Playing with delay: With poor timing comes poor performance, and experience follows suit

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***Abstract*—Delays are ever-present in interactive tasks, such as controlling a cursor with a mouse. Unfortunately, perceptible delays are likely to affect both quality of experience and task performance, and even imperceptible delays can potentially be harmful to performance. This paper presents a controlled behavioural experiment that explores the impact of delay on interactions with motor inputs and visual outputs. Because system and network delays interact and overlap, we address total interface delay, focusing on the effect rather than the cause. In the experiment, 51 participants played a simple game of chase-and-catch, using the mouse to intercept a bouncing target. The game includes three levels of difficulty, defined by the speed of the target, with controlled interface delay added between the mouse and the corresponding cursor. The delay values ranged from the system's minimum processing time of 40 ms up to a total of 440 ms. We evaluated participants' game performance, as well as perceived game responsiveness. In line with predictions, our analyses show a negative relation between delay and quality of experience, along with deteriorating performance. In contrast, performance does not co-vary with self-reported game skill. Moreover, an individual's experience with other time-dependent activities has no significant effect on neither performance nor experience, with one exception – musical practice appears to benefit performance for this type of interaction.**

I. Introduction

Application responses to user input are never instantaneous – the hardware and software required to capture the input, process the results, and render the effects require time. This time can range from milliseconds for a local system to seconds for a networked system. *Delay*, the time between between a user carrying out an action (such as moving a mouse) and the result being shown on the screen (such as a cursor changing position), can affect both quality of experience (QoE) and performance.

Delay as low as 80-100 ms can cause a decrease in QoE, an effect that increases with higher levels of delay [1], [2]. As for the feeling of being in control, the sense of agency is degraded above about 300 ms and ceases altogether above about 700 ms [3]. Perceived delay can affect the enjoyment of playing a game [4] and can even increase stress levels [5]. And, unfortunately, delay below 100 ms can be perceived [6]–[8]. Delay has also been shown to affect performance. Studies of delay in networked computer games show that delay up to 1000 ms is tolerable for some games [9], [10], but for the most sensitive games delay as low as 60 ms can be degrading to performance [11].

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While previous studies have been helpful in better understanding the effects of delay in interactive applications, several questions remain unanswered. In this work we set out to: 1) set the stage for isolated interactions in a controlled experimental environment, 2) apply a wide and detailed range of delay that allow for extrapolation to systems with variable restrictions, 3) measure performance and QoE for the isolated game interaction across the range of delay, 4) address the rarely explored relation between QoE and performance, and 5) investigate whether individual factors related to experience with temporal processes translate not only to performance on temporal tasks [12], but also to QoE.

Thus, we conducted a controlled behavioural experiment to investigate the impact of delay on play performance and QoE, taking into account task difficulty and individual factors. We designed and implemented a game that isolates the fundamental action of selecting a moving target with a mouse, where delay is introduced between the input and the rendered action and task difficulty corresponds to the target speed. Delays ranged from the system's minimum processing time of 40 ms up to a total of 440 ms and target speeds ranged from 550 to 1550 pixels / s. Our 51 participants completed 165 game rounds, with different speeds and delays, while the game recorded the time taken to select the target. A periodic visual prompt would request QoE ratings. Along with an initial background questionnaire, the game sets the ground for the study of an isolated action (target selection) across a wide range of delay in order to explore: a) correlations of QoE and play performance with delay, and b) correlations with individual factors on QoE and performance.

Our analyses point to an increasingly detrimental effect on performance and QoE with higher delay values. With performance, the effect is demonstrated by longer time taken to catch the bouncing target. For QoE, mean opinion scores begin to decrease around 140 ms, and significantly so at 190 ms. Furthermore, only musical experience appears to be connected to performance on this kind of time-dependent tasks, albeit for the task in general, not interaction delay.

II. Related Work

Time is a crucial factor for how we perform with and how we experience interactive applications. A natural consequence of the many processes that take place after a user's input is the delay of sounds, visual elements, operations and other outputs. This delay is usually termed *interface delay.* In many situations, we hardly notice interface delay; however,

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sometimes the system or the network slows down the processes to such a degree that the delay becomes highly noticeable. Interface delay may arise from both system and network processes. Even when working in a local application, there are many potential sources of delay. Input devices such as mice and keyboards themselves perform simple processing and have to send their data through an interface which adds some delay. Then, the data is processed in the computer, both by device drivers, the operating system and the application itself. Finally, output devices such as screens may add delay by processing the data or by simply waiting to refresh. Further, if the application communicates through a network, some, though not necessarily all, inputs must be sent through the network to a server, processed there and sent back before output reaches the user. Not only do networks add delay, the delay added is unpredictable making it difficult for developers to account for this delay.

A. *Perception and sense of agency*

Noticeable interface delays are likely to take a toll on how well we perform an interactive task by introducing continuous breaks in the work-flow. This question has been addressed from several perspectives. One is based on temporal integration, which seeks to establish how high delays can be before they become perceptible. Our perceptual system is able to discern very short intervals between a motor input and a visual output, well below 100 ms in fact [6]–[8]. However, simply being able to perceive a delay is not the equivalent of the delay interfering with the interaction. A closer approximation may come from another perspective that considers the sense of agency, the extent to which users perceive control of the action that triggers a response. For instance, if too much time passes between the push of a button and a visual response, users lose the sense of being the agent of the response [13]. Just how much time is too much depends on a number of factors [13], but it extends past 300 ms [13], perhaps even past 700 ms [3].

B. *Performance*

Yet another perspective disregards the plasticity of the perceptual system and seeks instead to evaluate the cognitive and behavioural consequences of interaction delays, assessed through task performance. Earlier studies demonstrate that perceptible delay makes it difficult to operate a controller [14] and it decreases game performance [9]. Although applied game studies tend to focus on network delay and disregard interface delay, they still gauge the cognitive and behavioural consequences of temporal disturbances in continuous and immersive interactions.

Among the most time sensitive type of games are *first person shooters* [15] in which players control a character that moves around freely in the world searching and shooting opponents. In these games 60 ms of latency can noticeably reduce both performance and experience of playing [11]. At the other end of the spectrum, in *omnipresent* [15] games, the player has no clear avatar, but controls the game from an outside perspective. This gives indirect control of the action. For these a latency threshold is difficult to establish, but the current consensus has 1000 ms as an acceptable upper bound for network latency [9], [10].

Games are far from the only temporally dependent interactions users engage in with digital technology. For instance, touch interfaces allow users to manipulate objects directly, with the tap or the stroke of a finger. This kind of direct tactile interaction appears to be very susceptible to temporal offsets, aptly demonstrated with degrading performance on a dragging task with delays as short as 25 ms [16].

While these applied studies involve tasks that rely on different input devices, from mouse and keyboard to touch screen and camera, they all involve indirect control of someone or something. Moreover, they all demonstrate how interface delays can lead to deteriorating performance. The values they present range from 25 ms to 1000 ms, suggesting that the detrimental effect of delay depends on a number of factors, such as pace, complexity, interaction mode and even experience. What is interesting is that the lower end of the scale presents values that are likely not even perceptible to an individual. In other words, it may well be that user performance on an interactive task is adversely affected by delayed visual feedback even when users are unaware of it.

C. *Quality of experience*

In addition to affecting performance, interface delays also make a difference when it comes to the quality of experience. Work in this field have found that perceptible delay affects the enjoyment of playing a game [4] – opinion scores decrease with increasing delay, in some cases from 100 ms [2] or even 80 ms [1]. Not only does QoE depend on the severity of delay, it depends on the genre. By attaching electrodes to the facial muscles of players, Lee and colleagues measured more fEMG acitivity with increasing delay values and consistently more for first-person shooter games, compared to action and role-playing games [5]. A third influential factor appears to be player proficiency. In an experiment on jitter in a first-person shooter game, a 100 ms latency condition was introduced to explore potential interactions between the variable disturbance of jitter and the constant delay caused by latency [17]. Even in the absence of jitter, latency caused lower mean opinion scores on QoE, especially for the players categorised as highly experienced. Thus, QoE may not be solely dependent on external factors, but also on internal factors, such as skill.

D. *Individual factors*

From earlier work, we know that the detectability of delays is highly subjective; some people can perceive extremely short offsets between a button push and a resulting change in the visual presentation, even below 100 ms [6], [18]. In many time-dependent interactions the effects depend upon experience. For instance, musicians are practiced at coordinating rhythm and tempo and perform well on temporal tasks [19]. This has been shown to be advantageous when learning the rhythm of a new language [20] or detecting audio-visual asynchrony [21]. Indeed, experience with time-sensitive tasks, such as playing an instrument, can translate to other domains and be a benefit in different temporal interactions [22]. It is still unknown whether this applies to interactive tasks on a computer. Gamers have another type of temporal training, where a typical gamer can have years of experience with fast-paced interactions between motoric action and visual results. A few gaming studies have found that experienced gamers do better at time-critical tasks, such as shooting at a moving target, compared to inexperienced gamers and that their skills transfer to temporal audiovisual tasks [12]. Seeing that some temporal skills translate across modalities, it may well be that both musical and gaming experience can surface as an advantage in other types of temporal interactions. This brings forward an question as to whether prior experience can also influence the enjoyment of engaging in other time-dependent tasks; and if so, whether experience and performance go hand in hand.

E. Bringing it together

Noticeably delayed responses are not always a bad thing. Sometimes the delays are natural, such as waiting for an avatar to move from A to B. Sometimes the delays are expected or even unavoidable, such as the time it takes for a software package to run. In this work, we progress from perception and noticeability of delays, which we have addressed in prior studies [6], [18] and extend our focus to the cognitive and behavioural consequences of delay. We investigate how delay between mouse input and system output affects participants, in terms of quality of experience and task performance, and whether the two are related. We further investigate individual factors and consider how prior experience can influence the impact of delay in human-computer interactions.

III. Method

In order to understand how individuals experience delayed reactions in a computer system and how their performance is affected by a constant delay following their actions, we designed and ran a behavioural experiment. Aiming to evaluate the direct relationship between an input device and its resulting, but delayed, consequence on-screen, we created a simple target-pursuit game where the movement of the mouse corresponds to the movement of the cursor. For every few rounds, the participant would be asked to rate the quality of experience. We also considered background variables that could potentially be related to variations in individuals' temporal sensitivity, such as gaming or musical experience.

A. Participants

We recruited a total of 51 volunteers by approaching people on the college grounds. The majority of these 43 male and 8 female participants were college students, with ages ranging from 20 to 36 years (M=24, SD=3). Seven participants reported corrected vision, and all 7 wore either glasses or contacts throughout the experiment. Forty-one participants classified themselves as right-handed, 8 as left-handed, and 2 as equally capable with both hands. Yet every participant preferred using the right hand when handling a computer mouse.

B. Questionnaire

Participants completed an on-line questionnaire assessing background variables and experiences that could correlate with their performance on the game task. In addition to age, gender, visual impairments and handedness, the questionnaire addressed gaming experience, including different genres and time spent on gaming, musical experience and time spent practicing song or musical instrument, practice of digital artwork, and daily time spent on using a computer with a mouse.

C. Game design

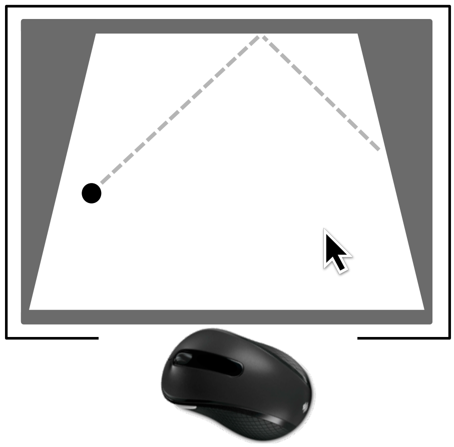

Fig. 1. Illustration of the experiment game in progress.

We designed and developed the game "Puck hunt" as a direct, engaging and highly time-dependent human-computer interaction. The goal of the game is simple: use the mouse to move the cursor, target the moving puck, click on the mouse button to catch the puck, and do it as quickly as possible. The basic game design is illustrated in figure 1.

The puck moves around in a confined space, bouncing off the walls in accordance with the laws of physics. Between every game round, the delay between the mouse movement and the corresponding cursor movement varies randomly, from approximately 40 ms[1] to 440 ms. The same delay also applies to the mouse-click. Furthermore, the speed of the puck varies randomly from round to round, moving at a slow (550 pixels / s), medium (1100 pixels / s) or fast (1550 pixels / s) pace. With 5 repetitions of every delay and speed condition, the experiment comprises a total of 165 trials, or game rounds; see Table I for a full overview. In order to diminish learning effects, the experiment is fully randomised; each participant plays through the same conditions and repetitions, but in different orders of appearance.

Because the game becomes increasingly difficult at higher speeds and larger delay values, we set the maximum duration of each round to 30 seconds. This way, participants would not become overly frustrated when unable to catch the puck. To assess QoE, we included 33 quality ratings; these appeared once for every experimental condition, on average every 5 rounds. Specifically, upon completion of a round, participants would be presented with the text "Rate the quality of the responsiveness of the previous game round". The 5-point Likert scale ranged from "low" to "high" and was presented visually; this allowed for continuous, rather than categorical, responses. Thus, two subjective measures are derived from the experiment: performance and quality of experience (QoE). A participant's performance on the game task is measured as the time it takes to target and catch the moving puck. QoE is assessed from the user's evaluation of the game's responsiveness.

[1] No system can process an input and render a result with zero delay. We use 40 ms to refer to the absolute minimum processing time for our test system based on a recorded averaged minimum time of 39 ms.

TABLE I. EXPERIMENTAL DESIGN, WITH LEVELS FOR THE DELAY AND SPEED CONDITIONS, AND NUMBER OF REPETITIONS AND TRIALS. THE EXPERIMENT WAS FULLY RANDOMISED, SO THAT THE ORDER OF THE 165 TRIALS DIFFERED BETWEEN PARTICIPANTS.

	Levels	# levels	Repetitions
Interface delay	40, 65, 90, 115, 140, 165, 190, 215, 240, 340, 440 ms	11	5
Puck speed	550 (slow), 1100 (medium), 1550 (fast) pixels / s	3	5
		33 conditions	165 trials

D. Equipment and procedure

We invited participants into a computer lab, where they were seated in front of an Apple Mac mini[2]. We tested a maximum of 5 participants at the time, spread out so that all had an empty seat between them. Before commencing, we informed participants about the purpose and the nature of the experiment and asked them to complete a consent form. Having done this, they moved on to the on-line questionnaire.

Once every participant had finished the questionnaire, we proceeded to the game experiment. We instructed participants to operate the mouse in front of them with the hand they preferred, and they all chose to use the right hand. We also instructed participants to adjust their seats and the monitor angle so that they were comfortable with both their position and the viewing angle. We then explained how to play the game and how to respond to the sporadic quality of responsiveness questions. Participants played the game at their own pace, with forced breaks introduced every 40 rounds.

Due to the variability in the time it took participants to complete the 165 game rounds, the total experiment duration varied from approximately 30 to 60 minutes.

IV. RESULTS AND DISCUSSIONS

Building on earlier work that concentrated on player performance (the time to catch the puck) [23], this paper focuses on quality of experience, measured by opinion scores on the responsiveness of the game. QoE responses are analysed along with participants' performance, demographics and experience, to ascertain correlations between individual participants' scores and experience.

A. Influence of delay on performance

Performance scores were derived from the time it took participants to complete a game round (5 repetitions for each delay level), taking the median of all such values. The median was chosen rather than the mean because each trial had a maximum playing time of 30 seconds. For the most difficult trials (fast moving puck with high delay), 42% of participants were not able to catch the puck within 30 seconds. Thus, mean values are skewed artificially low since the upper tail of time distribution is truncated to 30 seconds. In addition, the analysed delays start at 40 ms and increase with a long upper tail, creating an asymmetric distribution.

Figure 2 shows median performance scores plotted against total delay (local delay plus added delay). There are three trend lines, one for each of the three puck speeds. The trend line distinctions indicate that puck speed corresponds with difficulty and the trend line curvatures indicate that difficulty increases with delay. Earlier work has shown that this increase

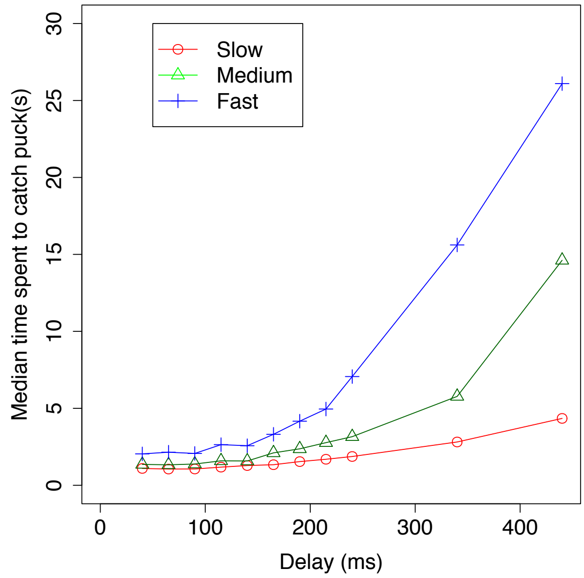

Fig. 2. Median time to catch puck by delay and movement speed.

is exponential [23]. At the slowest puck speed, participants are only slightly affected by delay, while at the higher speeds, the effect is much more pronounced.

B. Influence of delay on quality of experience

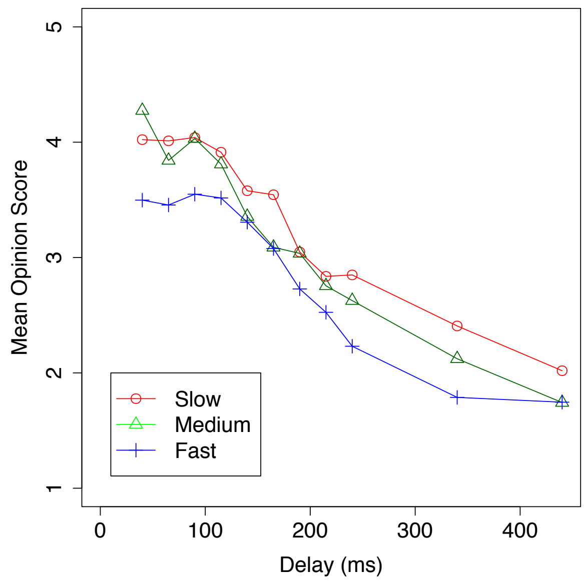

Fig. 3. Mean opinion scores for perceived responsiveness with trend lines for puck speed.

[2]Late 2012, 2.5GHz Intel Core i5, 4GB RAM, Intel HD Graphics 4000. Samsung S24C750 monitor at 1920x1080, 60Hz

Having found that delay affects the objective ability to play the game, we explored the effect on perceived responsiveness. Figure 3 shows the median opinion score versus total delay, with trend lines for each puck speed. The graph shows that the opinion scores decrease with increasing delay, as expected. Moreover, the majority of scores fall between 2 and 4. We see two possible explanations for this. One is related to scale itself, where participants could be inclined to choose the middle values and avoid the extreme scores, particularly if they find it difficult to discriminate the responsiveness. Another possibility is that the interface delay that follows the minimum processing time of 40 ms is sufficient to affect the game-play, consciously or subconsciously. In our earlier work we have observed large individual differences in temporal discrimination [6]; temporally sensitive individuals are capable of perceiving offsets shorter than 40 ms [16], [18], well below the middle values. Figure 4 shows that some participants do rate the minimum delay conditions as highly responsive. Possibly, these participants represent less temporally sensitive individuals, whose QoE is also less affected by interface delay.

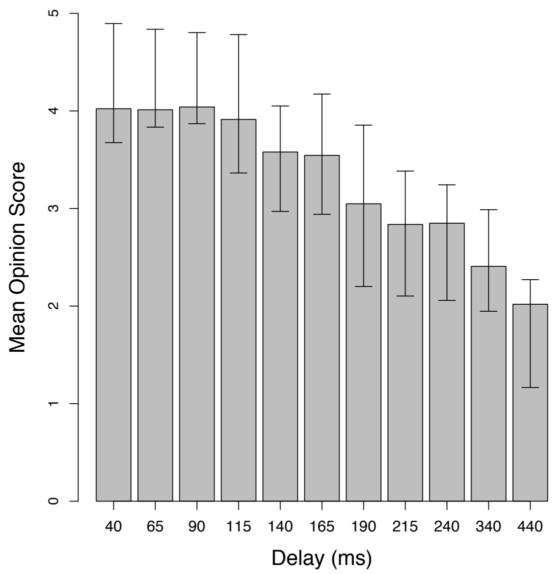

Fig. 4. Mean opinion scores for the slowest speed, error bars represent 25th and 75th percentiles.

Surprisingly, there is little difference between the perceived responsiveness for the three puck speeds, suggesting that participants observe the degraded responsiveness independent of task difficulty. Unlike the differences found between game types that vary in speed and mode of interaction [5], here QoE depends little on the difficulty of chasing a moving puck.

Looking closer, Figure 4 examines the data, focusing on variation, for the slowest puck speed. The bar chart shows mean opinion scores, plotted across the range of delay, with error bars for the 25th and 75th percentiles. In general, opinion scores are distributed asymmetrically around the average. However, for the lowest delays (40 ms, 65 ms and 90 ms), the distribution skews towards higher opinion scores, while for the highest delay (440 ms), the skew is towards even lower scores. In line with earlier work [1], [2], [4], and with our predictions, we see that delay does have an adverse effect on QoE. At the lowest levels, players appear to be unaffected by the delayed cursor movements, but it seems that they start to experience less responsiveness at 140 ms. From that point, QoE begins to decrease steadily with increasing delay values.

An open question concerns the relation between performance and experience, and whether playing a game skillfully across a range of delays will influence QoE. In order to address this question, we carried out individual regressions for performance and opinion scores and used each participants' slopes to represent objective and subjective sensitivity to delay, respectively. To explore the co-variation between these sensitivity scores, we ran another regression that revealed a non-significant relation ($R^2 = 0.02, F(1, 154) = 2.95, p = 0.09$). This indicates that the ability of our participants to compensate for delay and quickly catch the puck does not influence their experience of the game's responsiveness. Although the question was open, we did surmise that the more skillful players would be more adverse to delayed game interactions. For this particular set-up, that was not the case.

C. Relation between delay and individual factors

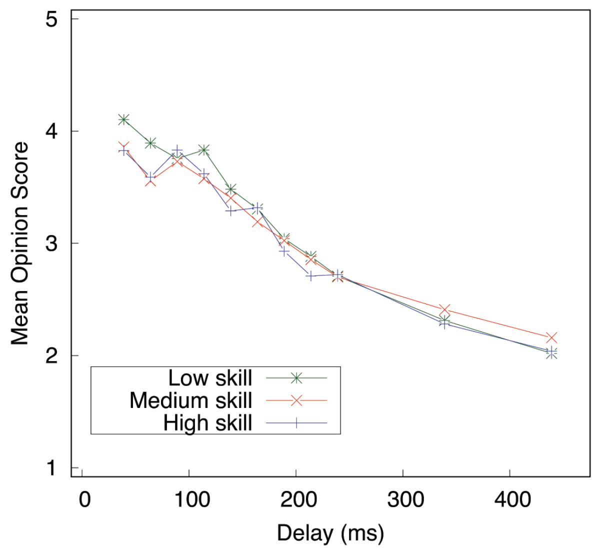

Fig. 5. Mean opinion scores for perceived responsiveness with trend lines for gaming experience.

With the self-ratings (1-5) of gaming skill and the number of responses, we clustered participants into low skill (rating 1-3, 19 participants), medium skill (rating 4, 17 participants) and high skill (rating 5, 16 participants). Figure 5 shows the mean opinion score versus total delay with trend lines for skill level. The trend lines overlap, indicating that perceived responsiveness with delay is independent of skill level. Similar to QoE, performance scores thus do not appear to differ across participants' skill levels. This somewhat contradicts previous studies that indicate that gaming experience can heighten a participant's sensitivity to delays [12], [17].

On the other hand, although the opinion scores of our musically experienced participants did not differ from the others, they did perform better. This effect was evident for the overall task, thus independent of delay (Wilcoxon rank sum, W = 404, p-value = 0.0111). Considering that our background questions only address whether participants have any musical experience and how long they spend practicing song or musical instrument, this result sheds just a little light on transferable skills. Consistent with research connecting musical practice with other temporal processes and tasks [19], [21], [22], the effect indicates that the temporal proficiency that comes from evaluating and reproducing time intervals in music can translate to another kind of temporal interaction.

Among the other background factors we evaluated, experience with digital artwork and frequency of mouse utilisation, no statistically significant contributions to game performance were found, nor to how they perceived game responsiveness.

V. Conclusions and Future Work

In a controlled behavioural experiment, we asked participants to play a chase-and-catch game with the cursor on screen delayed relative to the mouse movements. The more delayed the cursor, the longer it took to catch the moving target, a bouncing puck. QoE for responsiveness was similarly degraded; the more delayed the cursor, the lower the opinion scores. Taking one step further, we looked at the co-variation between objective performance scores and subjective experience scores, but found no relation between the two and delay.

The puck speed determined the difficulty of the game, and the faster target speeds added to the time required to catch the puck. Thus, performance in this game is markedly affected both by interface delay and by task difficulty. On the other hand, target speed has little or no effect on QoE.

None of the individual factors we investigated explained the variations across delay values. This may come as a surprise to our participants (and many gamers) – several of the people who reported being good at games expressed expectations of being more affected by lag. Although users with musical experience did not yield better performance with increasing delay, this participant group did show an overall tendency to perform well in the game. This may reflect a skill-set that translates from one type of temporal interaction to another, and from one sensory domain to another.

Compelling research suggests that musical experience, gaming experience and, likely, other individual factors, can predict performance on a temporal task. Among our participants, we had no professional musicians or computer gamers. While there may be no difference among people of ordinary skill, the very best could still demonstrate an increased ability to interact with delay. The role of experience and talent in time-dependent interactions is an interesting pursuit that could shed light on the human ability to train and transfer temporal skills.

Another fruitful pursuit would be to apply the controlled experimental setting of this study to similar settings, using other input devices. For instance, keyboards, hand-held controllers, joysticks and touchscreens. Moreover, an emerging body of work points to the detrimental effects of delays in virtual reality environments, a setting that involves complex interactions that are difficult to separate. Furthermore, extending this work to more complex games, while preserving the experimental control and the measure of precise interface delay, could help predict temporal sensitivity and performance based on realistic game parameters.

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