The Interplay Between Delay and Device in a Moving Target Selection Game

Aritra Kundu
Worcester Polytechnic Institute
Worcester, MA, USA, 01609-2882
Email: akundu@wpi.edu

Ragnhild Eg
Nofima
NO-9291, Tromsø, Norway
Email: Ragnhild.Eg@Nofima.no

Mark Claypool
Worcester Polytechnic Institute
Worcester, MA, USA, 01609-2882
Email: claypool@cs.wpi.edu

***Abstract*—Computer games have evolved alongside technologies such as personal computers, touchscreens, and virtual reality (VR). The devices have different interaction modes with distinct affordances, including direct physical control with tablets and immersive experiences in VR. Moreover, games are now easily accessible across devices due to cloud-based streaming. Despite this benefit, the challenge of delay persists and continues to affect both performance and quality of experience in games. The negative impact of delay is well-documented, but less is known about how its effect may interplay with a device's interaction mode. This study applies a cross-platform game with controlled levels of delay, where players use different interaction modes to select moving targets. The findings highlight how the detrimental effect of delay on player performance degradation varies across devices (worst on a PC compared to VR and a tablet, and best on the tablet) even while the interaction mode mediates the effects of delay (quality of experience is fairly stable across all conditions and devices, with VR the most immersive).**

I. Introduction

Computer games are a popular form of entertainment that has evolved together with consumer technology. Personal computers (PCs) have long been used for gaming, whereas more recent technology has introduced additional affordances that may alter the gaming experience. For instance, tablets allow users to interact with the game world directly through touch, whereas virtual reality (VR) replaces the physical world with one constructed for more immersive gaming experiences. At the same time, gaming via cloud servers has become a convenient option that facilitates streaming of games to lightweight devices. Despite its many benefits, cloud-based game streaming comes with the downside of added network latency, the consequences of which can be dire to player performance – at least for someone engaged in a battle or a race. This work targets the effects of delay on game performance, focusing on potential differences across the interaction modes of PCs, tablets, and VR.

A. Delay and Games

Real-time games require players to make numerous time-sensitive actions, such as aiming for a moving target, and delays as short as tens of milliseconds can be detrimental to both user experience and performance [1], [2]. Many games have some form of latency compensation [3], but these techniques primarily target network latency and are unable to mitigate all the different sources of delay nor do they all work with cloud-based games. Many of the studies that explore the effects of in-game delay center on commercial first-person shooter (FPS) games [1], [2], [4], owing to their delay sensitivity. Although the reported values vary, the research findings generally agree on the same detrimental effect of delay, both on player performance and quality of experience (QoE) [2], [5]. There are many reports on the physiological consequences of delayed visualizations in VR, but less is known about the consequences of delayed actions on performance. One prominent exception is a study by Slivar et al. [6] where they investigated user experiences while playing two-person commercial games in VR. The authors noted that latency compensations techniques made the tested games resilient to the impact of delay.

The context of full-featured games can be intuitively understood, but it is difficult to instrument and manipulate full games under controlled study conditions. When applying commercial games to studies of delay, the game is treated as a "black box" and the results are likely to be confounded by their latency compensation; moreover, while commercial games may allow for manipulation of delay, but not for experimental control such as the isolation of specific game events or actions. An alternative approach to the study of in-game delay is to avoid the complexity of commercial games and aim instead for controlled and measurable game actions.

B. Target Selection

Armed with the knowledge that both size and distance affect the difficulty of moving a pointer to a target area [7], researchers have tested the effects of delay in games that involve selecting a moving target. Their findings indicate that delays add to the difficulty of target-selection games, which can be particularly detrimental to performance accuracy and completion time [8], [9], [10], [11], as well as QoE [10], [11]. Related studies have also found that game parameters may mediate the impact of delay on performance, particularly parameters that add to the difficulty of the game, tend to exacerbate the negative effects of delay [12], [13], [14], [15].

These studies on target selection converge in their aim to understand how controlled amounts of delay can influence performance when playing a game. In addition to demonstrating

979-8-3503-5067-8/24/$31.00

how detrimental it can be when the rendered action lags behind the player's input, the findings also shed light on the mediating roles of different game parameters. Speed, distance, target size, and motion predictability, can all interplay with in-game delays, which adds to the difficulty of the game. However, game difficulty may also depend on the distinct interaction mode of the device, an aspect that has so far received little attention in research on game delay and performance.

C. Multi-Device Studies

The device in use has implications for how accurately a task can be performed, according to the findings of Mackenzie et al. [16]. In their user study, participants performed a simple task using standard pointing devices, including mouse, trackball, joystick, and touchpad. By comparing these devices across seven different accuracy measures, they established that target re-entry and movement offset were the only measures related to the pointing device throughput, at least for the task at hand. The accuracy of the devices varied between the different measures, but the mouse generally outperformed the other input devices.

The superior accuracy of mouse inputs may change when delay has an effect and lags the outcome of the task performance. Yet, the majority of research on game delay focuses on mouse interactions on a PC, disregarding potential differences that may arise from different interaction modes. One indication comes from a study that compared player performance and subjective experience across delay levels while playing a target-and-intercept game using a mouse, touchscreen, gamepad, and drawing tablet [10]. In line with most delay research, their results demonstrated a negative impact of delay on both performance and player experience. Furthermore, their findings revealed a mediating effect of device. Overall, the gamepad interactions yielded the best player performances with delay, whereas the touchscreen interactions were associated with the best experiences. In other words, both game parameters and input modes seem to interplay with the effect of delay on performance and subjective experience.

The approach of Gutwin et al. [10] emphasizes the value in investigating the potentially differential impact of delay according to device in order to gain insight on the temporal dependence of different interactions modes. Following their example, the starting point for the current investigation of interaction modes and in-game delay is earlier works on performance and subjective experience in target selection games with different parameters [9], [11] and in VR [17]. Our work builds upon the previous work [10] by incorporating VR for a comparative study of three popular devices with distinct interaction modes. We also add a cursor construct into the tablet interaction – not just using a finger as a pointer – to afford an equal comparison of pointing and selection across devices. In our study, the user's finger is used to touch and drag the cursor on the screen.

D. Motivation and Aim

To investigate the effects of moving target selection across devices with distinct interaction modes, we developed a cross-device game that runs in a Web browser with explicit control of the amount of delay introduced. By running in a Web browser, the same game can be played on a PC, tablet, or in VR. The PC condition serves as a common gaming platform with a mouse as input, the tablet provides a similar platform but with touch input, and VR serves as an emerging gaming environment that uses a game controller for input. Combined, the devices and the game settings allow for comparisons of player performance and QoE across delays and interaction modes.

In line with our aim to compare the potentially variable impact of delay on performance and user experience, we posed three research questions:

- R1 How does player performance differ according to the level of delay?
- R2 How does player performance differ according to the device's interaction mode, and does it mediate the effect of delay on performance?
- R3 How does QoE vary across delays and devices?

II. Methodology

In order to study game player performance for target selection with delay and different devices, we created a cross platform application and conducted a user study.

A. Devices

The study included three devices with distinct interaction modes: a laptop (PC) with a mouse as an input device, a tablet with a finger for input, and a VR headset with a hand controller as an input device.

The PC was a Lenovo Ideapad 510 running Windows 10 with a dual-core Intel i7 processor @ 2.5 GHz, with 20 GB of RAM and an NVIDIA GeForce 940 mx graphics card. The screen was 15.6" with 1920x1080 pixels @ 60 Hz. User input for target selection was via an external mouse with 1000 DPI and polling rate of 125 Hz. The application was run on Google Chrome version 89.0.4389 resized to match the screen size of the laptop.

The tablet was a Samsung Galaxy Tab S3t running Android with a quad-core Qualcomm Snapdragon 810 processor @ 2.15 GHz, with 4 GB of RAM. The screen was 9.7" with 1024x768 pixels @ 240 Hz. User input for target selection was via touch. The application was run on Google Chrome version 90.0.4430.82 resized to match the screen size of the tablet.

The stand-alone VR device was an Oculus Go running Android with a quad-core Qualcomm Snapdragon 821 processor @ 2.15 GHz processor, with 3 GB of RAM. The display resolution is 2560x1460 pixels @ 60 Hz, although an angular resolution for the VR headset would provide a better comparison to the other displays. The application was run using the built-in Oculus Quest Web-browser.

To provide for accurate assessment of the delays participants experienced in the study, the base system delay was measured on each device. A high-frame-rate camera (a Samsung Galaxy mobile phone) was setup completely external to the computer system and filmed at 250 frames per second, capturing the moment the input device was clicked inside the Chrome browser. By manually examining the video frames, the frame number when input was provided (e.g., finger bent) is subtracted from the frame number when the resulting output was visible, then multiplied by 4[1] to establish the local system delay in milliseconds. After 5 measurements for each device, the PC had a local delay of 69.0 ms (SD = 11.8), compared to the tablet at 31.4 (SD = 10.8) and VR at 31.6 (SD = 4.9). For all subsequent runs, extra delay was added to the tablet and VR (38 ms for the tablet and 37 ms for VR) so that their base delays were the same, 69 milliseconds, on each device. For this base delay as well as for the experiments, on the PC and VR, delay was added using the setTimeout() function in Javascript to the cursor object for movement and mouse up/down functions for clicking. On the tablet, the ontouchstart() or ontouchend() functions were used for adding delay for cursor movement and clicking.

B. Target Selection Game

The aim of the studied game is to control a wedge-shaped reticle to select a circular target bouncing around in an enclosed space, as illustrated in Figure 1. The target moves according to kinematic physics, bouncing off the sides of the screen/window, and varies in size and speed from round to round, as does the added delay. In order to maintain cross-platform compatibility, the game is implemented using HTML, CSS and Javascript using the InteractJS[2] library for participant input and the JQuery[3] animation library for target movement. To allow for direct comparisons, the game is presented the same way on all three devices. In VR, the game is displayed in a Web browser window projected in the VR space, which stays in the field of view at all times; the relative size and speed of the ball in the browser window is kept the same as for the other devices, even though the pixels sizes may change depending upon head orientation.

To play the game, the participant controls and moves the reticle with the input device and attempts to select the target by moving the reticle over the target and clicking (pushing the mouse button, pulling the trigger, tapping the screen, as appropriate for the device). If the tip of the reticle wedge intersects with any part of the circle while clicking, the target has been successfully selected. Upon successful selection, the target disappears and the participant is instructed to commence the next round by moving the reticle to click the button in the center of the screen. This situates the participant's reticle at the same starting location each round, whereupon the target spawns at a random location on the screen. Game performance is scored as both the number of clicks and the time taken to successfully select the target, the latter is also displayed to the participant as a timer that counts up from zero at the

[1]At 250 Hz, one frame is captured every 4 milliseconds.
[2]https://interactjs.io/
[3]https://jquery.com/

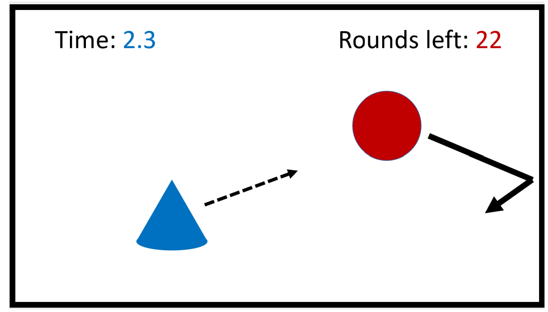


Fig. 1: In the target selection game, the user moves the wedge-shaped reticle to click and select the moving circular target. "Time" portrays the elapsed time for each round in seconds, and "Rounds left" indicates how many rounds are yet to be played in the session.

beginning of each round. To avoid fatigue and potential player frustration, each round is stopped after 30 seconds if the target is not successfully selected.

The difficulty of the game is determined by the target speed, target size, and delay, with levels established through pilot studies. The pilot studies provided values that bounded the most difficult setting so as not to be too frustrating that users would quit, the easiest setting so as not to be a trivial interaction (e.g., click anywhere), and medium conditions in between. With three levels each, this provides for 81 experimental conditions, repeated twice for a total of 162 experimental trials (168 game rounds with two practice rounds per device). Thus, each round the target is presented with one of three possible sizes, moves with one of three possible speeds, and the control of the reticle is delayed by one of three controlled values:

- 3 devices: PC, tablet, VR
- 3 target speeds: 0, 400, 500 pixels/s
- 3 target sizes: 50, 60, 70 pixels (diameter)
- 3 delay levels (total): 69, 144, 219 ms

C. Quality of Experience (QoE)

QoE was assessed once for every combination of device, delay, target speed, and target size, 81 times in total. The question "How was the previous game session?" was presented randomly during gameplay once for each of the experimental conditions, players chose from 5 options: Bad, Poor, Fair, Good or Excellent. MOS testing has been used for decades for traditional interactive voice calls and adapted to Voice over IP (VoIP) in the ITU standard [18]. We should note that there are more comprehensive evaluations of game experience that can be ascertained with longer questionnaires [19]. However, these instruments are more suitable for evaluating full-featured games since they require dozens of questions, and are prohibitive for user studies measuring the effects of several parameters (e.g., different latencies and compensation techniques) over a short period of time (e.g., 30 minutes).

Participants also completed a QoE questionnaire for each device, addressing the interaction experience, the ease of use, the feeling of control, and the immersiveness on a Likert scale ranging from 1 (Low) to 5 (High).

D. Procedure

Participants were invited to our dedicated, on-campus computer lab at a scheduled time. Upon arrival, participants were briefed on the overall aim of the study and its steps, the workings of the game, and the different devices they would be tested on. The instructions for the game were to use the input device to move the reticle and select the target as quickly and accurately as possible. After receiving this information, participants were given the opportunity to ask questions and would then sign an informed consent form. Prior to the main part of the experiment, participants also completed a demographic questionnaire.

Participants played the game on the three devices in a random order, the experimental conditions set by delay levels, target speeds, and target sizes were also shuffled so as to appear random from round to round. The two iterations for each condition were also shuffled (i.e., the 54 non-practice rounds were shuffled). Participants commenced with playing all 56 rounds on one device, during which the in-game QoE question would appear randomly 27 times (once per set of conditions) while the game was paused. Having finished the game on one device, participants completed the corresponding QoE questionnaire and then moved on to the next device.

The procedure was approved by our university's Institute Review Board (IRB).

E. Participants

We recruited 30 participants through University email lists, comprising predominantly young students of average age 20.7 years (SD = 4.0) and a gender bias (19 males, 10 females, 1 other) that aligns with the university's student population. All participants were eligible for a raffle to win a $25 USD Amazon gift card upon completion of the study, and many received course credit for volunteering.[4] Many of the participants had prior gaming experience, with an average of 3.6 (SD = 1.2) on a self-rated scale from 1 (low) to 5 (high). Their subjective reports of using devices similarly show frequent of game play and computer use among the participants, unlike VR which was rarely used:

- Game play: 10.7 hours per week (SD = 10.3)
- PC use: 46.9 hours per week (SD = 17.4)
- Tablet use: 3.0 hours per week (SD = 7.6)
- VR use: 0.2 hours per week (SD = 0.7)

III. Results

To address our research questions on player performance and user experience across delay and device, we collated the data into three data sets. The performance data set consisted of the time taken to select the target and the number of clicks used, for every participant and every trial. Adhering to the current study's focus on the interplay between device and delay, we collapsed the data across the two other game parameters, target speed and size. Two data sets cover user experience, one comprised of mean opinion scores for the quality of experience (QoE) collected during game play, and one with responses to the separate questionnaire completed after trying each device.

A. Analysis

The performance data comprised 4831 measurements of target selection times and clicks. Twenty-nine (29) measurements (less than 1%) were missing due to technical issues (no systematic bias, just random), and the target selection times for four game rounds (two on the PC, two in VR) were set to 30 seconds since they were not successfully completed in time. All data were collapsed across speed and size parameters, as well as repetitions, then imported into the statistical software SPSS.

We first analyzed the effects of the independent variables, device and delay, on the dependent variables, target selection time and clicks, with a multivariate analysis of variance (MANOVA). Because the MANOVA considers variations not only across independent variables, but also between dependent variables, it limits the combined error and provides greater statistical power to identify smaller effects than regular ANOVAs. This makes the MANOVA test well-suited for an experimental design with tightly coupled dependent measures, such as our experiments with target selection times and clicks. The reported MANOVA statistics include the F-value, which represents a ratio of variance attributed to the manipulated independent variables over random variance, the degrees of freedom (df), which refers to number of independent data samples, the p-value, which indicates the statistical significance of the effect, and the effect size (η_p^2), which corresponds to the explanatory significance.

Since the MANOVA does not identify whether significant effects apply to one or more dependent variables, nor distinguish between variable levels, we followed up significant effects with Tukey's Honest Significant Difference (HSD) post hoc tests that controls for multiple comparisons. The HSD yields a p-value for the statistical significance of the difference between two variable levels, which is presented as the difference between their means (Δ). We opted not to run the numerous post hoc tests required to follow up the significant interaction, these are instead illustrated as graphs with 95 % confidence intervals.

We applied the Friedman rank test to analyze differences between in-game QoE scores, yielding mean rank sums to indicate how devices and delays are ordered from low to high according to their subjective ratings. The corresponding χ^2 statistic provides a combined sum for the differences in ranking, and the p-value indicates whether the difference is sufficient to be statistically significant. Due to the limited number of scores for the device-specific QoE questionnaire,

[4] University gaming classes require 2% of a course grade for participating in user/playtesting studies.

TABLE I: Tukey's HSD post hoc tests for target selection time and clicks required to select the target, with mean differences between variable levels (Δ) and statistical significance (p).

Variable	Comparison	Δ	p
Device, selection time	PC vs Tablet	1.61	<.001
	Tablet vs VR	-0.84	<.001
	PC vs VR	0.77	<.001
Device, clicks to target	PC vs Tablet	0.53	<.001
	Tablet vs VR	-0.26	n.s.
	PC vs VR	0.27	n.s.
Delay, selection time	69 vs 144 ms	-0.28	n.s.
	144 vs 219 ms	-0.87	<.001
	69 vs 219 ms	-1.15	<.001
Delay, clicks to target	69 vs 144 ms	-0.07	n.s.
	144 vs 219 ms	-0.28	n.s.
	69 vs 219 ms	-0.35	.040

we refrained from carrying out any statistical analysis beyond means and standard deviations.

B. Performance

The MANOVA revealed significant main effects for both device (F(4, 9500) = 37.89, p<.001, η_p^2=.016) and delay (F(4, 9500) = 22.13, p<.001, η_p^2=.009), along with a significant interaction between the two (F(4, 9500) = 22.13, p<.001, η_p^2=.009).

Results from the Tukey's HSD post hoc tests following up the two main effects are summarized in Table I, the findings indicating that target selection time may be a more sensitive measure of performance than clicks. Nevertheless, as seen in Figure 2, both measures show better performance for a tablet compared to a PC, and worse performance for the highest level of delay compared to the lowest. Furthermore, the significant interaction suggests a mediating effect of device on delay's impact on performance. Figure 3 illustrates how selecting the target requires more time and clicks on a PC compared to the other devices when delay is at its highest. The differences between a tablet and VR are less prominent, but both show deteriorating performance with higher delay and this deterioration is somewhat worse for target selection times in VR compared to a tablet.

R1. How does player performance differ according to the level of delay?

The results revealed significant effects of delay only for the highest level. For selection times, this applied both compared to 69 ms of delay (0 added delay) and 144 ms of delay (75 ms of added delay), while for clicks it was significant only when comparing 69 to 219 ms of total delay. In general, participants spent a longer time selecting the target and used more clicks when the delay was 219 ms.

R2. How does player performance differ according to the device's interaction mode, and does it mediate the effect of delay on performance?

Our findings showed that participants' performances were significantly worse on a PC than on a tablet, taking longer and using more clicks to select the target. Performance in terms of selection times was also significantly worse for a PC, compared to VR, which in turn was worse than for a tablet. On average, participants spent more than 1.5 seconds longer to select the target on a PC than on a tablet.

The significant interaction between device and delay suggests that the effect of delay on performance is mediated by the device's input mode. Although the interactions between devices and delay levels reveal a similar pattern as the main effect, with poorer performance on a PC than on the other devices, there is also a marked negative effect of increasing delay for performance on a PC especially. Additionally, performance in terms of target selection times is somewhat worse for VR compared to a tablet.

TABLE II: Friedman rank tests for QoE scores, ranging from 1 (Bad) to 5 (Excellent).

Variable	Mean rank	χ^2	p
Device	PC: 1.54 VR: 2.12 Tablet: 2.34	539.329	<.001
Delay	219 ms: 1.87 144 ms: 1.96 69 ms: 2.15	157.514	<.001

TABLE III: Summary of participants' QoE across devices, ranging from 1 (Low) to 5 (High). Mean values are shown with standard deviations in parentheses.

Device	Interaction Experience	Ease of Use	Feeling of Control	Immersiveness
PC	3.3 (1.3)	3.7 (1.3)	3.1 (1.2)	2.4 (1.2)
Tablet	3.9 (1.0)	3.9 (1.0)	3.6 (1.1)	2.8 (1.0)
VR	3.8 (0.9)	3.6 (1.0)	3.5 (1.0)	3.9 (1.1)

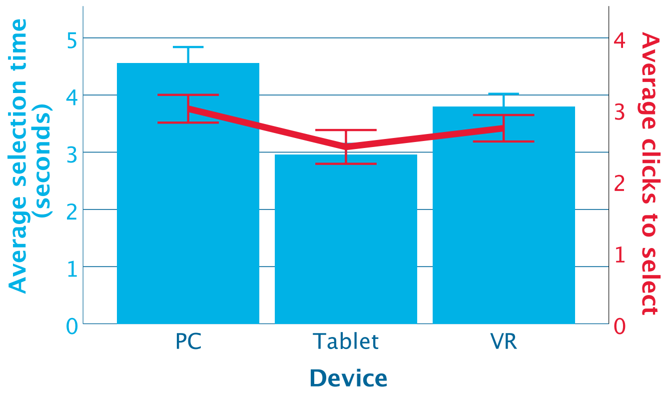
C. Quality of Experience

The results from the Friedman rank tests, outlined in Table II, revealed significant effects for both independent variables. However, the means and medians plotted in Figure 4 demonstrate that the differences are small. For device, QoE was somewhat worse for a PC than for a tablet or VR, and for delay it was slightly better when there was no added delay (69 ms).

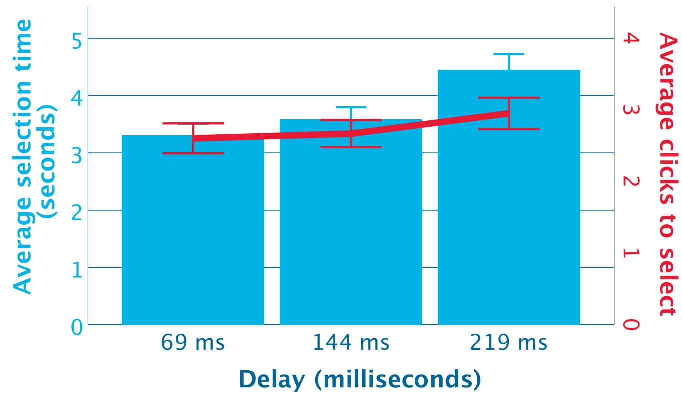
The results from the QoE questionnaire for each device are presented in Table III. They show that the interaction experience, ease of use, and feeling of control are fairly similar across devices. With that said, the means are slightly lower for a PC than for a tablet or VR, most notably so for interaction experience and feeling of control. Conversely, the difference between VR and the other two devices is quite distinct for immersiveness, with a markedly higher mean score for VR.

R3. How does QoE vary across delays and devices?

QoE does not vary much across delay levels or devices. Although we found that scores ranked significantly different

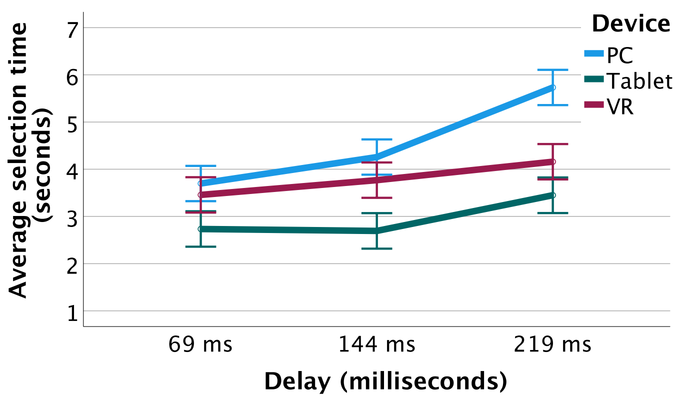


(a) Device

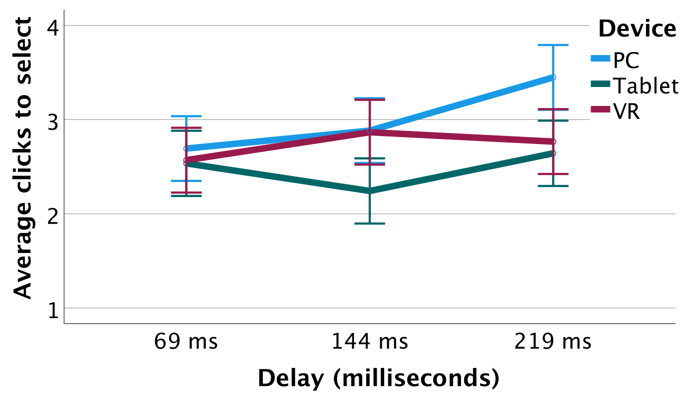


(b) Delay

Fig. 2: Average target selection time (left y-axis) and number of clicks to select target (right y-axis) for both main effects. Error bars represent 95% confidence intervals.

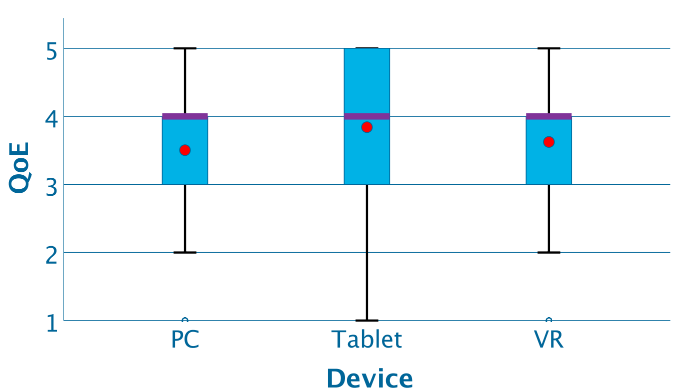


(a) Time: Device×Delay

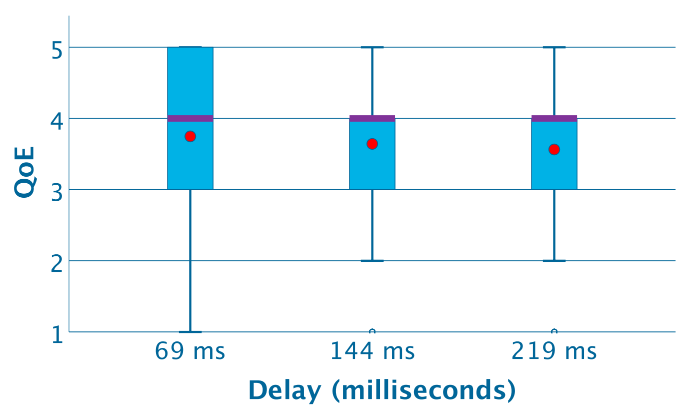


(b) Clicks: Device×Delay

Fig. 3: Average target selection time and number of clicks to select target for two-way interaction between device and delay. Error bars represent 95% confidence intervals.



(a) Device



(b) Delay

Fig. 4: Boxplots with mean (red dot) and median (purple bar) QoE scores on a Likert scale ranging from 1 (Bad) to 5 (Excellent). The boxes cover the 25th and 75th percentiles, and the whiskers correspond to minimum and maximum scores.

for both variables, the means showed little variation across variable levels and the medians were identical. The same applied to the interaction experience, the ease of use, and the feeling of control. However, immersiveness did stand out, with a distinctly higher mean for the VR experience.

IV. Discussion

The presented study was motivated by the pervasiveness of system and network delays, and the related consequences of inevitable delays during gameplay. Considering the variety of devices on the market and their distinctive interaction modes, the study targets the interplay between delay and device on how it affects game performance and QoE.

Our results revealed poorer performance for a PC compared to VR and a tablet – with the latter yielding the best results. Although delay did have a negative effect on performance, this was notable only at the highest level of delay. QoE remained fairly stable across all conditions; similarly, the other user experience measures did not differ much across devices, with the exception of immersiveness that was the highest for VR. Note, the small screen on the laptop (compared to, say, a typical desktop PC setup), may be at least partially responsible for the relatively poor PC performance – previous work found that larger display sizes provide better targeting performance versus those on a laptop [20].

In line with our aim, we defined three research questions centered on the potentially variable impact of delay and interaction mode on performance and QoE. We address the implications of the findings for each separately.

R1. How does player performance differ according to the level of delay? In this target selection game, delay only made a significant impact at the highest level, which corresponded to a total of 219 ms of delay. It is difficult to compare this level to that of earlier studies since delay can be implemented in various ways and since some studies include the base delay in their levels and others do not. Nevertheless, we did not uncover any significant effects on performance from delays on the lower end of the scale (69 ms and 144 ms), which have been documented earlier [13]. Yet our results show that performance decreased gradually with higher delay, which is in line with related studies [9], [10], [11]. Despite the non-significant effects for the shorter delays we tested, these results join a long line of research that demonstrate the detrimental impact of in-game delay, with relatively more novel results for VR.

R2. How does player performance differ according to the device's interaction mode, and does it mediate the effect of delay on performance? Performance for the target selection game was better when participants played on a tablet than on either a PC or in VR, both in terms of the target selection time and the number of clicks used. Intuitively, this makes sense due to the direct nature of the interaction, with the finger controlling the reticle without any intermediary device. However, this finding does go against earlier studies that have found better accuracy measures for the computer mouse [16] and better player performance for the game controller [10] compared to, among other devices, touchscreen interactions. We note that the earlier studies did *not* have the player move a reticle with their finger on the touchscreen device, as in our study – instead, selection in these earlier works was done by simply touching the target. Our results further point to a mediating effect of interaction mode on the delays' impact on performance, with the highest delay level having the most unfavorable outcome for selection times on a PC. This suggests that mouse interactions on a computer may be more temporally sensitive than the touch interactions on a tablet and the controller interactions in VR. Considering that the game in our study is fairly similar to experimental tasks described in earlier studies [10], [16], we can only speculate that the reason for our contrasting findings may be related to an interaction between the ease of using the device and the difficulty of playing the game.

R3. How does QoE vary across delays and devices? We found surprisingly small differences in QoE across delay levels and devices. The differences were found to be statistically significant, with degraded QoE for higher delays and PC particularly, but the effects are small enough to be negligible. The most noteworthy finding with respect to user experience was higher immersiveness reported for VR, compared to a PC and a tablet, which coincides with the technology's design.

The study has a focus on a specific task – selecting a moving target with a mouse. However, this action is common to many game genres – some examples include: 1) top-down shooters where a player aims a projectile by moving the cursor to the intended moving monster; 2) first person shooters (FPS) where a player uses the mouse to pan the game world to align a reticle over a moving opponent; and 3) multiplayer online battle arenas (MOBAs) where a player moves a skill shot indicator to aim at a moving opponent with a spell. Our results should generalize to games with these, and similar, actions, but may not hold for the effects of latency across devices for other actions.

V. Limitations and Future Work

There are several ways in which our study can be expanded to provide for more general application.

Our target selection game adds delay at the input device and while this represents local delay and mimics delays for cloud-based game streaming, traditional network games often experience network delay differently. With network delay only, game devices can still act on input immediately even as the input results travel to/from the server. Related to this, many games use latency compensation to mitigate network delays and some of these techniques are even applicable to local delays [3]. Future work can expand the type of delays tested with different latency compensation techniques.

Our target selection task includes both stationary and moving targets, but all target motion is simple with constant speeds and predictable changes to direction. Conversely, many game-related target selection tasks involve unpredictable movements, e.g., aiming for a target that jukes left or right. Future work could elaborate on the game parameters, such as target selection motion [9], and compare those effects across devices.

Many target selection tasks include tracking, where the player keeps a lock on the opponent (e.g., to hit a target multiple times). Target tracking is likely similar in some regards to target selection, but the user adjustments with delay may be different. The already large number of experimental conditions prevented us from expanding our actions tested, but additional studies could try out other game-related tasks.

Similarly, games often present more complex scenarios, such as a) multi-player, where players may be cooperating or competing to select targets first, or b) in-game strategies that affect target selection – e.g., in shooter games, players may have a choice of weapon types with different target selection abilities such as precision or fire rate.

Our local delay measurements only used 5 samples on each device due to the difficulty of the high speed camera approach. Alternate approaches with specialized hardware [21] may provide measurements of comparable accuracy but yield more samples.

Most of our participants made heavy use of a PC and mouse, but used tablets less frequently and VR very infrequently. Hence, the findings may be different for population groups that are more experienced with VR and/or tablets.

While the results did not reach significance at the lowest delays, other studies found significance for even smaller gaps in latency (e.g., [22], [23]). This may be because those those studies had up to hundreds of measurements for each conditions, compared to our two measurements per condition. The non-latency parameters (e.g., device, task difficulty) have a massive impact on time but differences at low delays may be dominated by noise from the other controlled variables.

VI. Conclusion

Game players have a variety of devices to choose from, from the traditional PC to the handheld tablet, and even fully immersive VR. Unfortunately, delay can degrade performance and subjective experience during gameplay on any device, and there is still a lack of knowledge on how this impact may differ between devices.

In our user study, we ran a controlled experiment where 30 participants played over 50 rounds on a PC, on a tablet, and in VR. We compared performance and QoE across controlled amounts of delay in a target selection game running on three devices with distinct inputs: a PC with a mouse, a tablet with touch and VR with a game controller. Analyses of the results uncovered significant effects of delay and device on player performance, along with a significant interaction that suggests a mediating effect of the device's interaction mode on the detrimental impact of delay. Although the subjective experience remained more or less the same across all conditions, VR did stand out as the most immersive device.

References

[1] P. Quax, P. Monsieurs, W. Lamotte, D. D. Vleeschauwer, and N. Degrande, "Objective and Subjective Evaluation of the Influence of Small Amounts of Delay and Jitter on a Recent First Person Shooter Game," in *Proceedings of NetGames*, Aug. 2004.

[2] R. Amin, F. Jackson, J. E. Gilbert, J. Martin, and T. Shaw, "Assessing the Impact of Latency and Jitter on the Perceived Quality of Call of Duty Modern Warfare 2," in *Proceedings of HCI – Users and Contexts of Use*, Las Vegas, NV, USA, Jul. 2013, pp. 97–106.

[3] S. Liu, X. Xu, and M. Claypool, "A Survey and Taxonomy of Latency Compensation Techniques for Network Computer Games," *ACM Computing Surveys*, vol. 54, no. 11s, Jan. 2022.

[4] S. Liu, A. Kuwahara, J. Sherman, J. Scovell, and M. Claypool, "Lower is Better? The Effects of Local Latencies on Competitive First Person Shooter Game Players," in *Proceedings of ACM CHI*, Virtual, May 2021.

[5] K. Chen, P. Haung, G. Wang, C. Huang, and C. Lee, "On the Sensitivity of Online Game Playing Time to Network QoS," in *Proceedings of IEEE Infocom*, Barcelona, Spain, Apr. 2006.

[6] I. Slivar, S. Vlahovic, M. Silic, L. Skorin-Kapov, and M. Suznjevic, "The Impact of Network and Social Context on Quality of Experience for Competitive Multiplayer Virtual Reality Games," in *Proceedings of GameSys*, Athlone, Ireland, Jun. 2022.

[7] P. M. Fitts, "The Information Capacity of the Human Motor System in Controlling the Amplitude of Movement," *Journal of Experimental Psychology*, vol. 47, no. 6, pp. 381–391, Jun. 1954.

[8] A. Pavlovych and W. Stuerzlinger, "Target Following Performance in the Presence of Latency, Jitter, and Signal Dropouts," in *Proceedings of Graphics Interface*, St. John's, NL, Canada, May 2011, pp. 33–40.

[9] M. Claypool, A. Cockburn, and C. Gutwin, "The Impact of Motion and Delay on Selecting Game Targets with a Mouse," *ACM Transactions on Multimedia, Computing, Communication and Applications (TOMM)*, vol. 16, no. 2, May 2020.

[10] M. Long and C. Gutwin, "Effects of Local Latency on Game Pointing Devices and Game Pointing Tasks," in *Proceedings of ACM CHI*, Glasgow, Scotland, UK, May 2019.

[11] R. Eg, K. Raaen, and M. Claypool, "Playing with Delay: With Poor Timing Comes Poor Performance, and Experience Follows Suit," in *Proceedings of IEEE QoMEX*, 2018.

[12] Z. Ivkovic, I. Stavness, C. Gutwin, and S. Sutcliffe, "Quantifying and Mitigating the Negative Effects of Local Latencies on Aiming in 3D Shooter Games," in *Proceedings of ACM CHI*, Seoul, Korea, 2015.

[13] S. Friston, P. Karlström, and A. Steed, "The Effects of Low Latency on Pointing and Steering Tasks," *IEEE Transactions on Visualization and Computer Graphics*, vol. 22, no. 5, pp. 1605–1615, May 2016.

[14] A. Pavlovych and C. Gutwin, "Assessing Target Acquisition and Tracking Performance for Complex Moving Targets in the Presence of Latency and Jitter," in *Proceedings of Graphics Interface*, Toronto, Canada, 2012.

[15] M. Claypool, R. Eg, and K. Raaen, "Modeling User Performance for Moving Target Selection with a Delayed Mouse," in *Proceedings of MMM*, Reykjavik, Iceland, Jan. 2017.

[16] I. S. MacKenzie, T. Kauppinen, and M. Silfverberg, "Accuracy Measures for Evaluating Computer Pointing Devices," in *Proceedings of ACM CHI*, Seattle, WA, USA, Mar. 2001.

[17] K. Raaen, R. Eg, and I. Kjellmo, "Playing with Delay: An Interactive VR Demonstration," in *Proceedings of MMVE*, Amherst, MA, USA, Jun. 2019.

[18] International Telecommunications Union, "Perceptual Evaluation of Speech Quality (PESQ) - An Objective Method for End-to-end Speech Quality Assessment of Narrow-band Telephone Networks and Speech Codecs," Feb. 2001, ITU-T P.862.

[19] J. Brockmyer, C. Fox, K. Curtiss, E. McBroom, K. Burkhart, and J. Pidruzny, "The Development of the Game Engagement Questionaire: A Measure of Engagement in Video Game Playing," *Journal of Experimental Social Psychology*, pp. 624–634, 2009.

[20] J. Kim, A. Madhusudan, B. Watson, B. Boudaoud, R. Tarrazo, and J. Spjut, "Display Size and Targeting Performance: Small Hurts, Large May Help," in *Proceedings of SIGGRAPH Asia*, Daegu, Republic of Korea, Nov. 2022.

[21] A. Schmid and R. Wimmer, "Yet Another Latency Measuring Device," in *Proceedings of EHPHCI*, Virtual, May 2021.

[22] J. Spjut, B. Boudaoud, and J. Kim, "A Case Study of First Person Aiming at Low Latency for Esports," in *Proceedings of EHPHCI*, Virtual, May 2021.

[23] J. Spjut, B. Boudaoud, K. Binaee, J. Kim, A. Majercik, M. McGuire, D. Luebke, and J. Kim, "Latency of 30 ms Benefits First Person Targeting Tasks More than Refresh Rate above 60 Hz," in *Proceedings of SIGGRAPH Asia*, Brisbane, QLD, Australia, Nov. 2019, pp. 110–113.