SSRG International Journal of Computer Science and Engineering
ISSN: 2348–8387 / https://doi.org/10.14445/23488387/IJCSE-V12I12P101

Volume 12 Issue 2, 1-18, February 2025

Original Article

Exploring Fitts' Law in Virtual Reality Applications

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Received: 12 December 2024 Revised: 19 January 2025 Accepted: 08 February 2025 Published: 26 February 2025

Abstract *- Fitts' Law posits that the time necessary for a user to move a pointer (such as a mouse or finger) to a target area is the function of the distance traveled and the size of the target. This translates to a simple rule that the smaller the target and larger the distance to the target, the longer it takes to reach and select. This principle is a fundamental consideration in the usability of any interface. Relatively little research has been done regarding the use of Fitts' Law in Virtual Reality (VR) environments. This paper attempts to demonstrate that Fitts' Law continues to hold when applied to VR interactions - specifically when a user is wearing a Head Mounted Display (HMD) and controlling a pointer with a VR controller. This oversight poses a significant problem as VR technology becomes increasingly prevalent in gaming, training, and many other applications. Understanding the applicability of Fitts' Law in VR is crucial for developing intuitive and efficient user interfaces in these immersive environments. This paper aims to bridge this gap by investigating whether Fitts' Law holds true in VR interactions. By measuring the time taken for participants to select a range of targets, a Fitts' Law linear model was created to test if the law still applied. The experiment demonstrated that Fitts' Law is still applicable in VR for pointing and selection with handheld controls, thereby filling an important gap in the understanding of user interactions in VR environments.*

Keywords *- Fitts' Law, Virtual Reality, Usability, Interface Design, Human-Computer Interaction.*

1. Introduction

Usability metrics are an often studied topic in the field of HCI and are a foundation for establishing best practices within a design space. Certain heuristics and rules usually evolve out of both success and failure stories, as well as scientific research involving user testing. The usefulness of various metrics varies, and there are always new metrics to discover or refine; however, common metrics tend to come to the forefront due to their applicability and usefulness.

One such measure is Fitts' Law, which is a ratio of the accuracy of a user in a user interface with certain inputs. At its most basic, Fitts' Law is an equation that relates the usability of an interface item to the distance and size of the target. This paper will provide a description of the development of Fitts' Law, including the various adaptations and applications of Fitts' Law. This section will then introduce relevant research touches on topics such as usability in gaming, Fitts' Law in Gaming, VR gaming, and usability in VR.

1.1. Fitts' Law

The psychologist Paul Fitts conducted his original device-pointing experiments in 1954 [1]. His initial experiments involved four conditions: two serial tapping tasks (a disc transfer task and a pin transfer task) using both a 1-oz stylus and a 1-lb stylus. For the tapping tasks, the user moved the stylus back and forth between two plates as fast as possible, tapping them at their centers. For the purpose of calculation in these tasks, the amplitude was measured as the distance between the two plates (targets), and the width of the plates was the target size/width. Using the data from these experiments, Fitts was able to develop a mathematical model of the pointing and selection task, proving an implicit relationship between human accuracy and the dexterity-based task being undertaken.

This experiment was done prior to the invention of the most dominant forms of devices for interacting with a computer. The ergonomics of any given device may vary, and yet the law holds for most pointing tasks, in particular, the selection of an interface involving the use of a mouse or a finger on a touchscreen. This is why Fitts' Law has remained relevant for our modern digital interfaces and is still widely used today [2].

Fitts' Law is comparable to Shannon's Theorem 17, which is a theorem of communication systems [3]. There exists a correlation between the transmission of information and movement where bits of information are categorized by indices of difficulty and are related to the time taken to move. In both of these theorems, measured time (MT) and index of difficulty (ID) have a high correlation, but certain problems exist. At low values of ID, the correlation becomes weaker.

It becomes important to understand that Fitts' Law exists on a continuum between a model and a theory. When translating between information models and experimental results, there are sources of discrepancies since the model involves human movement, which exists in the realm of physiological processes. Refinement of the original Fitts' Law to better fit is an ongoing iterative process in the literature [3].

Fitts cites in his original 1954 paper [1] that the initial Fitts' Law equation is a derivation based on Goldman's Equation 39, which is analogous to Fitts' Law using communication systems vernacular. Goldman's equation is in itself an approximation of Shannon's Theorem 17. This theorem is useful when the transmitted power is large in comparison with the noise [3].

Fitts' Law in its original form was stated as :

$$ID = \log_2 (2A / W)$$

$$MT = a + b \times ID = a + b \log_2 (2A / W)$$

MT is the Movement Time (unitless measure of relative time)
ID is the Index of Difficulty (unitless measure of task difficulty)
A is the amplitude (distance moved to complete the task)
W is the width (a measure of the target size)
a and *b* are the device-dependent constants

Understanding the relationship of this equation with Shannon's Theorem 17 becomes important when thinking about the limitations of this early version of Fitts' Law; the original equation failed for small values of ID.

Based on the information-theoretic basis for the original equation, Fitts realized that his data could be better modelled with the following equation, which is an even closer adaptation of Shannon's Theorem.

$$ID = \log_2 ((A + W) / W)$$

$$MT = a + b \times ID = a + b \log_2 ((A + W) / W)$$

It then follows the crux of the issue that certain situations are a bad fit for Fitts' Law's original inception when the ID is very small, such as less than 1 bit or with a negative ID. MacKenzie asserts that even Fitts himself recognized that an equation from Welford improved on his original and used it in subsequent research.

$$MT = a + b \log_2 ((A / W) + 0.5)$$

Regardless of this fact, however, many researchers still use Fitts' Law as it was originally conceived in motor behavior experiments; however, using a derivation more analogous to Shannon's theorem will almost always yield better results when ID is small [4].

Looking at the progression of Fitts' Law and its derivatives, it becomes clear that the variety brings a certain degree of ambiguity to a definitive definition and understanding of Fitts' Law. In a more contemporary paper, MacKenzie points out the incompatibility in comparing different Fitts' Law studies due to their differences in the method of experimentation and calculations done. As is hopefully evident from the previous section, this is not hard to imagine. Several different derivatives of Shannon's Theorem and Fitts' Law give the flexibility to deal with specific experimental conditions but make contrasting results difficult [2].

Hence, the usefulness of ISO 9241-9, which outlines standard methodologies for Fitts' Law research, with specific relevance for HCI. These standards come from technical committees made up of individuals from the research community. The standards provide things such as ergonomics requirements and visual display requirements. The two main testing procedures outlined in ISO 9241-1 are a methodology for one-dimensional and two-dimensional tasks that have appeared in several studies in the past decade or so [2, 5, 6, 7].

The problems that arise that necessitate a range of adaptations of Fitts' Law cannot be overstated, and this makes the push for standardization of practice for easier review and comparison more compelling. Still, it seems most studies adapt Fitts' Law to their research as needed, using whatever version of the base algorithm and equation that best fits their experimental design. There are several relevant examples of adaptations of the application of Fitts' Law and or evolutions of Fitts' Law that are worth looking at to better understand how versatile the application can be. Three examples of this will follow, one concerning a trajectory-based HCI task law, an adaptation called the "Prince" technique and modelling finger touch with Fitts' Law.

1.1.1. Trajectory Based Interactions

In trajectory-based interactions, that is, interactions through things such as nested menus, Fitts' Law does not model the creation of curves and movement in a 3D space in a one-to-one or succinct manner. In a series of four experiments, Accot and Zhai proposed what they called a 'steering law' as an adaptation to Fitts' Law [8]. The four experiments were described as follows :

- Goal Passing: constraining the ends of movement with a steering task in which subjects pass one goal line and another as fast as possible;
- Increasing Constraints: a steering task with constraints on both ends which mimics Fitts' tapping task;
- Narrowing Tunnel: a linear trajectory but a non-constant path width with beginning and end lines;
- Spiral Tunnel: traversal through a spiralling tunnel from the start line to the end line.

Shannon's Theorem and Fitts' Law are both fundamental concepts in information theory and human-computer interaction, respectively. While they originate from different domains, there is a relationship between them when it comes to understanding and optimizing communication and interaction systems.

The relationship between these two concepts lies in their shared goal of optimizing performance within constraints. In human-computer interaction, Fitts' Law can be used to design user interfaces that minimize the time and effort required for users to complete tasks. Similarly, Shannon's Theorem guides the design of communication systems to maximize data transmission rates while minimizing errors. Both theories emphasize the importance of efficiency and accuracy in their respective fields, and understanding the principles of one can provide insights into the other [3].

Accot and Zhai [8] proposed the following global law for predicting the time to perform a steering task :

Tc = a + b indefinite integral c of ds/W(s).

This assumes the index of difficulty for steering through the path as the sum of the curve of the elementary indexes of difficulty as related to curved path C, which is IDc, linearly related to time to steer through C, which is Tc. This law and experiment show that there exists a relationship between movement time and the width of a "tunnel" in steering tasks. This is formulated as a logical evolution of Fitts' Law and is an extension or localization to a different movement metric [8].

This shows the efficacy of Fitts' Law to model these sorts of relationships. Fitts' Law applies to point tasks, which happen to make up a large portion of conventional tasks on modern computers and interfaces; however, all dexterity-based tasks within the space of inputs to a user interface are intrinsically similar in that they will have a general law defining some ratio between task degree of difficulty and completion time. Theorem.

1.1.2. Prince Technique

A rather creative solution to the difficulty in pointing tasks is the Prince technique. Proposed by Kabbash and Buxton, this technique involves using an area cursor to offset the difficulty of otherwise difficult pointing tasks [9]. By having the cursor be an area instead of a point, Fitts' Law bound pointing tasks become more manageable.

Instead of the small target making the task difficult, the area cursor nullifies the difficulty by acting as a buffer to target size. This experiment and subsequent Fitts' Law modification show a novel way to improve outcomes in a Fitts' Law-based pointing task using the design of the interface inputs as opposed to changing the task itself.

If a task is difficult and poses a problem in a user interface because of target size, simply enlarging the target would have the same effect, but this technique provides a somewhat roundabout solution that may be useful if enlarging the target or changing the UI in some way is problematic for some other reason. It shows a good example that when using Fitts' Law in interactive design, there can be somewhat outside-the-box solutions to change the nature of a pointing task [9].

1.1.3. Modelling Finger Touch

The conditions that Fitts' Law is usually measured under involve the use of some sort of pointer or mouse; when the pointer is a human finger, as is the case with touch screens, the efficacy of the model for predicting performance with small target acquisition is lacking. This is not surprising as small target acquisition modelling is the crux of the problems with Fitts' original law, which MacKenzie spent a long time examining and showing methods to fix or improve upon [2].

This issue is exacerbated in finger-touch situations. Bi et al. propose a dual-distribution hypothesis to correct for the lack of precision with Fitts' Law in finger-pointing tasks with small targets [10]. Much of this struggle comes from the idea of "fat finger", being that small targets on a given screen might be fairly easy to select with a mouse or cursor, whereas a finger will cause failures due to the finger itself being possibly several times bigger than the target and having several possible targets close with only one being the correct target.

When performing pointing tasks using finger input, variation in the accuracy of the precision is due to the absolute precision of finger input and not solely because of the speed-accuracy trade-off. Bi et al. derived what they call the FFitts model, which is a refined form of Fitts' Law. The FFitts model simplifies Fitts' Law in cases where the precision factor is negligible compared to the target size or variance of the task [10].

The FFitts model gives another example of a variation/derivation of Fitts' Law for a specific problem space, again showing the generalizable paradigm of task degree difficulty and completion time. In this case, there was one other relationship to consider, the absolute precision of the finger, but the base relationship, as shown in Shannon's Theorem 17, remains evident.

1.1.4. Fitts' Law Summary

Recent studies on Fitts' Law have continued to explore its relevance and application in modern digital interfaces [11]. Contemporary research has expanded its application beyond traditional desktop environments to touchscreens and mobile devices. Multiple studies have examined the applicability of Fitts' Law to touchscreen interactions, finding that the law holds true but with modifications to account for the unique characteristics of touch input [12, 13]. This study revealed that touch-based input often requires adjustments to the index of difficulty, as factors like finger size and screen sensitivity influence movement times.

Further investigations have explored how Fitts' Law can be applied to various types of 2D interfaces, including those on tablets and smartphones. Research has repeatedly demonstrated that target size and spacing significantly affect user performance [10, 13]. These findings suggest that designers can enhance usability by considering Fitts' Law principles when creating touch-based interfaces, leading to more efficient and user-friendly designs.

These insights are crucial for developing interfaces that accommodate various input methods, ensuring accessibility and efficiency across different devices.

Fitts' Law, at its core, is the relationship of a speed-accuracy trade-off in dexterity-based pointing tasks. The ubiquitous nature of this paradigm means that Fitts' Law or an adaptation can apply to significantly different tasks and situations. It exists as a tool for approximating completion time, which then helps guide interface design to make common tasks as easy as possible. One such application area that would benefit from the use of Fitts' Law is Virtual Reality [14].

1.2. Fitts' Law in Gaming

Game design is a paradigm-rich design space from the technical to the abstract. As a medium that involves ample user input in dexterity-based tasks, Fitts' Law is important to consider in the context of serious games. Fitts' Law and any rule that helps guide ergonomic design is especially important as most video games have, at minimum, a user interface to consider and, in many cases, have accuracy and speed as the implicit mechanic that drives the experience. Thinking about video games through the lens of Fitts' Law or vice versa is not breaking new ground; there exists ample research relating the two.

Video game design exists as an umbrella term for a diverse and ever-growing pool of different tasks and input styles that can necessitate vastly different approaches to measuring accuracy vs speed. It would be naive to expect a single version of Fitts' Law to apply to all video game control systems. There needs to be a definition of what the user does in each game application, and each type of game/input style needs to be tested separately. Thankfully, though, many games exist in a similar spatial capacity (usually a 2-dimensional or 3-dimensional layout), and many use the same input devices, either a controller or a mouse and keyboard.

Many virtual training environments employ an egocentric or first-person viewpoint – using the same viewpoint as the First Person Shooter (FPS) game genre. These applications seem a natural candidate for Fitts' Law as the central mechanic in most FPS games is target acquisition. Past research has shown that most first-person environments use some form of metaphor for target acquisition that mimics a pointing task. Previous experiments with FPS games have shown that the player's times to acquire a target correlate to standard Fitts' Law predictions [15]. The skill and previous experience of the players had little impact on these times, which demonstrates that the difficulty/time trade-off that Fitts' Law describes is intrinsic to human motor function naturally rather than learned or practiced.

Expanding this research to consider a range of input devices for FPS games, it has been shown that when comparing a PC mouse, a Microsoft Xbox 360 game control, a Sony Playstation Move, and a Microsoft Kinect, Fitts' Law does not apply equally to all devices [16, 17]. Fitts' Law held well for the mouse and controller in first-person virtual environments, but the accuracy of prediction degraded for the Kinect and Move. This could be due to the limitations of the new forms of input technology in terms of having excessive input noise, latency, etc.

Other research has evaluated performance with touch-based interaction as well as mouse-based interaction in first-person virtual environments. The mouse input was used as a baseline and point of reference for comparison. Both methods yielded similar results that followed the same Fitts' Law accuracy/speed trade-off we would expect. However, the touch-based input was slightly faster, which correlates with other work done on more traditional 2-dimensional interfaces [18].

Other work applying Fitts' Law to first-person virtual environments has demonstrated that movement time linearly increases as the target's index of difficulty increases across a range of different input methods. One study compared three gesture-based interfaces and two conventional interfaces (mouse and touchscreen), proving that Fitts' Law can be generalized to a range of dexterity tasks in virtual environments [19].

Research shows that Fitts' Law is generalizable into a first-person virtual environment regardless of an input device and is therefore likely at play in most dexterity-pointing tasks in serious games regardless of input device. One input space application of Fitts' Law that is less studied due to the relative infancy of the technology is in Virtual Reality (VR).

1.3. Virtual Reality

VR gaming and VR environments are a developing subset of the serious games commercial sector. These experiences usually consist of a virtual environment that is displayed using a VR headset. There are a variety of existing low-cost, high-quality consumer VR headsets on the market and an already established market for VR video games.

VR has emerged as a transformative technology with applications spanning across diverse sectors, from entertainment and education to healthcare, architecture, and beyond. Its immersive nature has the potential to revolutionize how users interact with digital content, offering experiences that are both engaging and impactful [20].

In the realm of gaming, VR has significantly enhanced user experience by providing a more immersive and interactive environment. Players are no longer confined to observing the game on a screen but are now active participants in the game world. This heightened level of immersion has not only elevated the entertainment value but has also opened new avenues for game design and user engagement [21].

Beyond entertainment, VR has demonstrated immense potential in the field of education. VR-based learning environments offer students the opportunity to engage with educational content more interactively and intuitively. For instance, VR can simulate historical events, scientific experiments, and complex mathematical concepts, making abstract ideas more tangible and easier to comprehend. Research indicates that VR can enhance learning outcomes by providing a more engaging and effective educational experience [22].

The healthcare sector has also embraced VR as a valuable tool for training, therapy, and patient care. VR simulations are used to train medical professionals in complex procedures, allowing them to practice in a risk-free environment. In the field of architecture and design, VR provides architects and clients with a virtual walkthrough of their projects before construction begins. This allows for better visualization, improved design accuracy, and more effective communication between stakeholders [20, 23].

Most VR systems involve a form of audio and visual illusion, but future VR setups are likely to include more complex technology that will encompass more of the body. There are already a number of devices that utilize some form of haptic feedback; in the future, the amount of feedback is likely to increase as the technology incorporates more human senses than just sight and sound, which will likely be utilized in virtual reality.

VR applications, although similar in many ways to conventional serious games viewed on a flat screen, offer a level of immersion that is undeniably more complex than traditional setups, but they also bring unique challenges and problems. VR game design is perhaps not a suitable analogy to traditional established game design, as many features change in practice when technologies change. It is then important to look at some of the differences between traditional games and VR games.

Researchers have compared usability, emotional response, and sense of presence experienced in both VR experiences and non-immersive setups. Experiments have demonstrated that there is little statistical difference between immersive and non-immersive conditions regarding usability and performance scores. When it came to self-reported experiences of happiness/surprise, the analysis revealed that the sense of presence was far higher with a VR setup [24]. This is perhaps an unsurprising result, at least for the self-reported qualities of the experience, given the previous work on immersion within VR experiences.

However, the fact that experimental data showed no difference between usability and performance is more surprising. The literature highlights a weak spot in the translation between technologies, although it is a rather niche one. However, it is somewhat surprising that there is no statistically significant difference in usability between VR and traditional setups, given that they are quite different [24]. It should be noted that these metrics can be complex to measure, and more research work is needed in this area.

VR presents many opportunities for unique serious game applications, partially due to the nature of increased immersion. An example of this involves using VR technology for a Rehabilitation Gaming System (RGS) to evaluate and rehabilitate motor defects after a stroke. The system used an RGS to trigger the mirror neuron system, which would then promote cortical reorganization. Situations in RGS were designed to promote action observation. Researchers observed that the VR interface provided a positive impact on recovery following a stroke [25]. This was a specific use case, but there are many similar examples of serious game applications that could be enhanced by VR technology [26, 27].

One consistent issue with VR technology is motion sickness or virtual reality sickness when using current VR headsets. Motion sickness is affected by differences in Head Mounted Display (HMD) setups, such as resolution and refresh rate; the contents of the media also play a pivotal role. Research has shown that varying the virtual environment content recorded the highest rates of VR sickness with an emphasis on stimulation, locomotion and exposure time as key factors [28]. A specific study of VR driving simulators focused on measuring user comfort and experience across three different groups (those with traumatic brain injury, cerebral vascular accident victims, and healthy users). There was a consistent and distinct relationship between self-reported user rating and the experience of motion sickness across all three groups [29].

Even with the best VR technology, the quality of the experience can be hampered by motion sickness due to the content of the virtual environment. Motion Sickness is one example of the special and specific usability considerations that are unique to VR simulations.

1.4. Usability in Virtual Reality

Virtual Reality (VR) technology has revolutionized various fields, such as gaming, training, education, and healthcare, by providing immersive and interactive experiences. Despite the technological advancements, the usability of VR interfaces remains a significant challenge. Usability issues in VR environments can lead to user frustration, decreased efficiency, and reduced overall satisfaction. One of the primary problems is the difficulty users face in accurately and efficiently interacting with virtual objects, which is often exacerbated by the lack of tactile feedback and the limitations of current input devices. As VR applications become more prevalent, it is crucial to address these usability problems to enhance user experience and fully realize the potential of VR technology [30].

A notable research gap exists in the application of established human-computer interaction (HCI) principles, such as Fitts' Law, to VR environments. Fitts' Law, which predicts the time required to move a pointer to a target based on the distance and size of the target, has been widely validated in traditional interfaces. However, its applicability in VR settings, particularly when users are equipped with Head Mounted Displays (HMDs) and VR controllers, remains underexplored. This gap in research is problematic because intuitive and efficient user interfaces are critical for the success of VR applications. Without a thorough understanding of how principles like Fitts' Law apply to VR, designers may struggle to create interfaces that accommodate the unique challenges posed by virtual environments. Therefore, addressing this research gap is essential for improving the usability of VR systems and ensuring that users can interact with virtual worlds seamlessly and effectively. To understand usability in VR systems, examples of usability measurements in specific serious gaming situations will be examined. Figuring out which modalities and paradigms transfer from traditional usability on a computer (normally using a keyboard and mouse) to VR interaction avoids rerepeating the experimental discovery process [31].

In experiments comparing a low-cost VR HMD setup, a desktop setup and a setup with a projector, participants undertake several tasks on three different platforms [32]. Each participant played on each platform, and the order was distributed such that an equal number of users on each platform undertook the tasks in every order possible. Task success was measured multiple times during each subtask, and a rating was based on user satisfaction. Specific common usability metrics other than self-reported satisfaction and completion metrics were not used. It was found that there was a decrease both in performance and experience when using the projector setup and also a decrease in performance on the VR setup. However, it should be noted that performance in VR was only slightly worse than the desktop setup [32]. This study does not prove any specific usability metrics to explain any differences in performance; however, users reported similar levels of satisfaction when undertaking tasks in the multiple equipment setups used in this experiment.

One possible interaction modality that VR allows is the use of hand gestures. This is a significant shift in functionality from a traditional mouse and keyboard, and as such, will necessitate specific usability considerations. Researchers have compared gesture inputs against a traditional mouse and keyboard interface in three different VR tasks: regular pointing tasks, GUI navigation and a visualization tool [33]. Experimental data showed that input and task completion rate was greatly reduced for gesture input. However, even when used for a limited time, gesture input caused fatigue. Fatigue is an important usability consideration for this technology that is not as present when designing mice or controller interfaces. Gesture input has immense potential for satisfying and efficient use and makes sense as a logical step or tool to increase immersion, but this interaction modality faces unique design challenges [33].

A possible design consideration when designing for gesture interfaces is to consider the difference between the dexterity of the hand against the dexterity of the hand with a tool (as discussed above). It is possible that increases in the quality of computer vision and recognition techniques for gesture input could increase usability and performance dramatically. In suitable applications, overall usability in VR could increase.

A further experiment examined the usability of the Nintendo Wii® Fit Plus (NWFP) for the treatment of balance impairment in vestibular and other neurological diseases [34]. The experiment used a System Usability Scale (SUS), a widely used numeric satisfaction rating scale and a post-treatment questionnaire [35]. Fitts' Law constrained the tasks used in these experiments, and researchers found that high mean SUS scores correlated to successful use of the NWFP for treatment. Participants also reported that they had higher enjoyment and motivation with the NWFP than with their usual physiotherapy [34]. The various studies described above used an amalgamation of different experimental measurements and usability metrics, although many had a common thread measuring experience satisfaction. Overall, the evidence illustrates that the usability of many motor function considerations transfers across multiple equipment setups (desktop, VR controllers, etc) [32, 33, 34].

1.5. Other Measures of Usability in Serious Gaming

Serious game design is a domain where there is substantial existing work to create general guidelines, best practices, and heuristics for design and usability. Creating useful serious games is complex and challenging, and benefits from these templates and best practices, which often address common challenges. Many of these guidelines and templates have developed alongside the rise and popularity of video games in mainstream culture [36].

Much of the research described in previous sections has been physical in nature, either relating to the hardware and ergonomic choices in the design of serious games or the interaction technology (such as VR headsets or mouse/keyboard). Serious game design requires ergonomic considerations, rules and practices relating to more abstract ideas of game design, and an understanding of fundamental design rules (such as Fitts' Law).

A number of researchers have attempted to collect these guidelines into sets of usability principles; for example, Pinelle [37] created ten usability principles based on the analysis of 108 different video game reviews on the internet. Some of these principles were game-type specific, such as providing predictable and reasonable behavior for computer-controlled units, but other principles can be ubiquitously applied to serious game usability. These include such guidelines as [37]:

- providing consistent responses to the user's actions
- allowing users to customize video and audio settings
- providing unobstructed views appropriate to the user's current situation
- providing input mapping for the interface;
- providing controls that have an appropriate amount of sensitivity and responsiveness
- providing users with information on game status

Most of these principles are ergonomic and interaction considerations that improve the user experience and duplicate many existing basic HCI principles [38, 39]. These principles don't exist as specific design laws such as Fitts' Law or Hick's Law [2, 39], and they need to be interpreted for each specific use case as their application can vary dramatically between different goals with game design. This, unfortunately, is a long-standing problem with the application of usability guidelines in the field of serious games, as there will always be a spectrum of implementation for any given design choice [37].

Even with these challenges, it continues to be a goal of multiple researchers to attempt to codify game design. The Heuristics to Evaluate Playability (HEP) and its more specific refined list, the Heuristics of Playability (PLAY), are an example of such an effort [30]. Many of the items on these lists of heuristics overlap with Pinelle's list [37]. The PLAY list of heuristics is broken down into several categories of heuristics relating to Game Play: Coolness, Entertainment, Humor, Emotional Immersion, Usability, and Game Mechanics [40].

In the context of the work described in this paper, the usability and game mechanic heuristics are the most pertinent. Even though it is difficult to distil any of the above principles down to clear laws or rules of game design, certain more formal rules (such as Fitts' Law) can still be applied piecewise to guide design towards better usability.

1.6. Existing Fitts' Law and VR Research

Fitts' Law has been shown to apply to traditional serious game setups both in 3D and 2D environments. However, research into Fitts' Law within VR environments is much less prevalent in the literature. Most of the work is very recent and seems to have only appeared within the last decade. Most work still relates to generic 3D environments rather than specific situations using current VR technology. There are a few attempts to explore Fitts' Law performance models in VR. Triantafyllidis and Li address issues related to adapting Fitts' Law to VR environments and developing an adaptation of Fitts' Law that accounts for spatial arrangement, as well as translational and rotational requirements. Their model attempts to reconcile all these added dimensions under one formulation, and they found many problems with this approach [41]. Perhaps isolating variables and building up the model slower in a piecewise manner would be a better approach. Clark et al. explored Fitts' Law in 3D VR environments using low-cost VR technology. They developed an extended Fitts' Law model using an Oculus Rift for their experimentation. The model developed accounted for 64.5% of the variation in movement times [42].

The two pieces of research described above provide solid groundwork for the extension of Fitts' Laws into VR interfaces but also emphasize the need for further inquiry. As with many previous Fitts' Law studies, they focused on developing their own custom models. Usability studies applying Fitts' Law to VR interactions are underrepresented in the literature. This could potentially be attributable to the fact that many experimental usability studies are extended to VR environments from theory originating in traditional flat screen setups, and as such, the work would often encounter issues. However, as was suggested earlier, it is important to establish that each existing Fitts' Law usability principle can also be established within VR environments. Discovering where there is actual overlap between the application of 2D and 3D principles allows for both avoiding redundancy and demonstrating issues that need further investigation. It has already been demonstrated that when using VR technology, models that account for target depth improve predictive power over more traditional Fitts' Law formulations [41, 42]. Eventually, there will be a set of complex and fleshed-out Fitts' Law heuristics for VR environments that are not simply borrowed or appropriated from traditional heuristics from more classical 2D setups. The initial stages of this work involve starting with the simplest existing laws and principles and incrementally increasing the complexity of the experimentation and models developed.

2. Experimental Design

This experiment was set up to undertake an exploration of Fitts' Law, as it can be applied in VR environments. Specifically, the experiment used an Oculus Quest 2 headset in an attempt to examine the efficacy of the Law as a model of the speed-accuracy trade-off. The experiment was set up to determine the indexes of difficulty of various pointing tasks in VR and then correlate movement times from experimentation to see how well a series of regression lines fitted the experimental data.

2.1. Participants

Several participants were sought for the study with diverse demographic backgrounds. The study used twelve participants of varying ages who had a range of experience in using both computer technology and, specifically, VR technology.

2.2. Materials

An Oculus Quest 2 headset and controllers were set up in a neutral experimental environment. A connecting USBC cord connected the Oculus Quest 2 to a computer to record a number of experimental metrics that were measured in real time.

The software used included:

- Microsoft Excel is used for calculating the best fit linear regression line, undertaking R2 analysis and creating graphs;
- Adobe Premier Pro and Adobe Photoshop is used for video review and task time measurement;
- Gimp - for photo editing;
- Microsoft Word is used to create documents and present technology.

2.3. Experimental Design

Participants were initially provided with an informed consent form, and an experimental appointment was scheduled. At the beginning of each experiment, a range of anonymized demographic information was collected from each participant. The participants were each then given instructions on the task to be undertaken in the experiment. Both verbal and written instructions were given to each participant. The study involved each participant undertaking a series of 18-pointing tasks. Each task required the participant to move a cursor from a starting point to a specific target within the Oculus Quest 2's universal menu. The participants were expected to access and select 18 different buttons, with each button press being treated as a separate task within the data collection (Figure 1).

The time taken to perform these tasks was collected; additionally, the cursor starting and ending locations were recorded. Hence, the experimental tasks predominantly involved starting from a particular point, moving the cursor to a particular screen item, and then selecting that item – a common task in any serious game VR environment. To ensure accurate data collection, the experiment used an Oculus Quest 2 headset connected to a computer via a USB-C cord. This setup enabled real-time recording of the experimental metrics. The software used for data collection and analysis included Microsoft Excel for calculating linear regression lines and performing R^2 analysis, Adobe Premiere Pro and Adobe Photoshop for video review and task time measurement, and Gimp for photo editing. These tools ensured precise measurement of the movement times, target sizes, and distances travelled during each task. The experiment also involved initial calibration of the Oculus Quest 2 headset and controllers to ensure consistent and accurate tracking of cursor movements and selections throughout the study. Figure 1 contains various numbers corresponding to the experimental target buttons within the user interface. Participants were expected to access and select 18 of the buttons, and each button press was treated as a separate task within the data collection. A video of the screen capture for each individual task undertaken by each participant was also collected during the experiment. The Oculus Quest 2 universal menu provided a wide range of cursor movement distances and target sizes, which is needed to allow a Fitts Law model to be fully evaluated.

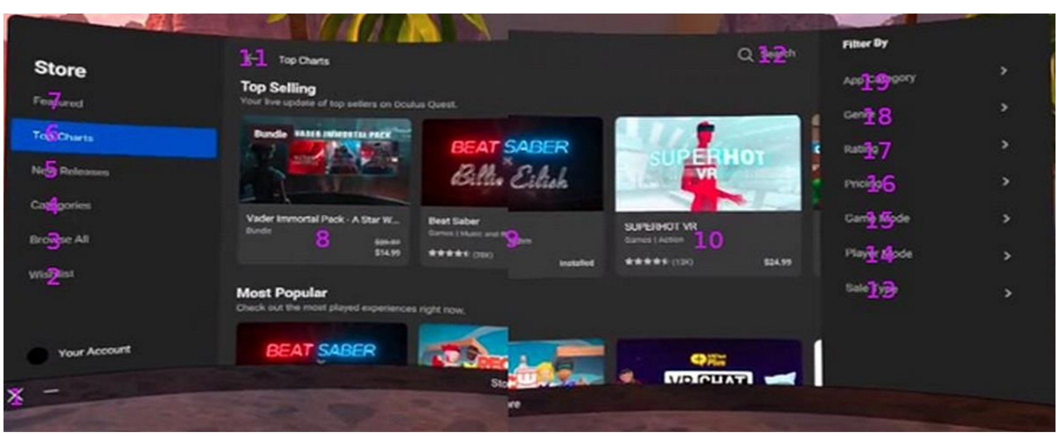


Fig. 1 Numbered menu selection task

Table 1. Participant demographic data

Participant	Gender	Age	Mouse/ Keyboard	VR Headset
P1	Male	29	High	Low
P2	Female	29	Medium	Medium
P3	Male	27	High	None
P4	Male	26	High	None
P5	Male	27	High	None
P6	Male	25	High	Low
P7	Male	27	High	Low
P8	Female	55	Medium	None
P9	Male	64	Medium	Low
P10	Female	69	High	None
P11	Male	25	High	None
P12	Male	30	High	None

3. Experimental Data

During each experimental session, a range of demographic data was initially captured from a form completed by each participant (Table 1). This demographic information was used to group individual results together by gender, age, prior experience, etc. All data was anonymized, and no identifying participant data was collected.

The study involved a total of twelve participants. These participants came from diverse demographic backgrounds and varied in age. Specifically, there were nine males and three females, with no other gender identities reported. The ages of the participants ranged from 25 to 69 years old. Of the twelve participants, six were between the ages of 25 and 30, one was between 31 and 55, and two were between 56 and 69 (Table 1). Regarding their experience with technology, eight participants had high experience with using a mouse and keyboard, while two participants had a medium level of experience.

In terms of VR headset experience, none of the participants had high experience; one participant had medium experience, seven participants had low experience, and four participants had no experience with VR headsets (Table 1).

This diverse participant pool was selected to cover a range of experiences with both general computer technology and VR technology.

Cursor locations at the beginning and end of each selection task were also collected and stored. This allowed the movement distance, Amplitude (A), to be measured. The sizes of each of the targets within the universal menu interface were also measured (Table 2). These were some of the variables needed for the Fitts' Law calculations required for the analysis. Screen-captured activity from each participant's individual pointing tasks was transferred from the Oculus VR headset to a digital storage medium. Premiere Pro was then used to record times for participant's individual pointing tasks.

The data collected during this experiment is shown in Table 2. The individual task identifiers (corresponding to the tasks in Figure 1) are shown in the first column. The measured target size (Width) and distance travelled (Amplitude) for each task are given, which allows the Index of Difficulty (ID) for each task to be calculated.

Table 2. Experimental task data

Task	Amplitude	Width	ID	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12
T1	292	67	3.13	0.634	0.835	0.635	0.969	0.702	0.668		1.003	1.303	1.485	1.002	0.703
T2	370	67	3.47	0.701	0.969	0.768	0.969	0.936	0.601	0.935	1.705	0.902	0.843	0.735	1.273
T3	447	67	3.74	0.735	0.902	0.771	1.069	0.635	0.634	1,169	2.173	0.969	1.080	0.935	0.871
T4	524	67	3.97	0.868	0.735	0.735	1.102	0.702	0.701	1.370	1.504	1.203	1.147	0.969	1.407
T5	599	67	4.17	0.868	0.768	0.802	0.969	0.635	0.668	1.403	1.605	0.935	1.518	1.036	1.005
T6	671	67	4.33	0.902	0.935	0.668	1.303	0.702	0.668	1.838	1.337	1.036	1.147	1.203	1.106
T7	818	171	3.26	0.802	0.802	0.902	1.136	0.802	0.601	1.437	1.304	0.902	1.147	1.370	1.307
T8	1116	171	3.71	0.935	0.835	0.902	1.269	0.836	0.634	1.971	1.772	0.935	1.002	1.270	1.206
T9	1431	171	4.07	0.868	1.035	0.768	1.203	0.635	0.668	2.005	1.404		1.470	1.871	1.977
T10	915	38	5.59	0.968	0.969	0.835	1.336	0.969	0.835	1.336	2.006	1.236		1.337	2.480
T1	1648	55	5.91	1.202	1.136	1.002	1.503		0.801	1.838	1.973	1.871			
T12	1693	67	5.66	1.136	1.203	0.969				1.637	1.605	1.904	1.236		
T13	1718	67	5.69		1.203	1.169	1.604			1.771		1.370	1.303	1.571	1.340
T14	1735	67	5.70		1.236	1.069	1.336			1.771		1.637	1.670		1.474
T15	1726	67	5.69		1.102		1.303			1.738					
T16	1743	67	5.71		1.103	1.002	1.336			1.537		1.403	1.303		1.608
T17	1767	67	5.73		1.204		1.437			1.504		1.437		1.704	1.273
T18	1837	67	5.78	1.436	1.002	0.902	1.403			1.871		1.370	1.269	1.637	1.575

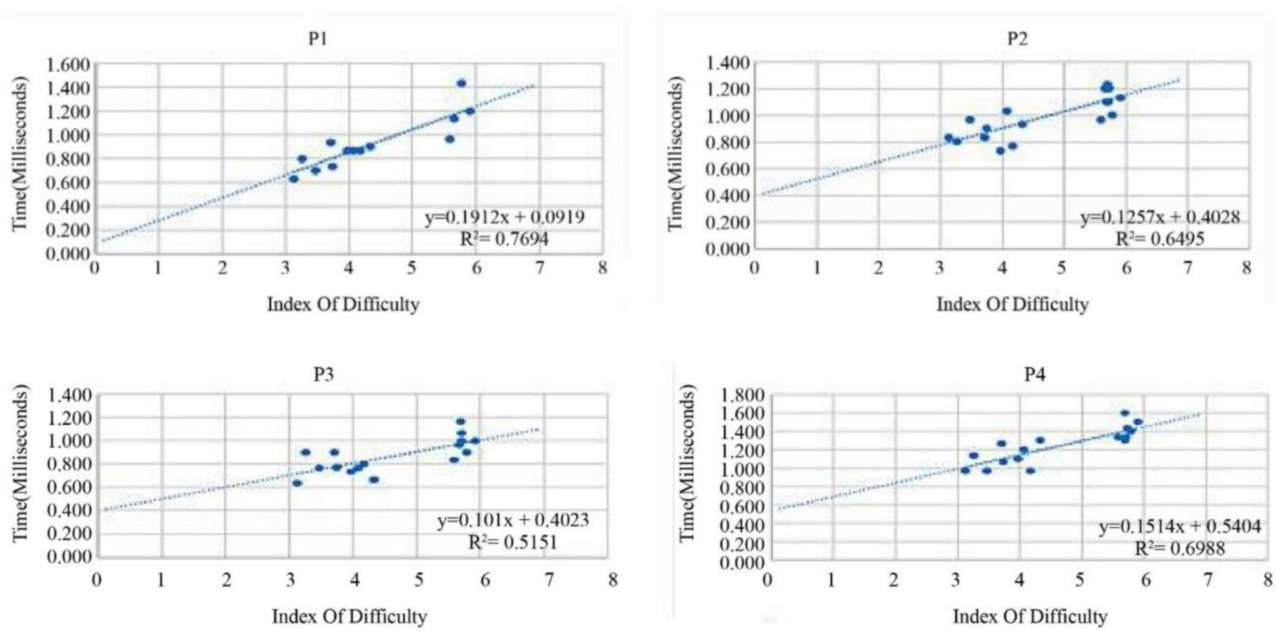
The calculated Indices of Difficulty have no units, and the measurement has no external meaning. However, the Indices are meaningful in relation to each other and allow an objective assessment of the relative difficulty of each of the pointing tasks. The time taken for each task by each participant (in milliseconds) is displayed on the right-hand side of Table 2.

These rigorous procedures were designed to provide a controlled and reliable experimental environment for testing the applicability of Fitts' Law in VR interactions. Since this experiment represents a measurement in 3D space that is abstracted to a 2D mathematical model based on a measurement of target width, the Fitts’ Law expression to be used requires special consideration.

The study primarily used linear regression to analyze the relationship between movement time (MT) and the index of difficulty (ID). Linear regression lines were fitted to the experimental data for each participant, plotting MT against ID. The coefficients of determination (R^2) were calculated to assess the goodness of fit for these regression lines. The R^2 values indicate the proportion of the variance in the dependent variable (MT) that is predictable from the independent variable (ID). Participants with R^2 values greater than 0.5, and particularly those with R^2 values higher than 0.75, showed strong correlations between MT and ID. These values were used to derive the constants a and b for the Fitts' Law equation, with a being the y-axis intercept and b is the slope of the regression line. The quality of the regression fits, and the corresponding R^2 values were used to evaluate the consistency and reliability of the data. Participants with low R^2 values ndicated weaker correlations and potentially higher variability in their data, which could suggest the presence of outliers or deviations from the expected model. The study acknowledged that some participants had lower R^2 values, reflecting a weaker correlation between MT and ID, but did not remove these outliers from the data set. One method for finding the size of a target when in a 2D model is to use the smaller model. This means that instead of using the status quo model of taking the width of a target without considering the height, instead either the width or the height is used as the width in the calculation, whichever one is smaller. Previous research has continually demonstrated that this calculation method gives better results in extended 3D situations than the status quo model [3, 8, 14, 16, 43].

The measured results were then used to plot a series of graphs showing the time taken for each individual task for each participant (Figure 2). Movement Time (MT) in milliseconds was plotted on the y-axis, and Index of Difficulty (ID) on the x-axis. As expected, the graphs all show a direct correlation and movement time increases as the difficulty of the task increases.

A linear regression line was fitted through each set of experimental data. Each individual graph also shows both the equation of the best-fit line and the resulting R-squared values. The linear regression lines clearly display the trend or direction in which the data points are moving as ID increases for each participant. This allows an immediate estimation of the strength and nature of the relationship between ID and MT, where the slope of the regression line indicates the rate of change, and the intercept provides a baseline value.



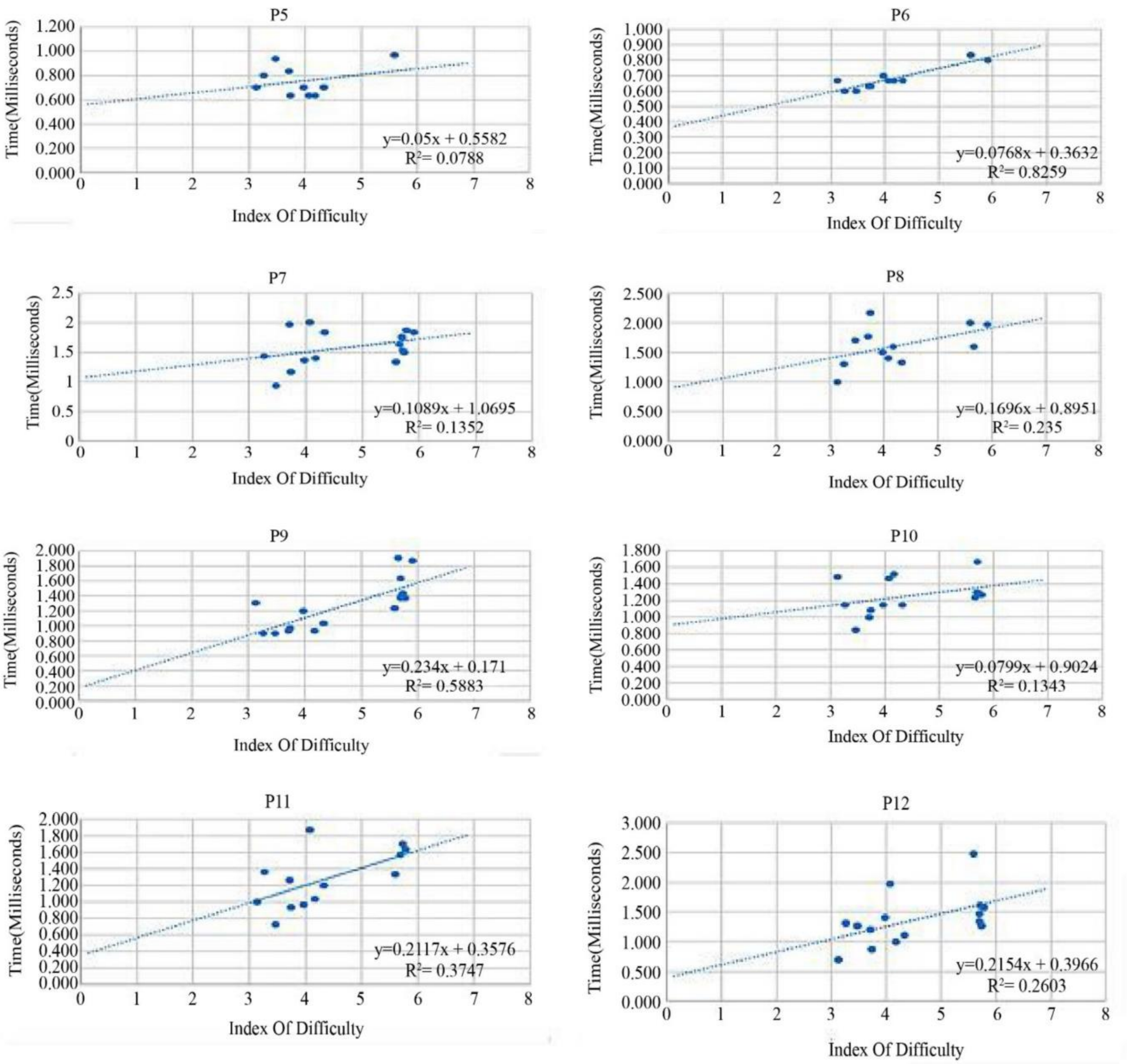


Fig. 2 Time taken for individual tasks plotted against ID for each participant

The linear relationships illustrated in each of the graphs in Figure 2 are as predicted since the target movement of the participants in the 3D environment is constrained by Fitts' Law.

The data from all of the twelve participants was aggregated, and a single regression line was plotted. This graph is shown in Figure 3.

The data collected was segregated based on the demographic data collected. Several graphs were created based on this segregated participant data (Figure 4). It was hoped that segregating the data in this way would identify specific trends among the different groups.

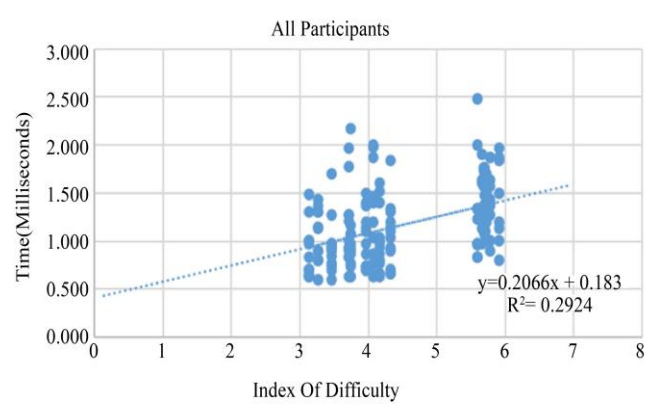


Fig. 3 Time taken for individual tasks plotted against ID

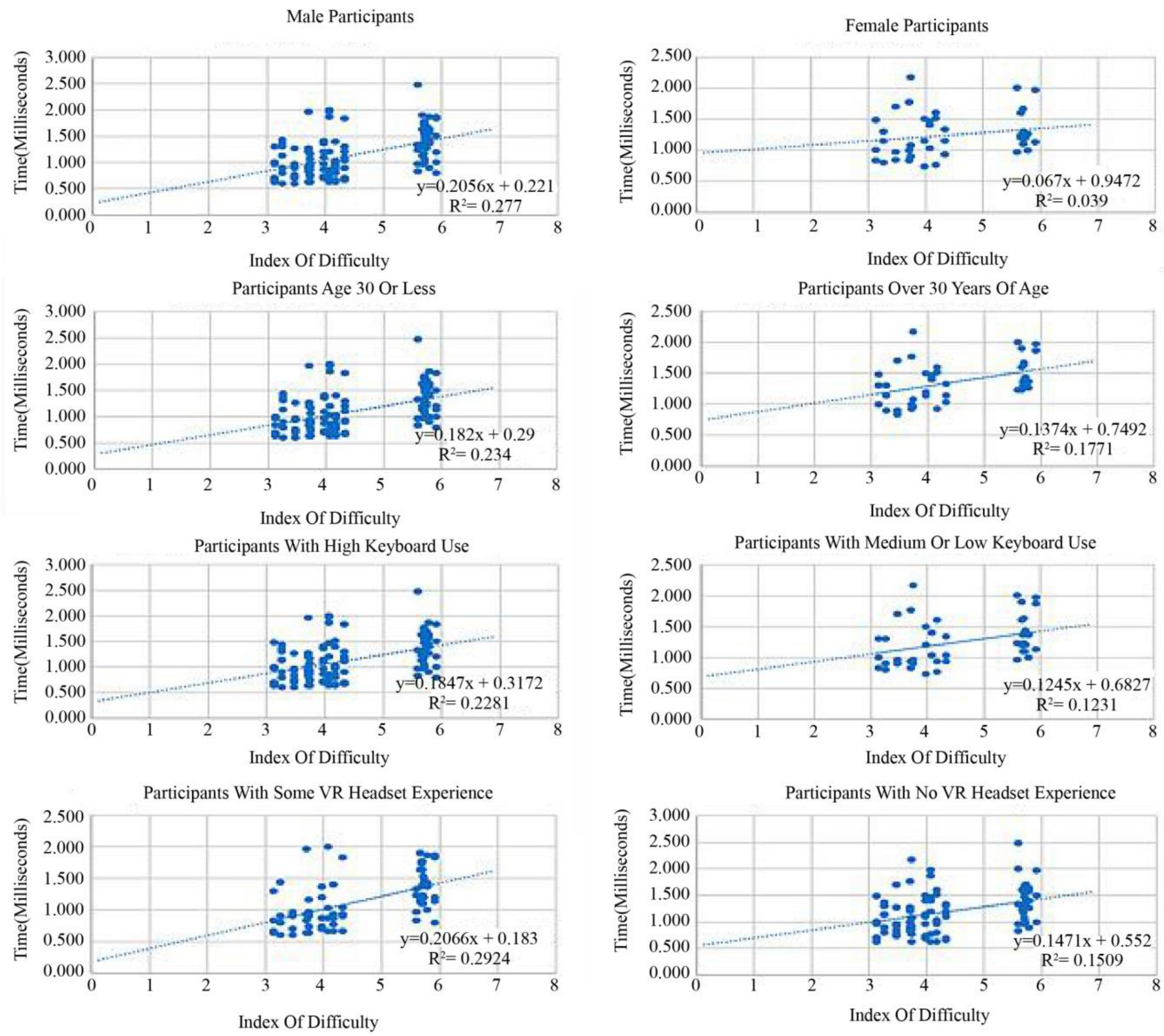


Fig. 4 Time taken for individual tasks plotted against ID for participant groups

The data was segregated in the following manner :

- Those participants identified as male or female (no other gender identities were reported by participants during this experiment).
- Participants were older than thirty years of age, and participants were thirty years of age or younger.
- Participants with a large amount (High) mouse/keyboard experience, and participants with less (Medium/Low) mouse/keyboard experience.
- Participants with some VR headset experience and participants with no VR headset experience.

4. Discussion and Analysis

The base Fitts' Law expression used for this study was :

$$MT = a + b\,[\mathrm{Log}_2\,(2A/W)] = a + b\,[ID]$$

A is Amplitude or Distance,

W is the Target Width (Based on the Smaller-Of Method)

ID is Index of Difficulty (Log2 (2A/W)

MT is the Movement Time measured during the experiment

a and *b* are constants which need to be determined

In this experiment, the Fitts' Law coefficients a and b were individually derived from each of the best fit linear regression lines, plotted from the experimental data for each participant.

The constant a is equivalent to the y-axis (MT) intercept, and b is equivalent to the slope of the regression line. The constants determined from the experimental data can be seen on the individual regression graph for each participant (Figure 2 and Table 3).

Table 3. Constants (a and b) derived from the regression lines For each participant

Participant	Equation	R^2	a	b
P1	y = 0.1912x +0.0919	0.7694	0.1912	0.0919
P2	y = 0.1257x+0.4028	0.6495	0.1257	0.4028
P3	y = 0.1010x+0.4023	0.5151	0.1010	0.4023
P4	y = 0.1514x + 0.5404	0.6988	0.1514	0.5404
P5	y = 0.5000x + 0.5582	0.0788	0.5000	0.5582
P6	y = 0.0768x + 0.3632	0.8259	0.0768	0.3632
PZ	y = 0.1089x + 1.0695	0.1352	0.1089	0.0695
P8	y = 0.1696x + 0.8951	0.2350	0.1696	0.8951
P9	y = 0.2340x + 0.1710	0.5883	0.2340	0.1710
P10	y = 0.0799x + 0.9024	0.1343	0.0799	0.9024
P11	y = 0.2110x +0.3576	0.3747	0.2110	0.3576
P12	y = 0.2154x +0.3966	0.2603	0.2154	0.3966
Aggregate	**y = 0.1700x+0.4071**	**0.1995**	**0.1700**	**0.4071**

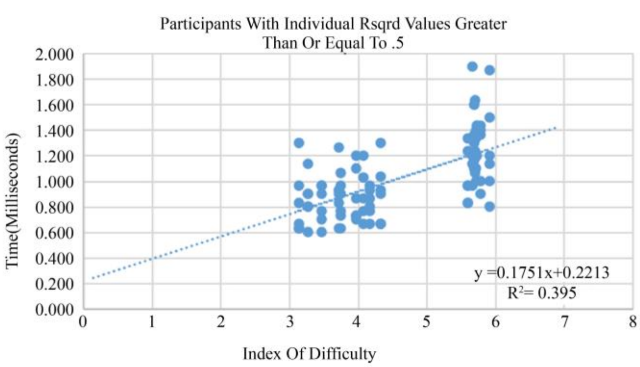
The aggregated values of the constants a and b are calculated as 0.1700 and 0.4071, respectively. The degree of confidence in these figures can be rated as relatively high, as the standard deviations of a and b are 0.11 and 0.26, respectively.

The constants can also be validated by comparing them to those derived from other, similar research. While the constants cannot be directly be directly compared due to the different experimental measurement techniques used, a quotient approach can be adopted, where the ratio of b/a is compared from different studies.

Using this method, it can be demonstrated that the ratio of the constants derived in this experiment (2.40) is comparable to those from other studies (2.78, 2.66), with a maximum error of around 13% [14, 15].

4.1. Data Variance

Overall, the regression lines provided what could be classed as a good 'fit' through the collected experimental data. The R^2 value, also known as the coefficient of determination, indicates the proportion of the variance in the dependent variable that is predictable from the independent variables.



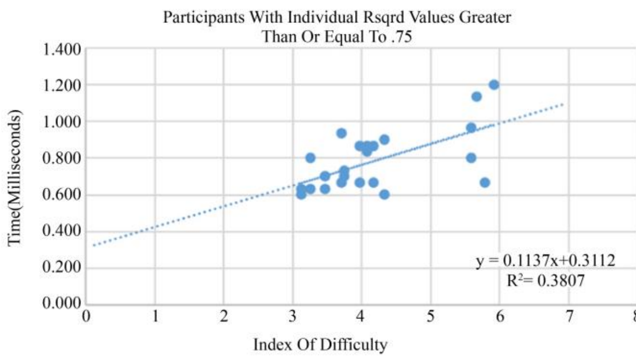


Fig 5 Time taken for individual tasks plotted against ID for different R^2 participant groups

Participants 1, 2, 3, 4, 6 and 9 had an R^2 value greater than 0.5, and participants 1 and 6 had R^2 values higher than 0.75 (Figure 2 & Table 3). Other participants had lower R^2 values, this being indicative of a weaker correlation. Participants with R^2 values greater than 0.5 and participants with R^2 values higher than 0.75 are compared in Figure 5.

However, all of the regression trend lines had a similar positive slope, indicating a strong correlation between movement time for the individual tasks and the indices of difficulty. In practical terms, this means that the independent variables demonstrate that Fitts' Law holds in this experiment and also holds for VR applications in general. This agrees with the findings of other researchers in the field [8, 14, 15, 18].

4.2. Model Accuracy and Prediction

The values of the Fitts' Law coefficients, a and b, have been experimentally determined as 1.1700 and 1.4071, respectively. It is now possible to substitute these values into the Fitts' Law equation and begin to use this as a predictive model for serious VR gaming applications.

Table 4. Errors between predictive Fitts' Law model and experimental results

Task	Amplitude	Width	ID	MT	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12
T1	292	67	3.13	1.442	0.000	0.284	0.002	0.473	0.096	0.048		0.521	0.945	1.201	0.520	0.098
T2	370	67	3.47	1.581	0.044	0.334	0.050	0.334	0.288	0.185	0.286	1.373	0.240	0.156	0.004	0.763
T3	447	67	3.74	1.692	0.107	0.129	0.056	0.364	0.248	0.250	0.505	1.922	0.223	0.380	0.175	0.085
T4	524	67	3.97	1.785	0.013	0.201	0.201	0.317	0.247	0.249	0.696	0.885	0.460	0.381	0.130	0.748
T5	599	67	4.17	1.864	0.091	0.233	0.185	0.051	0.420	0.374	0.664	0.949	0.003	0.826	0.146	0.102
T6	671	67	4.3	1.930	0.110	0.063	0.440	0.456	0.392	0.440	1.211	0.504	0.079	0.236	0.315	0.178
T7	818	171	3.26	1.496	0.183	0.183	0.324	0.654	0.183	0.101	1.079	0.891	0.324	0.670	0.984	0.896
T8	111	171	3.71	1.679	0.188	0.047	0.141	0.659	0.048	0.237	1.650	1.36	0.188	0.283	0.661	0.571
T9	1431	171	4.07	1.825	0.053	0.183	0.194	0.420	0.381	0.335	1.552	0.704		0.797	1.363	1.513
T10	915	38	5.59	2.446	0.532	0.531	0.720	0.013	0.531	0.720	0.013	0.933	0.154		0.011	1.602
T1	164	55	5.91	2.574	0.330	0.423	0.613	0.095		0.896	0.567	0.758	0.614			
T12	169	67	5.66	2.474	0.323	0.229	0.559				0.384	0.33	0.761	0.182		
T13	1718	67	5.69	2.483		0.237	0.285	0.329			0.564		0.002	0.096	0.282	0.044
T14	1735	67	5.70	2.488		0.197	0.432	0.055			0.559		0.369	0.416		0.139
T15	172	67	5.69	2.485		0.383		0.099			0.515					
T16	174	67	5.71	2.491		0.387	0.530	0.058			0.226		0.036	0.105		0.326
T17	176	67	5.73	2.499		0.252		0.076			0.171		0.076		0.453	0.155
T18	183	67	5.78	2.522	0.052	0.560	0.702	0.006			0.666		0.041	0.184	0.336	0.248
% Error					6.068	10.496	13.213	10.209	11.032	13.564	25.883	36.150	10.980	16.433	16.103	19.370

To evaluate the accuracy of this approach, the predictive model was used to calculate the Movement Time (MT) for the individual tasks in the serious gaming virtual environment from this experiment. The results of these predictive calculations are shown in Table 3.

Table 3 also considers each individual participant and compares their measured experimental performance (MT) to the performance predicted by the Fitts' Law model. It is important to note that direct comparisons cannot be made due to the unitless nature of the MT value calculated by Fitts' Law. However, by once again applying a quotient approach, the relative dimensions of the predictive and measured values can be compared.

This allows the differential between the predictive and measured values to be calculated. These values for each individual task, for each participant, are shown in Table 3. An average error percentage demonstrating the predictive accuracy of the Fitts' Law model for each participant can then be calculated.

It should be noted that there is a direct correlation between the participants with the lowest error percentages (i.e. those for whom the model was most accurate) and those with higher coefficients of determination, R^2 (Table 4).

4.3. Segregated Data Analysis

An analysis was undertaken based on the demographically segregated data (Table 1). Analysis of the regression lines through the segregated data shows low R^2 values (Figure 4), which is a general lack of correlation. The low R^2 values in each of the individual segregated data sets demonstrated a weak correlation between the Indices of Difficulty and Movement Time for the participants in these groups. However, the low R^2 values are to be expected with the smaller participant sampling groups used in the segregated data.

However, one specific trend was of interest and can be clearly seen from the data. The same participant group, which reported higher R2 values (and hence better fitted with the Fitt's Model predictions), was also seen to fit better with the model in the segregated groups.

This can be seen visually by comparing the graphs in the two columns in Figure 4. The participants with higher R^2 values, who match the Fitts' Law predictions, tend to be male, under 30 years of age, have some experience with VR headsets, and have a lot of mouse/keyboard exposure.

Assuming that some of these factors are dependent variables (e.g. younger people are more likely to have used VR headsets), it becomes obvious that users who are more experienced with the technology are more likely to fit the Fitts' Law prediction model better.

5. Conclusion

Developers are implementing applications within VR environments with increasing frequency. Even though these 3D environments have been more widely used in more traditional gaming domains, little fundamental research has been undertaken to extend traditional HCI design rules into these 3D spaces.

One good example of this lack of research is in the application of Fitts' Law in VR environments. This paper provided details of an experiment undertaken to determine the applicability of Fitts' Law in VR environments and, in particular, menu selection tasks. Menu selection is a fundamental component of any, if not all, serious gaming applications.

The experiment described in this paper successfully demonstrated that Fitts' Law can be extended for use within a serious VR gaming application. All of the participants demonstrated a Fitts' Law trend, with movement time slowing down as the indices of difficulty (based on amplitude and target width) increased (Figure 2).

Values for the constants a and b, used in the Fitts' Law model, were calculated for this experimental setup as 0.1700 and 0.4071, respectively. The degree of confidence in these figures can be rated as relatively high and was validated by comparing them to those derived from other, similar research.

Overall, the regression lines created during this experiment provided what could be classed as a good 'fit' through the collected experimental data. Participants 1, 2, 3, 4, 6 and 9 had an R2 value greater than 0.5, and participants 1 and 6 had R2 values higher than 0.75 (Figure 2 & Table 3). However, all of the regression trend lines had a similar positive slope, indicating a strong correlation between movement time for the individual tasks and the indices of difficulty.

A predictive model was used to calculate the movement time for the individual tasks in the serious gaming virtual environment from this experiment. These results were compared to the participant's measured experimental performance. An average error percentage demonstrating the predictive accuracy of the Fitts' Law model for each participant was then calculated. There was a direct correlation between the participants with the lowest error percentages and those with higher values of R^2 (Table 3).

By segregating the data based on demographic factors (such as gender, age, and experience with VR and computer technology), the study attempted to identify trends and account for variability in the data. The analysis showed that participants with higher experience levels and certain demographic characteristics tended to have better-fitting regression models, indicating more consistent adherence to Fitts' Law.

Overall, the study used linear regression as the primary statistical method and relied on the R^2 values to evaluate the fit of the data, indirectly addressing potential outliers through demographic analysis and the variability in the regression fits. The analysis of demographically segregated data revealed low R^2 values, indicating a general lack of correlation between the Indices of Difficulty and Movement Time for participants in these groups. However, this was perhaps expected due to the relatively small participant sampling groups used in the segregated data.

Participants with higher R^2 values tended to be male, under 30 years old, had experience with VR headsets, and were familiar with mouse/keyboard usage. This suggests that experience with technology plays a significant role in the accuracy of the Fitts' Law prediction model.

The findings from this study reinforce the applicability of Fitts' Law within VR environments, particularly for pointing and selection tasks using handheld VR controllers. Despite the unique challenges presented by 3D immersive environments, the core principles of Fitts' Law hold true, demonstrating a strong correlation between movement time and the index of difficulty. This underscores the versatility and robustness of Fitts' Law as a predictive model for user interactions across a wide range of digital interfaces, including emerging VR technologies.

Furthermore, the consistency of the results across a diverse participant pool, varying in age, gender, and experience levels, highlights the generalizability of Fitts' Law in VR settings. This study provides a solid foundation for future research and development of VR applications, offering valuable insights for designers aiming to create intuitive and efficient user interfaces. By leveraging the principles of Fitts' Law, developers can enhance the usability and overall user experience in VR, paving the way for more immersive and accessible virtual environments.

The work described in this paper achieves better results in comparison to state-of-the-art techniques or those already reported in the literature for several reasons:

- *Adaptation of Fitts' Law for VR Environments:* The work described in this paper successfully demonstrates that Fitts' Law, originally developed for 2D interactions, can be adapted for use in VR environments. This adaptation takes into account the unique characteristics of VR interactions, such as the use of Head-Mounted Displays (HMDs) and VR controllers, which are different from traditional input devices like mice and keyboards. By creating a Fitts' Law linear model specifically for VR, the paper provides a more accurate and relevant framework for predicting user performance in these immersive environments.
- *Comprehensive Experimental Design:* The experiments involved participants with diverse demographic backgrounds and varying levels of experience with VR and computer technology. This comprehensive approach allowed for a more accurate assessment of how Fitts' Law applies in VR, accounting for factors such as target size, distance, and the use of VR controllers. The detailed data collection and analysis contributed to the robustness and reliability of the findings.
- *Validation Against Real-World Tasks:* The experiments focused on practical, real-world tasks that users commonly perform in VR environments, such as menu selection and pointing tasks. By using these realistic scenarios, the authors were able to demonstrate the

applicability and effectiveness of their adapted Fitts' Law model in actual VR usage. This practical approach ensures that the findings are directly relevant to the design and development of VR applications.

- *Addressing Previous Limitations:* The paper identifies and addresses limitations in earlier research by refining the Fitts' Law model for better accuracy in VR settings. The authors highlight the issues with small index of difficulty (ID) values and propose modifications to the original Fitts' Law equation to account for these challenges. This iterative process of refinement and validation against experimental data enhances the overall reliability and predictive power of the model.

By addressing these key factors, the paper not only bridges the gap in understanding user interactions in VR environments but also provides a solid foundation for further research and development in this area. The combination of theoretical adaptation, comprehensive experimentation, and practical validation sets this paper apart from previous studies and state-of-the-art techniques.

The experiment resulted in several sets of participant data that support the efficacy of Fitts' Law usage in VR-based serious games. Virtual Reality. Although some of the demographically segregated participant models had weak correlations, the majority of the participant data was consistent enough to provide compelling evidence. All models showed a positive correlation consistent with the premise of Fitts' Law. Ultimately, further experimentation would definitely lead to more accurate models and more widespread usage of this widely used UX design law in more serious 3D gaming applications.

The findings from this study reinforce the applicability of Fitts' Law within VR environments, particularly for pointing and selection tasks using handheld VR controllers. Despite the unique challenges presented by 3D immersive environments, the core principles of Fitts' Law hold true, demonstrating a strong correlation between movement time and the index of difficulty. This underscores the versatility and robustness of Fitts' Law as a predictive model for user interactions across a wide range of digital interfaces, including emerging VR technologies.

Furthermore, the consistency of the results across a diverse participant pool, varying in age, gender, and experience levels, highlights the generalizability of Fitts' Law in VR settings. This study provides a solid foundation for future research and development of VR applications, offering valuable insights for designers aiming to create intuitive and efficient user interfaces. By leveraging the principles of Fitts' Law, developers can enhance the usability and overall user experience in VR, paving the way for more immersive and accessible virtual environments.

5.1. Future Work

This study successfully demonstrated the application of Fitts' Law in 3D pointing and menu selection tasks. However, to enhance the robustness and generalizability of these findings, further experimentation needs to be undertaken.

There are a few obvious main areas where further work could improve the results :

- Increasing the size of the participant pool would allow for a much more comprehensive analysis, addressing potential confounding factors and allowing better correlations among the demographically segregated data.
- The research would benefit from increasing the diversity of the participant pool. A more diverse participant pool would ensure that the findings of the experiment are more likely to be applicable to a broader population. This would reduce biases and ensure that the conclusions drawn from the experiment can be generalized to a wider audience.
- Experimenting with a range of VR equipment (not just the Oculus 2 Quest headset used in this experiment) would improve the external validity of the results and widen the general applicability of the calculated experimental variables.
- Plan multiple experiments based on specific demographic groupings, ensuring that experiential factors (such as previous VR usage) do not create significant correlation effects on the experimental data. This should remove the direct correlation between the participants with the lowest error percentages (i.e. those for whom the model was most accurate) and those with higher coefficients of determination, R^2 (Table 3).

When considering the experimental procedure, a few improvements could be made :

- Increasing the precision of the time-based measurements. In this experiment, all time measurements were made by a human researcher using video editing software. Automatically capturing the time taken for the pointing task could reduce errors and increase the accuracy of the data captured.
- Finally, different Fitts' Law equations are compared and contrasted, i.e., changing the way the Index of Difficulty (ID) is calculated. This experiment used the smaller-of method to calculate ID; experimenting with and testing multiple ways to calculate the ID (area, status quo, angular, etc.) would perhaps allow a more robust correlation to be determined.

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