Understanding Player Performance and Gaming Experience while Playing a First-Person Shooter with Auditory Latency

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ABSTRACT

Visual latency is known to decrease player performance and experience starting at 25 ms. Less is known about the effects of auditory latency in video games. To investigate the effects of auditory latency, we added auditory latency to a publicly available and latency-sensitive first-person shooter game. Using the game, we conducted a study with 24 participants playing the game with four different levels of auditory latency (0 ms, 50 ms, 100 ms, 200 ms). The results of a Bayesian analysis support a model with no true effect of auditory latency on game experience and player performance in first-person shooter games. Hence, our preliminary results indicate that auditory latency may not affect gamers with the same magnitude as visual latency.

KEYWORDS

Video Games, Latency, Audio, Auditory Latency

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1 INTRODUCTION

Sound is an essential part of immersive virtual environments. In video games, a well-designed audio landscape increases immersion and involvement [11, 12] and evokes emotion in players, causing fear, bliss, or even anxiety [33].

Interactive system, however, are affected by latency [26]. Multiple works have shown that high latency leads to a reduced user experience and performance when using said systems [1, 16, 28, 29]. In video games, fast-paced games such as first-person shooters (FPS), are particularly affected by latency [5]. Latency in FPS games leads to players scoring fewer points, needing more time to complete in-game tasks, or preventing them from finishing tasks at all [4, 23]. Furthermore, latency also negatively affects the players' gaming experience [9, 25]. These adverse effects increase when gamers use wireless gaming equipment such as wireless headsets as they have a fundamentally higher latency caused by transmission and processing than their wired counterparts. Typical Bluetooth (BT) headsets have a latency of 200 ms [27]. When playing with a BT headset, this additional 200 ms audio latency adds to the overall latency, thus potentially decreasing the gaming experience. Previous work researching latency and its effects on players, for the most part, focused on visual latency but does not investigate the effects of auditory latency.

Therefore, it is currently unknown if standalone high auditory latency leads to the same systematic decreased experience and performance as visual latency. This work starts closing the gap between visual and auditory latency by investigating auditory latency in a fast-paced custom FPS game. For this, we customized a publicly available FPS game, which has previously been evaluated to be latency-sensitive [13], and added multiple levels of artificial auditory latency. We then conducted a pilot study with 24 participants. Null-hypotheses testing and Bayesian inference analysis indicate that auditory latency may not impact player performance and experience. We found up to strong evidence that our data is in favor of a model with no true effect of auditory latency in the game. However, one needs to be careful to generalize our findings to the vast gaming landscape with its countless types of games and genres. With our work, we aid a first step to a better understanding of auditory latency and its effects on games and players.

2 RELATED WORK

Latency in interactive systems is the time between a user-generated input to a system and the system's output [26]. However, while sub-latencies, such as network and local latency, and their effects on users are investigated independently, previous work generally does not separate latency by perceptual channel. Earlier work investigating latency in video games combines visual and auditory latency or does not factor in auditory latency at all. Some work, however, does investigate the effects of auditory latency on specialized user groups such as disc jockeys.

Recent work found that visual latency in an interactive system leads to diminished performance when users are interacting with

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it. Jota et al. [16] and Annett et al. [1, 2] found that visual latency above 25 ms decreased the user performance in pointing tasks or when operating a touch device. While visual latency below 25 ms generally does not decrease user performance, users still perceive it. Ng et al [29] found that visual latency starting at 2 ms is perceived by users of a touch device.

Work on auditory latency, on the other hand, has not yet revealed the a systematic influence of auditory latency on user performance and experience. Kaaresoja and Brewster [17] investigated the latency of touch screen devices by perceptual channel and found that auditory latency ranges from 35 ms to 375 ms. In similar work, Ye et al. [37] investigated the auditory latency of different operating systems such as *Windows* and *MacOS*. The authors found that auditory latency of the investigated systems ranged from 5 ms (*MacOS*) to 382 ms (*Windows*). Besides these substantial variations of the auditory latency induced by the used operating system or device, the headset is another factor influencing auditory latency. Depending on the codec used, typical BT headsets have an auditory latency between 150 ms and 250 ms [27]. Simon et al. [32] investigated the effects of auditory latency in DJ interfaces and found that novice users were not negatively influenced by auditory latency. Simultaneously, they found that experienced DJs performed worse starting at an auditory latency of 130 ms. Simon et al.'s work suggests that auditory latency is negligible for the day-to-day user.

The adverse effects of visual latency on player performance in video games manifest in different ways, such as players scoring less points [4, 6, 9]. Armitage et al. [3], furthermore, revealed that starting at 150 ms of visual latency, player performance starts to worsen. Recent work, however, showed that FPS games are negatively affected by latency starting at 25 ms [23]. In other work, Liu et al. [23, 24] also found that a visual latency of 150 ms reduces the overall quality of experience by 25 %.

Sound in video games can be divided into two parts: (1) diegetic sounds which reflect events in the game world and (2) non-diegetic sounds which do not refer to an event in the game world [10]. In a study, Grimshaw et al. [12] found that both types of sound have a significant but different effect on the players' game experience: While diegetic sounds increased the immersion, non-diegetic sounds decreased tension and the negative effect associated with the game. Sound in video games also influences player performance as it is used to convey information about the game world [30]. In FPS games, for example, sound is crucial to performing well. Whether a player listens for enemy footsteps or tries to locate where a gunshot originates, every additional information obtained increases the chances of winning.

Recent work shows that visual latency negatively affects user performance starting at 25 ms [1, 16]. Additionally, it shows that auditory latency fluctuates [37] and can reach up to average values of 250 ms [27]. Auditory latency starts to affect experienced users at 130 ms. Everyday users seem to be unaffected by auditory latency [32]. In video games visual latency is known to negatively influence player performance and experience [4, 6, 9] starting at 25 ms [23]. While it is clear that audio is an essential part of video games to increase immersion [10, 12] and performance [30], the effects of auditory latency are unknown. Therefor, currently, it is unclear if standalone high auditory latency in video games leads to the same systematic decrease of game experience and performance as visual latency.

3 INVESTIGATING THE EFFECTS OF AUDITORY LATENCY IN FIRST-PERSON-SHOOTERS

To investigate the effects of auditory latency on player performance and experience, we customized a publicly available FPS game. The game we utilized was developed by Halbhuber et al. [13] to investigate novel latency compensation techniques. Players rated the game with a lower game experience and performed worse when playing with high latency compared to playing with reduced latency. Since latency negatively influences the game and its' players, it is a viable apparatus to investigate auditory latency. Additionally, investigations are not as strongly influenced by prior game experience as it would be the case when investigating a commercial game. Furthermore, the implementation allows us to independently manipulate visual and auditory latency.

3.1 Game Development

To adapt the game for our work, we updated every sound-generating game object, such as the player's weapon, firing feedback, hit recognition, and sound generated by enemies spawning to introduce auditory latency. If, for example, an enemy spawns, the actual event (the spawning of an enemy) was triggered. However, the corresponding sound (the sound generated by the spawning enemy) was delayed for a fixed amount of time. Players in the original version were only able to locate enemies visually. We added a specifically designed sound to allow players to localize opponents by sound using *Unity's* 3D-Sound engine. In addition, we added walls to the game world to bring the auditory game elements even more into focus. These walls block the view on the monsters. Hence, players had to rely on auditory information to track enemies. Through these modifications, we emphasized the auditory components of the game. The left side of figure 1 shows the modified game world. The right side of the figure 1 shows the player's view during gameplay. The game was developed using *Unity3D* (Version 2019.f16.2), for modification we also used *Unity3D* (Version 2021.2.7f1).

3.2 Measuring Local Auditory Latency

We measures the used system's local latency to account for it in further analysis. We utilized a 240 f/s camera (*GoPro Black 7*). However, contrary to related work investigating visual latency [15, 25], we first had to determine the camera's offset between visual and auditory input. This is not required when measuring the latency between two visual events, but since we were need to measure the latency between a visual event(the clicking of the mouse button) and a subsequent auditory event (the firing sound), the camera's offset between visual and auditory input needs to be determined. Thus, we recorded a sound-generating event - the poking of a cup using a metal pin. By examining the recorded material frame-by-frame, we visually determined the exact moment the pin touched the cup - this moment serves as the start point of our offset measurement. Further investigating the recorded material, while observing the audio input channel of the used software allowed us to establish the moment audio was first recorded. The audio peak represents the

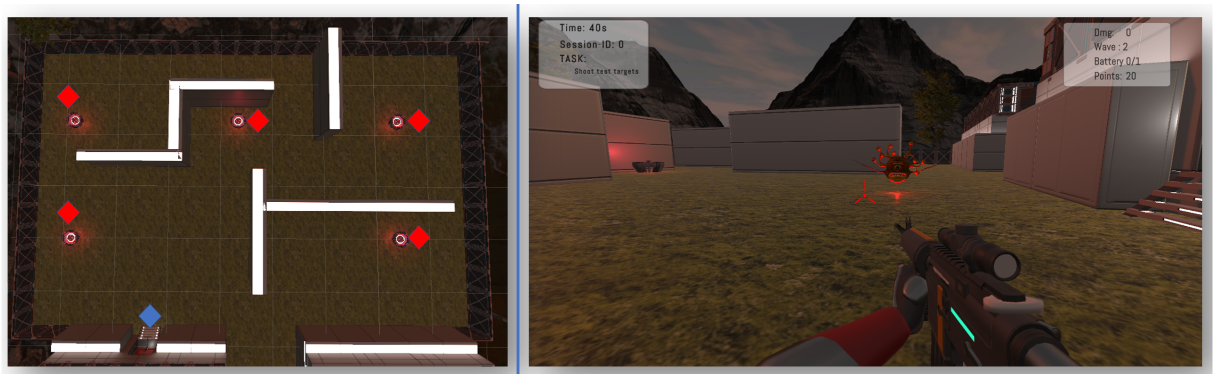

Figure 1: Shows two screenshots. The left side shows an aerial overview of the game world. The red marker indicates enemies' spawn points. The blue marker players' starting point, and the white areas are the walls. The right side of the figure shows the players' views during gameplay. The UI provides game-related information such as score and time left to the players. Additionally, the figure shows one hostile monster moving toward the player.

end point of our offset measurement. Investigating the number of frames between the start (the poke) and endpoint (the audio peak) of the recorded event allowed us to estimate the audio-video offset of the used camera. We ran the experiment 20 times and found that the *GoPro Black 7* records material with an video-audio offset of 29.85 frames (SD = 0.91 frames) this corresponds to an offset of 124.37 ms (SD = 3.78 ms).

Utilizing the determined audio-video offset of the camera, we measured the auditory latency baseline of our test system running the modified game. We again recorded a visual event - a user clicking the mouse button to fire their weapon - and compared it to the auditory effect - the sound generated by the weapon firing heard through wired headphones. We ran the measurement 20 times. Comparing the recorded material frame-by-frame revealed a baseline auditory latency of 49.85 frames (SD = 2.17 frames), which corresponds to a latency of 83.33 ms (SD = 9.04 ms). All further auditory latencies are based on the measured baseline auditory latency without explicitly mentioning it.

3.3 Study Design

We conducted a study to test if auditory latency impacts game experience and player performance. We used Audio Latency as a within-subject variable. The levels of Audio Latency are based on the latency range of the commercially predominantly used Bluetooth protocol, which averages from 150 ms to 250 ms [27]. Additionally, visual latency is known to negatively affect game experience and player performance at 25 ms [23] and respectively 125 ms [24]. To cover all ranges, we categorized Audio Latency in four levels: (1) 0 ms, (2) +50 ms, (3) +100 ms and (4) +200 ms auditory latency. To measure game experience we used the *Game Experience Questionnaire* (GEQ) [14] with its sub-scales: *Competence* (COM), *Sensory* (SEN), *Flow* (FLO), *Tension and Annoyance* (TEN), *Challenge* (CHA), *Negative Affect* (NEG) and *Positive Affect* (POS). Player performance is measured using three dependent variables: (1) *Score* - the amount of points players achieved by shooting monsters, each monster awarded 10 points, (2) *Accuracy* - quantifies how accurately the players shoot and is built as the quotient of the total amount of shots fired and the number of hits, and (3) *EnemyHit* - corresponds to the number of monsters that hit the players avatar. All of our measures were also used by Halbhuber et al. [13] and are sensitive to visual latency.

3.3.1 Apparatus. We used the same setup as in our baseline auditory latency measurement. The game was executed on a stationary workstation in our laboratory. The workstation (Intel i7, Nvidia GT970, 16 GB RAM) was attached to a monitor (24" FullHD @60Hz), a computer mouse (Logitech M10), and a wired headset. Participants played the game using the same wired headphones evaluated in the baseline measurements. All participants played with all levels of auditory latency. We used a Latin Square to balance the condition to prevent a bias induce by sequence effects.

3.3.2 Procedure and Tasks. After being greeted in our laboratory, participants signed the consent form and agreed to data collection. Participants were not informed about the exact purpose of the study (investigating the effects of auditory latency) but were told to test a novel game. Participants played each condition for 10 minutes and were told to reach as many points as possible by shooting monsters. After playing for 10 minutes, the game referred the participants to the GEQ. After completing the GEQ, the next round started with a different auditory latency level. After finishing all conditions, the participants were debriefed and referred to a final demographic questionnaire.

3.3.3 Participants. We invited 24 participants (5 female, 19 male) using our institution's mailing list. The participants' mean age was 23.16 years (SD = 2.34 years), ranging from 19 to 30 years. Participants were asked to rate their gaming experience and their experience playing FPS games on a 5-point Likert scale spanning from no experience to very experienced. Participants' mean self-rated experience with video games in general was 4.41 points (SD = 0.85 points), and with FPS games 3.63 points (SD = 1.29 points). All participants were students at our institution and were compensated with one credit point for their study course.

4 RESULTS

In the following, we first describe the gathered data, then we report results of a classical null-hypothesis analysis and a Bayesian inference analysis investigating if AUDIO LATENCY had an effect on game experience and player performance.

Shapiro-Wilk's test was used to determine the assumption of normal distribution for all measures. Results show violation of normality for all GEQ sub-scales ($p < .05$) and shows normality for the performance measures ($p > .05$). Hence, we use non-parametric Kruskal-Wallis tests [19](GEQ sub-scales) and ANOVAs (performance measures) for null-hypothesis testing. All pairwise cross-factor comparisons are conducted using Wilcoxon tests and are Bonferroni α corrected. For Bayesian inference, we used *JASP* [34] and the default prior probability distribution recommended by Wagenmakers et al. [35]. Bayesian post-hoc tests were conducted using Bayesian t-tests. Posterior odds were corrected utilizing Westfalls' approach to the correction for multiplicity [8, 36]. Bayes factors [18, 20] are formulated as BF_{01} which indicates how much more likely H_0 over H_1 is, and are interpreted using Lee and Wakenmakers' postulation [21] to Bayes factor interpretation.

4.1 Descriptive Results

Participants rated their game experience on a 5-points Likert-scale. Table 1 (top) shows mean GEQ scores rated by the participants for each level of AUDIO LATENCY. Participants assigned the highest scores when playing in the *0 ms* condition in all categories except of the *Flow* and *Tension* categories. In both, *Flow* and *Tension*, the *200 ms* was assigned the highest scores by participants.

Table 1 (bottom) shows mean values for each performance variable (*Score*, *Accuracy*, and *EnemyHits*) categorized by levels of AUDIO LATENCY. Participants reached the highest *Score* values when playing in the *+50 ms* condition (1852.01 points, SD = 504.85 points) and the lowest when playing in the *0 ms* condition (1705.41 points, SD = 422.26 points). *Accuracy* values remained stable over all condition, only in the *+50 ms* condition standard deviation fluctuated stronger (0.17, SD = 0.05). Participants were hit the most by hostile monsters when playing in the *+50 ms* condition (6.21 hits, SD = 9.79 hits) and were hit the least when playing with 100 ms artificially added auditory latency (3.92 hits, SD = 5.08 hits).

4.2 Null-Hypotheses Testing

Kruskal-Wallis' test using the within-subject factor AUDIO LATENCY test revealed no significant effects on the GEQ sub-scales *Competence* (χ^2 = 2.14, p = 0.54, df = 3), *Flow* (χ^2 = 0.29, p = 0.96, df = 3), *Sensory* (χ^2 = 1.68, p = 0.64, df = 3), *Challenge* (χ^2 = 3.08, p = 0.38, df = 3), *Negative Affect* (χ^2 = 4.35, p = 0.22, df = 3), and *Positive Effect* (χ^2 = 0.59, p = 0.89, df = 3). The test did reveal a significant effects of AUDIO LATENCY on *Tension* subsection (χ^2 = 8.08, p = 0.04, df = 3). An alpha-corrected Bonferroni post-hoc test, however, did not reveal significant differences in pairwise-comparison for *Tension* (all $p > 0.05$)

An ANOVA, with the within-subject factor AUDIO LATENCY, did not reveal significant difference in the performance measures *Score* (F(3,92) = 0.68, p = 0.91), *Accuracy* (F(3,92) = 0.15, p = 0.93) and *EnemyHits* (F(3,92) = 0.58, p = 0.62).

4.3 Bayesian Inference

Previous tests consistently did not reveal significant effects of AUDIO LATENCY on any measure. However, classical null-hypothesis testing only reveals differences between distributions - ANOVA either accepts or rejects a null hypothesis. It can not reveal if the missing of a significant difference is an indication for equivalence between the investigated distribution. Thus, to investigate equivalence in our data we conducted a Bayesian analysis. Rather than just rejecting a null-hypotheses, a Bayesian ANOVA calculates a probability of how likely the acceptance of the null hypothesis (no differences in distribution) is correct [7, 35]. Contrary to classical null-hypothesis testing Bayesian inference calculates probabilities for both: H_0 and H_1.

We found moderate evidence [21] for correct acceptance of H_0 in the distributions of *Competence* (BF_{01} = 5.45), *Challenge* (BF_{01} = 7.46), *Tension* (BF_{01} = 9.03), *Negative Affect* (BF_{01} = 6.06), and strong evidence for H_0 in *Flow* (BF_{01} 15.77), *Sensory* (BF_{01} = 11.47) and *Positive Affect* (BF_{01} = 11.67). The data from the sub-scales of the GEQ have not been influenced by AUDIO LATENCY with at least moderate ($BF_{01} > 3$) and partly with strong evidence (BF_{01}>10). A Bayes factor BF_{01} of 15.77, as in the *Flow* sub-scale, indicates that the data is 15.77 times more likely under the null hypothesis postulating no effects induced by AUDIO LATENCY. Table 2 (top) shows Bayes factors BF_{01} for all pairwise post-hoc comparisons for the GEQ sub-scales. In post-hoc testing we found anecdotal (BF_{01} > 1 and BF_{01} < 3) to moderate (BF_{01} > 3) evidence for H_0 regarding data from the GEQ.

For the performance measures we found moderate evidence for *Score* (BF_{01} = 8.53), and *EnemyHits* (BF_{01} = 9.31), and strong evidence for *Accuracy* (BF_{01} = 16.58) in favor of accepting H_0. Post-hoc tests are, again, depicted in table 2 (bottom) and show anecdotal to moderate evidence as well.

5 DISCUSSION

Our preliminary results show that artificially added auditory latency does not significantly affect players' game experience and performance in a custom FPS game. Furthermore, Bayesian analysis revealed strong evidence that the data gathered while playing with four different levels of auditory latency is in support of a model with no true effect of auditory latency. With this work, we contribute first evidence that auditory latency does not affect players in the same way as visual latency.

In this section, we first discuss the Bayesian evidence for a model with no true effect of auditory latency on the game experience and performance. We then explore the implications of our findings for gamers, developers, and latency researchers.

5.1 Effects on Game Experience and Player Performance

We did not find any significant effects of auditory latency on the players' game experience, despite the fact that our measures previously have been shown to be latency-sensitive [13] - the lack of significance could be due to multiple reasons.

Firstly, it is possible that the game is not sensitive to auditory latency but only to visual. Since it is a fast-paced first-person shooter

Game Experiences Scores							
Audio Latency	**Competence**	**Sensory**	**Flow**	**Tension**	**Challenge**	**Neg. Affect**	**Pos. Affect**
0 ms	3.10 ±1.07	1.60 ± 0.76	2.14 ± 0.94	1.11 ± 0.25	1.81 ± 0.94	1.54 ± 0.65	2.68 ± 1.01
+50 ms	2.6 ± 0.80	1.43 ± 0.95	2.06 ± 0.86	0.81 ± 0.81	1.51 ± 1.10	1.41 ± 1.04	2.45 ± 0.83
+100 ms	2.83 ± 0.73	1.31 ± 0.97	2.02 ± 0.87	0.89 ± 0.88	1.72 ± 1.02	1.14 ± 0.92	2.43 ± 0.91
+200 ms	2.85 ± 0.74	1.45 ± 0.99	2.21 ± 0.88	0.87 ± 0.99	2.02 ± 0.94	1.18 ± 1.03	2.56 ± 0.87

Performance Measures			
Audio Latency	**Score**	**Accuracy**	**EnemyHits**
0 ms	1705.41 ± 422.26	0.17 ± 0.04	4.01 ± 5.59
+50 ms	1852.01 ± 504.85	0.17 ± 0.05	6.21 ± 9.79
+100 ms	1767.08 ± 429.94	0.17 ± 0.04	3.92 ± 5.08
+200 ms	1706.66 ± 326.65	0.17 ± 0.04	5.04 ± 5.25

Table 1: Shows the mean scores and standard deviation of each sub-scale of the *Game Experience Questionnaire* (top) as well as the mean and standard deviation of the performance (bottom). Participants assigned playing with 0 ms the highest game experience score, expect for the *Flow* and *Tension* sub-scale. Both sub-scales were assigned the highest score when playing with 200 ms auditory latency. Participants reached the highest score when playing with 50 ms auditory latency, but simultaneously received the most amount of monster hits in this condition. Accuracy remained almost stable over allconditions.

Post-Hoc Bayesian t-test BF01 values corrected for multiple testing - GEQ								
Level 1	**Level 2**	**Comptence**	**Sensory**	**Flow**	**Tension**	**Challenge**	**Neg. Affect**	**Pos.Affect**
0 ms	+50 ms	1.24	2.91	3.33	1.13	2.72	3.15	2.58
	+100 ms	2.27	2.02	3.17	2.11	3.35	1.08	2.51
	+200 ms	2.43	3.05	3.47	2.13	2.74	1.54	3.19
+50 ms	+100 ms	2.76	3.21	3.44	3.32	3.17	2.42	3.47
	+200 ms	2.61	3.47	3.39	3.40	1.44	2.73	3.24
+100 ms	+200 ms	3.46	3.12	3.24	3.47	2.27	3.45	3.16

Post-Hoc Bayesian t-test BF01 values corrected for multiple testing - Performance Measures				
Level 1	**Level 2**	**Score**	**Accuracy**	**EnemyHits**
0 ms	+50 ms	2.09	3.39	2.43
	+100 ms	3.13	3.37	3.47
	+200 ms	3.48	3.25	2.92
+50 ms	+100 ms	2.92	3.48	2.32
	+200 ms	1.89	3.46	3.13
+100 ms	+200 ms	3.06	3.45	2.78

Table 2: Shows BF_{01} values for post-hoc testing using a Bayesian t-test for data of the *Game Experience Questionnaire*(top) as well as all gathered performance Measures (*Score, Accuracy, EnemyHits*) (bottom). Tests were corrected for multiplicity using Westfalls' correction [36]. All post-hoc tests revealed anecdotal (BF_{01} > 1 and BF_{01} < 3) to moderate (BF_{01} > 3) evidence for H_0.

- players are put under constant stress. They have to fight a never-ending stream of monsters to achieve a score as high as possible. Therefor, players may relied on their most dominant sense - visual perception. This assumption is in line with work, showing that humans prioritize their visual perception over all other senses [31]. Since players had to react quickly and accurately, they only focused on the visual input and thus did not notice the auditory delay. Secondly, individual player skill and experience with a certain game may change the perception of latency. Liu et al. [22], for example, showed that higher skilled players are stronger affected by the negative effects of latency. We, however, used a custom game to prevent introducing a bias caused by previous experience in a game. Since our participants had no experience with it, we created a fair and comparable situation for our study. Nevertheless, it is possible that auditory latency only starts affecting players at a certain skill level. Lastly, another reason for the lack of significant effects of auditory latency may be that the tested latency was to small. There may be an auditory latency threshold we did not cross. Similarly to the different latency thresholds for different game genres found by Claypool and Claypool [5], it is reasonable to assume that auditory latency has a perception threshold. We oriented our latency levels on the commercially used *aptX* codec. Thus, the investigated latency values are those everyday gamers have to deal with. If auditory latency is not perceivable under a certain threshold, and if our work did not cross that threshold, it means that auditory latency in the wild does not decrease gaming experience. Thus, this would also mean the higher price tag of low-latency gaming equipment is not justified and it is merely a marketing scheme.

5.2 Implications of our Findings

Our findings have implications for players and researchers. Day-to-day players directly benefit from our findings since we showed that an increase in auditory latency is neglectable regarding game experience and player performance. Thus, spending the extra money to buy specialized low latency audio equipment such as headsets and headphones is unjustified. However, auditory latency may affect players with a high skill level. Nevertheless, since most players do not compete at such a high skill level, our findings apply to most parts of the gaming community. Our findings have implications for researchers and the research community as well. We found first evidence that auditory and visual latency does not impact players in the same way. We encourage researchers to start to differentiate 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.

5.3 Conclusion

In this work, we provide first evidence that auditory latency does not affect gamers with the same magnitude as visual latency. Future work should focus on further researching auditory latency as a concept on its own, rather than investigating it combined with visual latency. Ultimately, further deepening our understanding of latency, its types, and the individual effects of auditory and visual latency allows us to better understand gamers and games alike.

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