 90% of the time” (J Griesemer, personal communication, March 7, 2017), which based on whether or not the player chose to switch the mapping from that which the preference check had determined to be the player’s preference at any time later during gameplay.

Future Research

Adaptation of both Axes

An observation made by the researcher during the experimental procedure involved a number of participants attempting to overcome the perturbation caused by being forced to use their non-preferred y-axis mapping by manipulating the controller in such a way that seemed to indicate they believed that *both* axes had been reversed from their preferred mapping, rather than just the y-axis. This would occur in both the target selection and target following tasks. For example, if the participant was determined to prefer the normal y-axis mapping by the preference check, when forced to use their non-preferred mapping (mismatched condition) during the target following task, if the target moved up and then right, the participant would correctly move the control stick down to correct for the mismatch but then to the left—the opposite input required on the x-axis—to attempt follow the target to the right. This adaptation strategy would result in considerably worse accuracy scores than those who attempted to adapt their movements on only the y-axis, but the exact nature of this difference could not be determined or speculated on using the results recorded by this particular design and may warrant specific future research.

Overcorrection during Adaptation

A further observation was anecdotally made by the researcher while running the participants through the experimental procedure. While participants were completing the tasks in the non-preferred y-axis mapping (mismatched condition), many were observed manipulating the controller in such a manner that movements of the camera were made in the extremes that the control stick of the XBox controller would allow. If the control stick could be imagined to have in input of 0% when no input is being made and up to 100% in any direction when an input is made, the researcher observed the inputs made during the mismatched conditions of both tasks to be closer to 100% in all directions and were often characterized with dramatic changes in direction which could be audibly identified as ‘clicks’ from the physical controller when the participant switched from one extreme of the control stick input to another. As no measure of controller input with respect to the scale in which the input was made was recorded for this study, future research which takes this observation into mind may look to study the reasons for this overcorrection.

Isolation of Axes during Adaptation

Two distinct but similarly themed observations were made during the procedure and subsequent analysis of results that may explain why there was a significant difference in performance present during the target following task but not present during the target selection task. Taking a closer look at these observations may inform future research about the isolation of axes during tasks performed in first person camera controlled 3D virtual environments.

The first observation that was anecdotally made by the researcher during the process of participants being exposed to the entire experimental procedure but involves only the target selection task. During the trials which were presented in the participant's preferred y-axis mapping (matched condition), when a target was presented in any of the eight possible locations, the participant often manipulated the camera such that it travelled along a relatively direct and straight path to the target. However, when the trials were presented in the non-preferred y-axis mapping (mismatched condition), the participants were often observed as having more difficulty creating a direct path to the target when they appeared in the top-right, top-left, bottom-right, or bottom-left locations—the angled positions. This is supported by the results of the post hoc analysis of the target selection task, as participants were slower to completed trials with targets in angled positions. Participants were observed trying to overcome this difficulty by separating the movement required into two parts: first, a horizontal movement right or left, and then a vertical movement up or down. This is again supported by the result that participants were able to complete targets in non-angled locations more quickly. Given the nature of the task, unfortunately the frequency of this theoretical strategy being utilized or even identified objectively can only be speculated, as there is no data representing the path the participant took to reach the targets during the target selection task. That said, if so desired, it could be analyzed by also recording and calculating the Fréchet distance between the path travelled by the camera to reach the target and a straight line path from the centering box to the target (a perfect path)—a consideration for future research.

A second observation of similar note was made during the analysis of the target following task accuracy data. In particular, the results of the third trial of the non-preferred y-axis mapping (mismatched condition) were scrutinized (see Figure 15). Despite the results of the difference in performance for each trial across the matching condition revealing that all were consistent with the main effect, i.e., that there was a significant difference between the matched and mismatched performance, a visual inspection of the results indicate some level of performance increase for a the single trial. Because each participant was given the same sequence of previously determined random target paths to follow, all of the participants experienced the same third trial in the mismatched trial block. Upon reviewing recordings from pilot study data, it was revealed that the path travelled by the target for the third trial in the mismatched condition contained only horizontal and vertical movements with square corners. Every other trial presented during the target following task, in both conditions, had at least one or more sections of the target's path that required angular movement of the camera to follow the target. This parallels the previous observation made during the target selection task: Isolated movements along a single axis was a method some participants may have used to overcome the adaptation required during the target selection task. It is also supported by the result of the post hock trial analysis of the target selection task, as movements towards targets in non-angled directions were generally performed better by participants. It could be concluded that as a result of these findings and the interpretation of the anecdotal observations, that to improve performance when an individual is forced to use their non-preferred y-axis mapping that they isolate the movements to only those in the cardinal—exclusively horizontal and vertical—directions. Of course, it should be noted, that in other fields, such as those that this study may inform, an isolation of the axes of movement may not be feasible and would therefore only be encouraged when the absence of an option to set the user's camera control y-axis mapping to that of their preference is not available or possible.

Conclusion

Virtual environments continue to evolve as a viable and valuable method for providing authentic experiences for different types of educational and learning applications (Gregory, Scutter, Jacka, McDonald, Farley, & Newman, 2015; Hew & Cheung, 2010; Seymour & Røtnes, 2006; Steils, Tombs, Mawer, Savin-Baden, & Wimpenny, 2015; Wang & Burton, 2013). It is important for designers, developers, and users of these technologies to be aware of how the limitations of something as seemingly simple as the controller mapping of the camera perspective in a first person camera controlled 3D virtual environments can effect users' performance. The goal of this study was to determine the effect that mismatch from preferred camera controlled Y-axis mapping has on performance in first person 3D virtual environments. This extends previous research by Dardis, Schmierbach, and Limperos (2012) who found users to experience decreased levels of object recall when forced to use a less natural control device while completing tasks in a virtual environment, as well as the research of Frischmann, Mouloua, and Procci (2015) who found varying levels of user presence and frustration when completing tasks a first person 3D virtual environment while being forced to use a non-preferred method for controlling the camera perspective. The first example involved performance measure made outside the virtual environment, while the second made conclusions made from measurements inside the environment but were not performance based.

The results of this study indicate that that forcing users to manipulate the camera in a first person 3D virtual environment with their non-preferred mapping lead to varying levels of performance for two different types of tasks—target selection and target following. Although accuracy was unaffected, there was a significant decrease in task completion time during target selection tasks. The study also found a significant decrease in accuracy during target following tasks. This is important information for the developers and designers of 3D virtual environments, as it may indicate that more of users' attention is being spent on manipulating the camera, if the controller mapping does not match their preferred y-axis mapping. If there are educational goals the software is designed to teach or expose the user to, it can be speculated that they may not be as able to learn from the experience, as too much of the cognitive load is being spent on manipulating the camera. It should be noted that many first person perspective 3D virtual environments allow for the user to select which of the two y-axis mappings, inverted or normal, they wish to use, allowing users the opportunity to match their preference—if they are aware of it. To that end, this option should remain available in as many contexts as is possible. Furthermore, users should be made aware of the ability to change between the mappings, so they are not inadvertently forced to use a non-preferred mapping, unaware that there is no other option available. That said, the results of this study also suggest that if a mapping must be selected as a default, a normal mapping would be advised, as users performed better on the same tasks mentioned earlier while using the normal mapping regardless of their preference. Further research on this finding is suggested. Moving forward, this study should encourage developers and designers of experiences that involve first person perspective 3D virtual environments to consider the effect of y-axis controller mapping to ensure that their users have the best opportunity to achieve their highest levels of performance.

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