The Effects of Auditory Latency on Experienced First-Person Shooter Players

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ABSTRACT

Latency is inherently part of every interactive system and is particularly critical in video games. Previous work shows that visual latency above 25 ms reduces game experience and player performance. However, latency does not only affect visual perception but also may influence auditory elements of video games. It is unclear if auditory latency impairs the gaming experience and player performance with the same magnitude as visual latency. Therefore, we conducted an experiment with 24 participants playing a first-person shooter game. Participants played with four levels (0 ms, 40 ms, 270 ms, and 500 ms) of controlled auditory latency to reveal effects on game experience and player performance. Our analysis shows that auditory latency in video games increases the perceived tension, decreases positive feelings towards the game, and on its highest tested level (500 ms), even causes significantly stronger associations with negative feelings towards the game. Furthermore, we found that the negative effects of auditory latency are particularly pronounced for high-skilled players. We conclude that auditory latency negatively affects video games and their players. Therefore, researchers should investigate it with the same rigor as visual latency.

CCS CONCEPTS

• **Human-centered computing** → *User studies*; • **Applied computing** → **Computer games**.

KEYWORDS

video games, auditory latency, latency, first-person shooter

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1 INTRODUCTION

Latency - the time between a user-generated action and the corresponding output of an interactive system - leads to worsened user experience and performance when using interactive systems [3, 37, 38]. Two aspects categorize the arising latency in technical systems: (1) Its technical origin and (2) the perceptual channel to which it is subject. The former category includes local latency and network latency [55]. Local latency is due to the used system including the periphery such as the computer mouse, the keyboard, and the monitor. Network latency, on the other hand, originates through communication over a network such as the Internet. The latter category separates latency by its perceptual channels, such as the visual, haptic, and auditory perception. Previous work showed that users perceive visual latency starting at 2 ms [4, 38]. Starting at 25 ms visual latency significantly decreases user experience and performance [28]. Since auditory information is often considered to be not as relevant as visual or haptic information, for example, when investigating users conducting a *Fitt's Law* [18] or *Accot's Law* [2] task, less is known about the effects of auditory latency on user experience and user performance. However, there is one domain of *Human-Computer Interaction* (HCI) that is strongly affected by latency [25, 30, 31] and in which audio is essential: video games.

In video games, audio increases players' immersion and involvement [20, 21], evokes emotions such as fear, bliss, or even anxiety [51], and conveys game-relevant information. Video games, as they are interactive systems, are also affected by latency [16]. High visual latency leads to players scoring fewer points or needing more time to complete tasks in the game [7, 10]. Especially fast-paced video games such as first-person shooters (FPS), which require split-second decision making, are negatively affected by visual latency. Liu et al. [32], for example, showed that an increase from 25 ms to 150 ms visual latency linearly decreases the player performance and quality of experience in the FPS game *Counter-Strike: Global Offensive* (CS:GO) [12]. In the same work, Liu et al. [32] also demonstrated that experienced players are more affected by visual latency than inexperienced players. While the effects of visual latency on game experience and player performance are well researched, less is known about the effects of auditory latency in video games. The lack of research regarding auditory latency is surprising, considering that well-crafted audio is a crucial part of a satisfactory game experience. The effects of audio latency in video games become even more opaque in light of emerging technological developments such as wireless headphones. Current wireless headphones predominately use *Bluetooth* (BT) to transmit audio signals [42]. BT headphones, however, have an inherently higher latency of up to 270 ms compared to their wired counterparts [22]. When playing with wireless BT headphones, this additional latency is added to the overall latency. Ultimately, BT headphones lead to higher audio latency and a de-synchronization between visual and auditory perception. The higher latency and the de-synchronization between visual and auditory channels potentially decrease game experience and player performance.

Currently, however, it is unknown if auditory latency leads to the same systematic decrease of game experience and player performance as visual latency. Furthermore, it is unclear if experienced players are differently affected by auditory latency than novice players. This work starts closing the knowledge gap between the effects of auditory and visual latency by investigating controlled auditory latency in the highly competitive, fast-paced, latency-sensitive game CS:GO. We modified a gaming setup and induced four levels of controlled auditory latency (0 ms, 40 ms, 270 ms, and 400 ms) to CS:GO. Then, we conducted a study with 24 participants to test whether auditory latency influences game experience or player performance. Additionally, we investigate how player skill alters the effects of auditory latency. Our results show that high auditory latency significantly decreases game experience. Particularly, we found that highly skilled players are stronger affected by auditory latency than novice players. We did not find a significant effect of auditory latency on player performance.

In conclusion, our work shows that auditory latency negatively affects game experience. Game researchers should therefore not neglect nor ignore auditory latency when investigating the effects of latency in video games. Not accounting for auditory latency potentially leads to missing significant effects on players and game experience. Furthermore, our work shows that while BT headphones do not entail an inherent performance disadvantage, gamers, particularly high-skilled gamers, should use wired headphones to optimize their gaming experience.

2 RELATED WORK

Latency is a crucial factor influencing user experience and performance in interactive systems [5]. Thus, a growing body of work investigates the effects of latency in different domains such as user interfaces [5, 29, 34], games [23, 25, 30–33], virtual reality [45, 52] and musical instruments [26, 27].

This section first provides an overview of the origin of latency research in HCI and its current state. Next, we elucidate how latency is researched in video games. We then discuss the effects of auditory latency of interactive systems and showcase how audio is used in video games. Lastly, we summarize this section by highlighting that auditory latency and its effects on game experience and player performance needs to be considered when researching latency.

2.1 Latency and System Response Times in HCI

Latency is the delay between a user-generated input and the corresponding reaction of the interactive system [6]. Besides the perceptual channel it is subject to (visual, haptic, auditory), it is categorized into local latency and network latency. Local latency is due to the used periphery such as the computer mouse, the keyboard, and the used monitor. Network latency, on the other hand, originates through communication over a network such as the Internet [25]. Software systems, such as multiplayer games, chats, and browser-based programs, depend on network connections. Network latency influences the responsiveness of these systems and, therefore, the user experience. Latency is also known as System Response Time (SRT) [5] and has been researched since Millers' first latency studies in 1968 [36]. Multiple lines of work recommended a SRT below 100ms [5, 9, 36, 49].

However, more recent research questioned the amount of latency recommended by experts. Battle et al. [6] showed that the tolerance for latency depends on several factors, especially task complexity. The authors conducted a study showing that more complex tasks lead to a higher latency tolerance. Seow [47] points out that users' expectations also influence the tolerance for latency. Moreover, the tolerance for latency depends on the output modality. Users are more tolerant of visual latency (100-150 ms) than audio or haptic latency (70-100 ms) [29]. Ng et al. [38] as well as Jota et al. [28] showed that for systems with extremely low latency between 1 ms and 10 ms users still preferred the system with less delay.

Even users who do not actively notice latency are negatively influenced by it. For example, Ivkovic et al. [25] found that participants performed worse in a 3D aiming task with latency above 41 ms. However, they were more likely to reliably notice that latency is present if the latency level was above 114 ms. Furthermore, Friston et al. [19] found a negative effect off even lower latency levels for pointing tasks. In their study participants performed significantly worse if the latency was above 16 ms. Previous work, thus, suggests that latency that goes unnoticed still negatively impacts the performance and experience of users [25, 28, 38].

2.2 Latency in games

Even though insights from HCI studies help to understand the effects of multiple types of latency on users, Ivkociv et al. [25] point out that in 3D games such as FPS games, the effects might differ since the environments are more complex, and movements change the entire scene through parallax and other motion effects. Therefore, the authors conclude that FPS games are susceptible to small amounts of latency. This is additionally due to the fact that FPS games requires swift actions in response to other players and events [23]. Furthermore, Liu et al. [30] investigated the effects of network latency on competitive FPS game players in CS:GO. The authors used 25, 50, 100, and 150 milliseconds of network latency. Their results show that if latency is reduced from 150 ms to 25 ms, both the *Quality of Experience*, as well as players' performance, improved linearly. In subsequent work, Liu et al. [31] compared the effect of latency on players with different skill levels in CS:GO.

The authors found that highly experienced players were more affected by increased latency compared to inexperienced players. Furthermore, the authors found that experienced players report a worse gaming experience than inexperienced players at high latency. While the decrease in performance correlated almost linearly with the latency for experienced players, the results for less experienced players were much more scattered but still noticeable. In other work, Claypool and Claypool [10] found that network latency affects players in games with a first-person view, such as racing games or FPS, more than in games with different gaming perspective such as third-person. The authors also discovered an overall downward trend in player performance with increasing latency, with a particularly steep decline starting at a network latency of 100 ms.

2.3 Audio Latency

Previous work primarily focused on visual delays. One exception is the work of Kaaresoja et al. [29] who found that participants had a higher sensitivity to auditory latency than to visual latency. Some of the participants could perceive a delay of 19 ms between a button being pressed and the corresponding sound. This is about half of the minimal noticeable delay for the visual feedback in their study at 32 ms. However, most users only experienced a negative impact of audio latency between 70 and 100 ms.

Another strand of research focuses on the auditory latency of digital musical instruments. Wessel and Wright [53] suggested that digital musical instruments should have a latency of less than 10 ms with a jitter of less than 1 ms to not disturb the musicians' performance. More recent work empirically verified these figures [26, 27]. While the performance of trained percussive musicians was the same at 20 ms and 0 ms, their subjective experience was significantly worse [26] with 20 ms of latency. This is consistent with the findings of Dahl and Bresin [14], who found that musicians were able to maintain synchronization up to 55 ms of latency. Without jitter, the musicians were unaffected by a latency of 10 ms [27]. Jack et al. [26] suggest that the worse experience may result from the lack of control intimacy, which describes the feeling of a musician that his actions correspond to the way the instrument produces a sound.

2.4 Audio in Games

Wireless input and output devices are gaining popularity, and their use increases the latency [15] of the auditory feedback loop. Games, however, often rely heavily on auditory output [8] to modulate the game environment.

Recent developments in games changed the role of audio from being solely music and relevant for the ambience to become a source of information, which has made audio more crucial to video games [39]. This shift occurred because game developers realized that the inclusion of audio can convey more details than a purely visual output [8]. Sound can convey knowledge through volume, location, timbre, timing, speech, tempo, and musical themes. These attributes are used to communicate locations and characteristics of objects and non-player characters, presence of dangers, feedback to user inputs, and emotions [40]. The messages conveyed by audio can be complementary, redundant, or contradicting to the visual channel, which can be used by the game developers [39]. Usually, data conveyed by audio is available earlier and faster than the corresponding equivalent information delivered by the visual representation of the game [39].

Studies in serious games showed that the use of multi-sensory information significantly improves the learning performance, the users' immersion, and the speed of processing of the information [46]. Additionally, it triggers emotional responses and reduces mental workload [13]. Furthermore, pedagogical research revealed that multi-sensory information simulates natural settings, which improves learning performance [48]. Moreover, it is known that auditory information increases the immersion of players [20] and that highly immersed players perform better [50].

Considering FPS games, sounds are mainly used to convey information about the enemies. Sounds can be preemptive, providing information about enemies that are close by but not yet attacking, reactionary, if they hold information about an attacking enemy, or providing feedback about the state of the enemy or player [39]. In the case of CS:GO listening to footsteps is essential, as it provides information about the location of enemies through the direction of the sound and the ground the enemies are walking on [54].

2.5 Summary

Previous work in HCI showed that network and local latency negatively affects user performance and experience [3, 37]. Moreover, even low latency at 2 ms are noticeable by humans [38]. Video games are also negatively affected by visual latency. Starting at 25 ms, visual latency in video games leads to players scoring fewer points, needing more time to complete takes, or not being able to solve tasks at all [7, 10, 16, 31]. Additionally, increasing visual latency in video games linearly decreases the players' perceived game experience [32]. While work on auditory latency in games is limited, research on auditory latency in the field of digital instruments showed that a low latency of 20 ms negatively influences musicians' performances [26]. It is clear, that audio is an essential part of video games to increase immersion [17, 21] and performance [39] but the effects of auditory latency are unknown. In particular, it is unclear if high auditory latency in video games leads to the same systematic decrease of game experience and performance as visual latency.

3 METHOD

To investigate the effects of auditory latency on game experience and player performance, we modified a computer's audio output pipeline to induce four levels of controlled auditory latency and installed the FPS game CS:GO on it. FPS games are susceptible to latency as they are fast-paced and require split-second decision-making to perform well [11]. Therefore, we conducted a study with 24 participants to investigate if auditory latency influences game experience and player performance using this setup.

3.1 Study Design

We conducted a study to investigate if auditory latency impacts game experience and player performance in CS:GO. Furthermore, we investigate if player skill alters the effect of auditory latency. We used Audio Latency and Repetition as independent within-subject variables and participants' Experience as between-subject variable. The levels of Audio Latency are based on the range of the latency of the commercially predominantly used BT protocol, which ranges from 40 ms (*aptX low latency*) [35] to 270 ms (sub-band-coding (SBC)) [22]. Furthermore, visual latency is known to influence game experience within the chosen range negatively [32]. To fully explore the effects of auditory latency, we also investigated a considerably high level of 500 ms. While the latter is higher than most latency found in modern devices some have measured similar delays using smartphones and bluetooth headphones [41]. Thus, we categorized Audio Latency in four levels: (1) *0 ms*, (2) *40 ms*, (3) *270 ms*, and (4) *500 ms* of added auditory latency. These levels also covered a wide enough range to potentially reveal trends in the effects of latency as seen in similar studies on visual and network latency [32, 34]. We also coded the number of times a participant played with one auditory latency configuration in Repetition. Repetition is categorized in two levels: (1) *1st* - first time playing with a particular auditory latency level, and (2) *2nd* - second time playing with a particular auditory latency. We recorded Repetition to investigate potential habituation effects of auditory latency. Furthermore, we used Experience as an independent between-subject variable. In line with related work, which also investigated the effects of latency in dependency of player skill in CS:GO [31], we categorized Experience on two levels: (1) *Expert* - participants with more than 100 hours of playtime in CS:GO, and (2) *Novice* - participants with less than 100 hours of playtime in CS:GO.

To measure game experience, we used the standardized *Game Experience Questionnaire* (GEQ) [24]. In our study we utilized the sub-scales *Competence* (COM) - indicating how skillful players felt, *Flow* (FLO) - stating how immersed the players were, *Tension and Annoyance* (TEN) - revealing how tense or annoyed the players were, *Challenge* - describing the level of challenge experienced, *Positive Affect* (POS) - indicating a positive gaming experience, and *Negative Affect* (NEG) - corresponding to a negative gaming experience. As other previous work [31] did, player performance was measured by recording the players' scores in the game. *Score* increased every time a player successfully eliminated an opposing bot. Players did not lose points if they were eliminated.

In summary, we tested four different conditions based on the levels of Audio Latency. Latency levels were presented to the participants following a Latin square design to prevent sequence effects from biasing the results. Participants played two consecutive rounds on each current latency, reflected in the Repetition variable.

3.2 Apparatus

As apparatus, we used a stationary workstation in our laboratory. CS:GO was installed and executed in full-screen mode. CS:GO is a team-based tactical shooter and frequently used in research investigating the effects of latency in video games [31, 32]. Two opposing teams compete for an objective or aim to eliminate the enemy team in the game. However, since playing in a team involves playing with other players (either humans or AI-controlled), it is not a suitable model for a study. In team-based gameplay, it is impossible to control for all variables such as the skill of the other players, communication in the team, or synergy between different players. Hence, to guarantee replicability, we used, in line with related work investigating CS:GO [31, 32], CS:GO's *Deathmatch* mode. In *Deathmatch* there are no teams. Each player fights on their own. The goal in this mode is to eliminate as many opposing players as possible in a given amount of time. To further increase replicability, we disabled the ability to buy weapons - all players played with the automatic rifle *M4A1* and were not able to change the weapon during gameplay. Additionally, we controlled the game map and prevented players from changing it. All gaming sessions were played on the map *Mirage*, which is one of the most played maps in CS:GO. We set the duration of each *Deathmatch* round to 5 min of gameplay. While playing, participants faced AI-controlled bots with medium difficulty.

We used *Voicemeeter Banana*[1] (VBAN) to manipulate the workstation's auditory latency. VBAN is a free-to-use audio mixer application designed to mix and manage multiple audio streams. By installing a virtual sound device, the application can delay a local audio stream; thus, the application can introduce auditory latency out-of-the-box. VBAN supports continuously delaying the audio stream for up to 500 ms. The workstation (Intel i7, Nvidia GTX980ti, 16 GB RAM) was attached to a 1440p@60Hz monitor (HP E272q), a wired mouse (Sharkoon Shark Force), and a wired keyboard (Dell L100). For audio output, we used wired headphones (Superlux HD-681 Evo). Participants played with all artificially added auditory latency levels, resulting in four tested conditions: (1) 0 ms, (2) 40 ms, (3) 270 ms, and (4) 500 ms controlled auditory latency.

3.3 Procedure and Task

Participants were greeted at our institution's laboratory by the experimenter. Participants were informed about the procedure and the general purpose of the study. However, they were blind to the exact purpose (investigating the effect of auditory latency). After signing the consent form and thus agreeing to data collection, participants were seated in front of the computer running the game in full-screen mode. After the introduction, each participant played one warm-up round of CS:GO *Deathmatch* without headphones and audio. In the warm-up round participant could ask questions about the game and procedure. After the warm-up, participants had to fill out a questionnaire about their demographic, prior gaming experience with games, and particularly their gaming experience with CS:GO. Subsequently, each participant played two 5 min rounds of *Deathmatch* with each level of Audio Latency. Thus, overall, participants played eighth rounds of CS:GO. After each round, participants filled out the GEQ on a different computer, and we recorded the round's score. After playing all eight rounds, participants were debriefed. In debriefing, participants were informed about the manipulated auditory latency in the game and had the opportunity to give qualitative feedback about their gaming sessions. The study took about 75 minutes per participant. Figure 1 shows one participant playing CS:GO in our study.

3.4 Participants

In line with the number of participants tested by previous work [32–34], we invited 24 participants (9 female, 15 male) using our institution's mailing list. The participants' mean age was 22.21 years (SD = 6.08 years), ranging from 20 to 51 years. Participants could

[1] https://vb-audio.com/Voicemeeter/banana.htm

obtain 1.5 credit points for their study course as compensation for participating.

Figure 1: Depicts a participant playing *Counter-Strike: Global Offensive* in our study. Participants played with wired headphones and four levels of controlled auditory latency (0 ms, 40 ms, 270 ms and 500 ms).

4 RESULTS

24 participants played eight rounds of CS:GO. Thus, we recorded 192 score measurements and 192 responses to the post-experience questionnaire. Furthermore, we recorded 28 relevant notes made by our participants in qualitative feedback. We first report a statistical analysis of gathered game experience metrics in the following. We then continue to report the analysis of the logged performance metrics. We concluded by outlining the qualitative feedback received from our participants.

4.1 Game Experience

Descriptive data showing the mean score and standard deviation for each sub-scale of the *GEQ* is shown in table 1. The data in the table is grouped by the tested levels of Audio Latency and separated by Experience (top and bottom).

For statistical analysis we used a three-way mixed model ANOVA (Audio Latency: *0 ms*, *40 ms*, *270 ms*, *500 ms* x Repetition: *1st*, *2nd* ~ Experience: *Novice*, *Expert*) as the prerequisites for ANOVA were met (Shapiro-Wilk test for all measures p >0.05). Three-way ANOVA showed no significant main effect of Audio Latency on the sub-scales *Challenge* (F(3,66) = 2.55, p = 0.065, ρ_T = 0.91) and *Flow* (F(3,66) = 1.80, p = 0.145, ρ_T = 0.92). ANOVA, however, revealed a significant effect of Audio Latency on *Competence* (F(3,66) = 3.85, p = 0.029, ρ_T = 0.85), *Positive Affect* (F(3,66) = 4.09, p = 0.027, ρ_T = 0.93), *Negative Affect* (F(3,66) = 3.77, p = 0.026, ρ_T = 0.87) and *Tension* (F(3,66) = 6.84, p = 0.002, ρ_T = 0.86). Subsequently, we investigated the sub-scales showing significant differences using a Wilcoxon test with Bonferroni Alpha-correction. Wilcoxon's test found significant differences between *0 ms* and *500 ms* (p = 0.041), and *270 ms* and *500 ms* (p = 0.017) for the *Positive Affect* sub-scale. All other pairwise comparisons for *Positive Affect* were not significant (all p > 0.185). Further post-hoc tests revealed a significant difference between *0 ms* and *500 ms* for the *Negative Affect* sub-scale (p = 0.048) while all other comparisons did not reach significance (all p > 0.066). We also found significant differences for *Tension* between *0 ms* and *270 ms* (p = 0.003) as well as between *270 ms* and *500 ms* (p = 0.002), all other pairs were not significant (all p > 0.169). We found no significant differences in the pairwise comparison of the sub-scale *Competence* (all p > 0.095). Generally, playing with a higher level of Audio Latency led to a decreased *Positive Affect* and an increased level of *Tension* and *Negative Affect*. Figure 2 shows the statistical analysis of all significant sub-scales.

An ANOVA revealed no main effect for Repetition (p = 0.108). However, we found a significant main effect of Experience on the *Competence* sub-scale (F(1,22) = 7.26, p = 0.013). *Experts* provided significantly higher *Competence* rating compared to inexperienced *Novice* players (p = 0.014). However, Experience did not influence the players *Positive Affect* F(1,22) = 0.42, p = 0.523), *Negative Affect* (F(1,22) = 1.16, p = 0.292), *Challenge* (F(1,22) = 0.00, p = 0.994), *Tension* (F(1,22) = 0.03, p = 0.870), and *Flow* (F(1,22) = 1.98, p = 0.173). Further investigation showed neither an interaction between Audio Latency x Repetition on the *Positive Affect* (F(1,22) = 0.44, p = 0.677), *Negative Affect* (F(1,22) = 0.35, p = 0.765), *Competence* (F(1,22) = 0.27, p = 0.850),*Challenge* (F(1,22) = 1.62, p = 0.201), *Tension* (F(1,22) = 2.11, p = 0.110), and *Flow* (F(1,22) = 0.56, p = 0.647), nor between Audio Latency x Experience on the *Positive Affect* (F(1,22) = 1.14, p = 0.333), *Negative Affect* (F(1,22) = 1.31, p = 0.279),*Competence* (F(1,22) = 0.21, p = 0.812), *Challenge* (F(1,22) = 1.21, p = 0.948), *Tension* (F(1,22) = 0.97, p = 0.391), and *Flow* (F(1,22) = 0.39, p = 0.757). Moreover, there was no significant interaction between Repetition x Experience for *Positive Affect* (F(1,22) = 0.16, p = 0.697), *Negative Affect* (F(1,22) = 0.46, p = 0.503),*Competence* (F(1,22) = 0.76, p = 0.392), *Challenge* (F(1,22) = 0.96, p = 0.338), *Tension* (F(1,22) = 0.02, p = 0.902), and *Flow* (F(1,22) = 0.80, p = 0.382). And no interaction effects between Audio Latency x Repetition x Experience for *Positive Affect* (F(1,22) = 1.43, p = 0.249), *Negative Affect* (F(1,22) = 0.61, p = 0.594),*Competence* (F(1,22) = 0.46, p = 0.712), *Challenge* (F(1,22) = 0.13, p = 0.922), *Tension* (F(1,22) = 1.79, p = 0.162), and *Flow* (F(1,22) = 2.42, p = 0.074).

Additionally, we investigated the effects of Audio Latency and Repetition using Experience as a between-subject variable and split all players in two even (N = 12) groups (*Novice* vs. *Experts*). We found a significant effect of Audio Latency on the sub-scale *Tension* (F(1,33) = 4.45, p = 0.028) for the *Novice* group. However, alpha-corrected post-tests did not reveal significant differences (all p > 0.092). The other subscales *Positive Affect* (F(1,33) = 1.07, p = 0.362), *Negative Affect* (F(1,33) = 0.93, p = 0.435), *Challenge* (F(1,33) = 1.22, p = 0.318), *Flow* (F(1,33) = 0.82, p = 0.489), and *Competence* (F(1,33) = 1.70, p = 0.210) were not significantly affected by Audio Latency. Repetition also showed no significant effects on *Positive Affect* (F(1,33) = 0.05, p = 0.830), *Negative Affect* (F(1,33) = 0.38, p = 0.548), *Challenge* (F(1,33) = 3.13, p = 0.104), *Tension* (F(1,33) = 0.17, p = 0.690), *Flow* (F(1,33) = 0.40, p = 0.541), and *Competence* (F(1,33) = 4.26, p = 0.063). There were no significant effects of Latency x Repetition in the Novice group for the modules *Positive Affect* (F(3,33) = 0.82, p = 0.384), *Negative Affect* (F(3,33) = 0.39, p = 0.665), *Competence* (F(3,33) = 0.67, p = 0.565), *Challenge* (F(3,33) = 0.88, p = 0.459), *Tension* (F(3,33) = 2.20, p = 0.106), and *Flow* (F(3,33) = 2.75, p = 0.066).

Investigating the *Expert* group revealed a significant effect of Audio Latency on *Positive Affect* (F(1,33) = 4.09, p = 0.027) and *Tension* (F(1,33) = 3.78, p = 0.035). However, the subscales *Negative Affect* (F(1,33) = 2.9, p = 0.079), *Challenge* (F(1,33) = 1.42, p = 0.253), *Flow* (F(1,33) = 1.40, p = 0.259), and *Competence* (F(1,33) = 2.68, p = 0.072) did not show significant effects. Post-hoc tests revealed

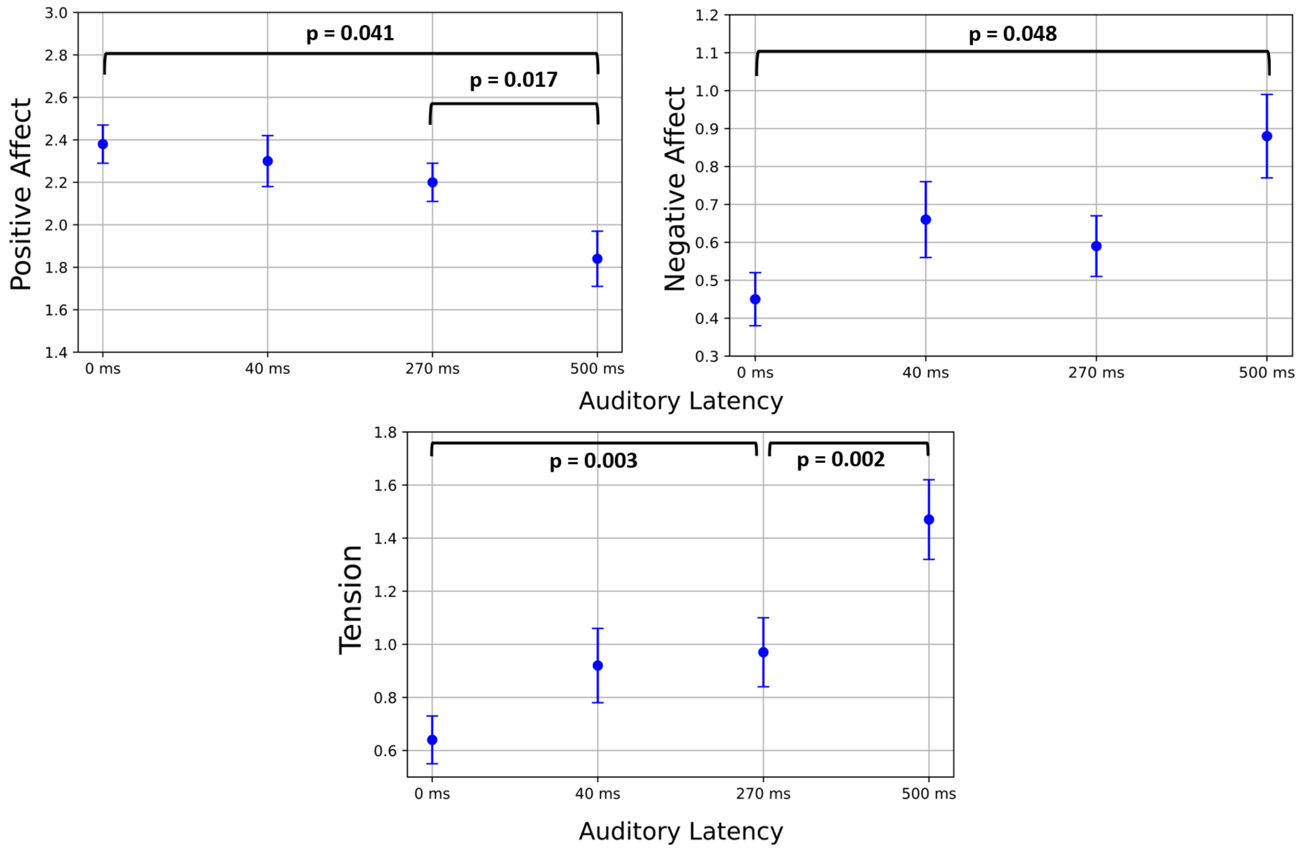

Figure 2: Shows the scores provided by all participants, averaged over both repetitions, for the *Positive Affect* (top left), *Negative Affect* (top right), and *Tension* (bottom) sub-scale of the *Game Experience Questionnaire* [24]. Significant differences are marked. Error bars show the standard error. Participants rated the *Positive Affect* sub-scale significantly worse when playing with 500 ms of auditory latency compared to playing with 0 ms and 270 ms of auditory latency. Similarly, the *Negative Affect* was significantly higher when playing with 500 ms compared to playing with 0 ms. Lastly, the experienced *Tension* was rated the highest when playing with 500 ms of auditory latency. Post-hoc testing showed significantly higher *Tension* rating when playing with 270 ms compared to playing with 0 ms, and when playing with 500 ms compared to playing with 270 ms.

no significant differences for *Positive Affect* (all p =>0.062). However, we found significant differences in *Tension* between *0 ms* and *500 ms* (p = 0.041), as well as between *270 ms* and *500 ms* (p = 0.018) of audio latency in the *Expert* group, while there were no significant differences between all other comparisions (all p > 0.827). *Experts* playing with a 500 ms of Audio Latency experienced the significantly highest level of *Tension*. Figure 3 shows the scores given by *Experts* in the *Tension* sub-scale - significant differences are highlighted. There were no significant effects of Latency x Repetition in the Expert group for the modules *Positive Affect* (F(3,33) = 0.97, p = 0.407), *Negative Affect* (F(3,33) = 0.66, p = 0.585), *Competence* (F(3,33) = 0.04, p = 0.990), *Challenge* (F(3,33) = 0.86, p = 0.447), *Tension* (F(3,33) = 1.72, p = 0.197), and *Flow* (F(3,33) = 0.86, p = 0.472).

4.2 Player Performance

Participants, on average, achieved an in-game score of 240.4 points ± 118.8 points. The average score was highest when playing with 0 ms of Audio Latency (252.5 points ± 125.4 points). All performance measures are normal distributed (Shapiro-Wilk test for all measures p >0.05). Hence, we used a three-way ANOVA (Audio Latency: *0 ms*, *40 ms*, *270 ms*, *500 ms* x Repetition: *1st*, *2nd* ∼ Experience: *Novice*, *Expert*), however, ANOVA showed no significant main effect of Audio Latency (F(2,66) = 1.84, p = 0.154) on *Score*. A three-way ANOVA also revealed no significant effect of *Repetition* (F(1,66) = 1.72, p = 0.229) on *Score*. Further investigation showed no interaction between Audio Latency x Repetition (F(3,66) = 2.14, p = 0.108), Audio Latency x Experience (F(3,66) = 0.63, p = 0.581), Repetition x Experience (F(3,66) = 1.71, p = 0.205), and no interaction between Audio Latency x Repetition x Experience (F(3,66) = 0.32, p = 0.798).

To investigate the effects of Audio Latency and Repetition in dependence of Experience, we, again, split the data in two even groups (N = 12, *Novice* vs *Experts*). *Novice* players achieved a mean score of 149.92 points ± 51.46 points, while *Experts* achieved an

Game Experiences Scores - Novice Players						
Audio Latency	Tension	Competence	Flow	Challenge	Pos. Affect	Neg. Affect
0 ms	0.72 ± 0.83	1.56 ± 1.26	2.67 ± 0.81	1.62 ± 0.62	2.13 ± 1.04	0.48 ± 0.60
40 ms	0.85 ± 0.88	1.53 ± 1.27	2.74 ± 0.59	1.72 ± 1.10	2.18 ± 1.01	0.51 ± 0.63
270 ms	1.04 ± 0.96	1.48 ± 0.94	2.54± 0.66	1.64 ± 0.64	2.12 ± 0.73	0.5 ± 0.56
500 ms	1.28 ± 1.03	1.10 ± 0.83	2.53 ± 0.68	1.83 ± 0.46	1.88 ± 0.65	0.66 ± 0.61

Game Experiences Scores - Expert Players						
Audio Latency	Tension	Competence	Flow	Challenge	Pos. Affect	Neg. Affect
0 ms	0.56 ± 0.49	2.55 ± 0.75	2.47 ± 0.76	1.63 ± 0.92	2.62 ± 0.72	0.43 ± 0.49
40 ms	0.99 ± 1.05	2.43 ± 0.80	2.32 ± 0.90	1.65 ± 0.88	2.43 ± 0.95	0.80 ± 0.74
270 ms	0.89 ± 0.89	2.29 ± 0.70	2.13± 0.63	1.65 ± 0.74	2.28 ± 0.90	0.68 ± 0.54
500 ms	1.65 ± 1.08	2.11 ± 0.95	2.21 ± 0.61	1.88 ± 0.68	1.80 ± 1.06	1.10 ± 0.90

Table 1: Shows the mean scores and standard deviation of each sub-scale of the *Game Experience Questionnaire* [24] for each level of tested Audio Latency. Additionally, the data is separated by the two levels of Experience. Top shows the data of *Novice* players, bottom shows the *GEQ* scores rated by *Expert* players.

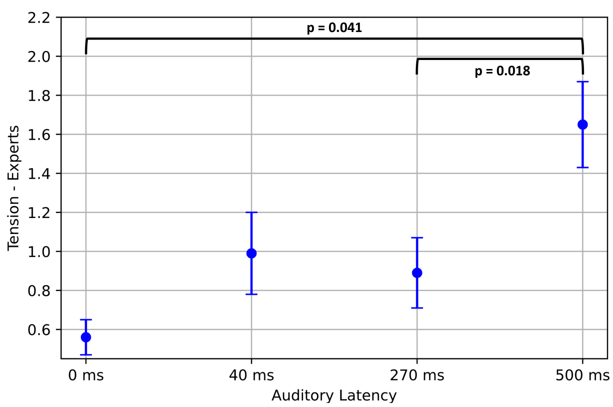

Figure 3: Shows the scores given by the *Expert* group in the *Tension* sub-scale of the *Game Experience Questionnaire* [24]. Significant differences are highlighted. Error bars show the standard error. *Experts* rated the game with 500 ms auditory latency with the highest *Tension* rating. Post-hoc testing showed that playing with 500 ms of auditory latency led to a significantly higher *Tension* rating compared to playing with 0 ms and 270 ms of auditory latency.

average score of 330.95 points ± 83.79 points. ANOVA revealed no significant effect of Audio Latency (F(1,33) = 1.38, p = 0.274) nor of Repetition (F(1,33) = 0.01, p = 0.979) on *Score* in the *Experts* groups. Similarly Audio Latency had no effect (F(1,33) = 0.78, p = 0.51) on the *Score* of *Novice* players. However, ANOVA revealed a significant effect of Repetition (F(1,33) = 5.31, p = 0.004) on the *Score* of *Novice* Players. Inexperienced players achieved a significantly higher *Score* in the *2nd* round. Furthermore, we found no interaction between Audio Latency and Repetition neither for Experts (F(3,33) = 1.04, p = 0.379) nor for Novices F(3,33) = 1.69, p = 0.189). Table 2 shows mean *Score* values and standard deviation for each Experience group separately and both groups combined for each level of tested auditory latency.

In-game Scores by Experience			
Audio Latency	Novice	Expert	Novice + Expert
0 ms	151.1 ± 50.4	348.7 ± 94.8	253.2 ± 122.0
40 ms	145.0 ± 52.8	333.2 ± 82.9	239.1 ± 117.0
270 ms	148.7 ± 46.4	317.8 ± 80.6	233.3 ± 107.1
500 ms	148.4 ± 55.0	324.1 ± 72.1	236.2 ± 108.8

Table 2: Shows mean in-game scores achieved by groups (*Novice* vs *Experts*) and combined (*Novice*+ *Experts*). *Experts* achieved the highest in-game score when playing with *0 ms* Audio Latency.

4.3 Qualitative Feedback

In general, all participants enjoyed participating in the study. However, some participants stated that they felt like the game was not responding to their actions. All *Experts* were able to tell that we manipulated the auditory latency of the game. Only one *Novice* came to the same conclusion. *Novices* mainly thought we manipulated in-game mechanics such as the frame rate of the game or the bot difficulty. Manipulation check showed that no participants, regardless of the level of experience, could correctly tell in which round the auditory latency was the highest.

5 DISCUSSION

In this section, we first discuss found effects of auditory latency on players' gaming experience. Next, we continue by examining the influence of auditory latency on the players' performance. Subsequently, we summarize with a general discussion on the our findings and our work. Finally, we conclude this section by exploring the implication of our findings for gamers, developers, and game researchers.

5.1 Game Experience

Our results consistently show that 40 ms of auditory latency did not influence the game experience while playing CS:GO. However, starting at 270 ms auditory latency negatively affects the perceived tension while playing as well as worsen the positive associations with the game which results in a heighten negative and a reduced positive affect towards the game. At 500 ms players significantly stronger associated negative feelings with the game. Furthermore, we found that the adverse effects of auditory latency on the perceived tension while playing are more pronounced for experienced players. Our findings align with related work investigating the effects of visual latency in video games. Firstly, previous work showed that increasing visual latency decreases the perceived game experience such as the negative [32] and postive affect [23]. Secondly, related research showed that visual latency affects experienced players stronger than inexperienced players [31]. Our work shows that the same is true for auditory latency. Considering that we did not find an effect of auditory latency on the game experience of novice players but did find an effect when investigating the data of experienced players, we can conclude that the tolerance for auditory latency decreases with prior knowledge and experience with the game. We conclude that there are two possible explanations for the differences found for the in-game experiences: (1) Previous work showed that visual latency tolerance increases with task complexity [6]. Since inexperienced players have little knowledge about the game and its mechanics, the perceived complexity is higher than the perception of high-skilled players. Thus, their latency threshold is higher. (2) Our second perspective on the found effects is that more experienced players, which have spent a considerable amount of time (>100 hours) in the game, are disturbed by the shifted perceptual input-output schema. Those players are used to the game responding in a certain way. They, additionally, are used to playing on their own setup; by disturbing the mental image of how the game behaves typically, we also disturb their gaming experience. Every time they played with an artificially increased auditory latency level, their mental representation of the game was shifted. The higher the auditory latency was, the more pronounced this shift manifested. A larger discrepancy between what the players are used to and how the game actually responded in the study led to a more severe negative influence on the perceived gaming experience.

Our findings regarding the effects of auditory latency on the gaming experience for small amounts (≤ 40 ms) are negligible. On the other hand, our work shows that higher auditory latency (≥ 270 ms) negatively affects the gaming experience. However, auditory latency is not as impacting compared to visual latency, which starts negatively influencing game experience at 25 ms.

5.2 Player Performance

While a downwards trend is noticeable in the achieved scores, our analysis did not reveal a significant effect of auditory latency on players' performance, neither for novice nor expert players. We did find a significant effect of the number of times one particular auditory latency level was played on the score of the inexperienced players. However, we assume that the increase of score in the second round by novice players is not due to habituation to the auditory latency but rather due to novice players learning the game mechanics. Thus, novice players started getting better in the game instead of adapting to the auditory latency. This is also supported by the fact that we did not see the same significant increase of points in the expert group. Achieved points stayed the same in both rounds for the experienced players. Hence, we cannot conclude, as related work does for visual latency [43] that players adapt to auditory latency.

The lack of significant effects of auditory latency on player performance might be due to multiple reasons. For example, as games predominately use the visual channel to convey game-relevant information, players might rely stronger on visual information than on auditory information. This is also in line with previous work, which found in a large-scale study that humans prioritize their visual perception over other senses in stressful situations [44]. Since CS:GO, and especially the mode we tested in our study, puts players in a position where they have to defend themselves against a never-ending stream of enemies, it may be possible that stress was induced. Thus, it is more likely that players rely solely on their most dominant sense - visual perception.

Overall, we found that auditory latency does not negatively influence player performance. Furthermore, comparing auditory latency to visual latency, it is evident that the adverse effects of auditory latency on player performance are not as pronounced as those of visual latency.

5.3 General Discussion

We conducted this work amidst the ongoing Covid-19 pandemic. Although all regulations of our institution were constantly controlled and thoroughly documented, we nevertheless minimized the amount of in-person exchange required. Thus, we also aimed to minimize the number of participants needed to run our study. We did this by following related work investigating visual latency. Previous work, showed that a small number of participants is sufficient to investigate the effects of latency in video games generally (Long and Gutwin: n = 18 [33] and n = 20 [33], MacKenzie and Ware: n = 8 [34]) and in CS:GO (Liu et al.: n = 25 [32]) in particular. However, while previous and our work shows that this approach reveals significant effects when investigating latency, it also may results in missing small effects of auditory latency. Investigating a larger number of participants may allow for a more detailed analysis of the effects of auditory latency on game experience and player performance.

Generally, it needs to be noted that our test system had an inherent auditory latency that we could not manipulate directly. Computers have an auditory latency of up to 70 ms. This baseline auditory latency is influenced by the applications running, the used operating system, the installed sound drivers, and the utilized hardware. Our system's baseline latency might be too high to reveal the effects of adding small amounts (40 ms) of auditory latency to CS:GO. There may be an auditory latency threshold that our system's baseline crossed. However, since end users' systems as well have a base latency our work replicates a natural gaming setup. Nevertheless, with our work, we successfully showcased the effects of large amounts of added auditory latency.

Furthermore, while the distinction between Expert and Novice players based on the hours previously played in CS:GO was used in prior work and seems to be reasonable based on the differences we found between the groups, this distinction might not always reflect the skill of an individual player. In addition, the threshold of

100 hours was chosen based on results of prior studies and is not necessarily ideal. Some people might learn the game faster due to their talents and strengths. Others perform better with less hours because they played similar games before. Moreover, if participants are used to different hardware than provided in our lab, they could perform worse than someone with less experience but similar peripherals. Consequently, the classification based on hours played is simple and in our case effective but could be improved in future works to achieve a more nuanced and realistic graduation of skill levels.

We evaluated player performance using a single metric –the score. While this metric was used in other studies, is easy to analyse and understand, and combines several aspects of performance such as kills as well as assists, recording other and more metrics could have revealed more details or other results concerning the changes in behaviour when playing with auditory latency.

Futhermore, we used the Game Experience Questionnaire to asses the subjective gaming experience of the players. Previous work has noted reliability issues with the GEQ's constructs. However, we report a high Cronbach's Alpha (all $\rho_T > 0.8$) for all tested dimensions which shows that our findings are reliable. Nevertheless, using a different questionnaire, such as the Player Experience Inventory (PXI) [1], may reveal different results.

Lastly, we discuss the chosen game for our work. We used a FPS game for our work because this type of game is extremely fast-paced and requires split-second decision-making to perform well. Additionally, previous work showed that the adverse effects of visual latency are particularly pronounced in FPS games [10, 30, 32]. While our findings are valid for CS:GO, one needs to be careful to generalize it to the vast landscape of gaming with its numerous type of genres, games, and gamers. It is possible that investigating auditory latency in other games or genres, such as arcade games, leads to the unraveling of effects unnoticed by our work.

5.4 Implications of our Findings

Our findings have implications for gamers, developers, and researchers alike. Gamers should be aware of the effects that auditory latency may have on them. Starting at 270 ms of auditory latency, these negative effects can be induced by commercially available sound equipment using the SBC codec. Therefore, gamers should avoid buying equipment using the SBC codec and instead obtain headphones using the *aptX low latency* standard, which has an auditory latency of less than 40 ms. However, while this recommendation is generally applicable, it may not be necessary to exchange existing equipment. As we showed, the effects of auditory latency are more pronounced for experienced gamers. Casual gamers, spending only little time in gaming, may not profit from the reduced auditory latency of pricier *aptX low latency* hardware.

Game developers can also benefit from our findings. Since we showed that auditory latency does not affect players to the same extent as visual latency, developers can prioritize their resources accordingly. This means that reducing visual latency should be a priority in the development pipeline. Developers should focus on providing players with visually appealing and responsive games. While audio latency should not be neglected entirely, it can be ranked at lower severity, allowing developers to implement, test, and fix more critical game elements first. This implication is particularly relevant in light of novel gaming paradigms such as cloud-based game streaming (CGS). In CGS, games are streamed via the Internet; A high network latency thus leads to higher overall latency. Since auditory latency does not affect players with the same magnitude as visual latency, CGS providers should prioritize delivering visual information if the players' connection is not stable or fast enough to receive audio and visual information synchronously.

Finally, the most important implication of our results concerns researchers and the research community. We found first indication that auditory and visual latency does not affect players in the same way. Previous work showed that latency in video games generally reduces player experience and performance. However, previous work has not distinguished between visual and auditory latency. Therefore, it is possible that the effects of auditory latency have not been considered. As we showed that auditory latency does affect high-skilled players, we encourage researchers to distinguish between visual and auditory latency. Both types of latency have different effects on players. Ideally, researchers should measure visual and auditory latency independently, design experiments considering both types of latency, and report accordingly. This would allow researchers to expand their knowledge of latency and its effects on players.

6 CONCLUSION

In this work, we investigated the effects of auditory latency in *Counter-Strike: Global Offensive*. 24 participants with two different skill levels (novices and experts) played eight rounds of *Deathmatch* in which they had to fight an endless stream of AI-controlled enemies. Each round was induced with one of four levels of controlled auditory latency (0 ms, 40 ms, 270 ms and 500 ms). We found that expert players experience a significantly higher level of tension and a significantly decreased positive affect starting at 270 ms of auditory latency. At 500 ms auditory latency, those negative effects are amplified and additionally, experts started to significantly stronger associate the game with negative feelings. We found no effect of auditory latency on the game experience of novice players. Furthermore, we did not reveal significant effects of auditory latency on players' performances - regardless of their skill level.

With our work, we provide first empirical evidence that auditory latency negatively affects the game experience of expert gamers in CS:GO. However, since we tested only CS:GO, our findings may not generalize to the entire gaming landscape. Future work, thus, should investigate the effects of auditory latency in other video games and game genres, such as rhythm games or *Real-time Strategy* games. Furthermore, considering that we found negative effects of auditory latency on expert players despite the relatively small number of participants in this group (n = 12), it is possible that we missed smaller effects. Future work should build on our work and further investigate the negative effects of auditory latency on expert players. Moreover, since auditory latency is seldom a standalone issue in real gaming scenarios, and players are constantly confronted with a mixture of visual, auditory, input, and network latency, future work should also address the interaction between different types of latency. It might be the case that the negative effects of auditory latency are influenced by other types of latency, such as visual latency.

Further deepening our knowledge about latency and its effects on players aids researchers in better understanding players and their interaction with games. Furthermore, game developers can build upon this knowledge to develop games with a maximized gaming experience.

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