2020 Twelfth International Conference on Quality of Multimedia Experience (QoMEX)

Investigating the Relationship of Mental Immersion and Physiological Measures during Cloud Gaming

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***Abstract*—The ultimate goal of designing game applications is to evoke a state of mental immersion in human users. Recently, advancing and very promising cloud gaming services catch high interest of the research community and industry. Cloud gaming services reduce computational costs of a client by outsourcing the game logic and rendering to a remote server. Consequently, the degree to which a game runs smoothly and enables uninterrupted interaction depends on impairments of the network connection between client and server. Furthermore, the visibility of such impairments may be constrained by properties of the visual display at the client-side. The present paper investigates the impact of common network impairments (bit rate, delay, packet loss) and screen size (small, medium, large) on mental immersion. In addition to traditional subjective assessment using the Immersive Experience Questionnaire (IEQ), also less intrusive, continuous physiological methods are employed (electrocardiography, ECG; electro-dermal activity, EDA). Participants engaged in playing an action platform computer game under different combinations of network impairments and screen sizes. Results revealed a small main effect of screen size on gaming Quality of Experience and real-world dissociation ratings between the small and medium screen size. Effects of network impairments on all IEQ scales were significant and also manifested as increased heart rate variability for packet loss. Besides, positive correlations were found between IEQ scales and heart rate variability. These findings suggest that network impairments influencing gameplay interaction might be of higher importance for immersive experience than varying screen size. Heart rate variability shows promise as a useful ECG measure in future studies on gaming immersion.**

***Index Terms*—Cloud Gaming, Immersion, Physiological Assessment**

I. Introduction

Developers' primary goal is to create games with an optimal level of immersion, which in turn is considered to be an important influencing factor on player experience and overall satisfaction with a gaming application. Up to this point, the research community has not yet agreed upon a conclusive definition of "immersion" [1]. However, it appears probable that immersion represents a rather global and multidimensional subjective phenomenon that includes other relevant subordinate phenomena like involvement and engagement [2], place and plausibility illusions as well as social presence [3], [4].

A basic distinction can be made between *system immersion*, which comprises all objective elements of the multimedia system, and *mental immersion*, which various aspects of subjective user experience that are affected by those system factors. Similar dichotomies were proposed between (system) immersion and presence by Slater [5] or, concerning multimedia systems in general, between Quality of Service (QoS) and Quality of Experience (QoE) by the Qualinet network [6].

In the gaming industry at large, a growing use of online streaming and cloud services can be observed. Moreover, the game logic and rendering increasingly run on distant servers, which are accessed by clients that merely function as a graphical and response interface to the user—a development summarized under the term *cloud gaming*.

This paper examines the impact of two common system influencing factors in a cloud gaming context, *screen size* and *network condition*, on mental immersion. While both factors, by definition, constitute parts of system immersion, it has remained unclear as to what extent they also determine mental immersion. Inspired by a taxonomy of immersion presented in [1], we refer to mental immersion (during gameplay) as a state of the user linked to mental absorption, mediated by the game content including narrative elements and challenges. Different screen sizes like smartphone, computer and television screens occupy varying amounts of the visual field, which could affect the sense of being surrounded or enveloped by the virtual world. Temporal and informational impairments in network connection like delay, packet loss and bit rate reduction are further perceived as lowered video quality and input quality as demonstrated in ITU-T Rec. G.1072.

A multi-method approach is chosen to investigate the effects of *screen size* and *network condition* on immersive experience during active gameplay. Subjective measures are collected post-hoc, using the Immersive Experience Questionnaire (IEQ), while peripheral bodily responses are captured in a continuous fashion by means of electro-encephalography (ECG) and electro-dermal activity (EDA) measurements.

More specifically, the present paper attempts to answer the following research questions:

- Do relationships exist between extracted physiological features (as measured by ECG and EDA) and subjective ratings of mental immersion ratings (as assessed by IEQ)?
- Does the screen size of a device used for a cloud gaming service affect mental immersion?
- Do network impairments that reduce interaction and perceived video quality also affect mental immersion?

The remainder of this paper is organized as follows. The next Section II gives an overview on related work. In Section III the methodology and details about the user test design will be described. The results of the conducted experiment will be summarized in Section IV. Lastly, Section V provides a discussion of the findings and possible future work.

II. Related Work

In this Section, a short overview on definitions of immersion, its assessment and influencing factors is given, with specific focus on the application context of online gaming.

A. Gaming Immersion

Although it is commonly agreed upon that immersion constitutes an important aspect of gaming QoE, there is no general consensus about a precise definition of "immersion" *per se* and differences with the concept of presence are still widely debated [1]. This status quo might be due to the high number of domains in which the term is used. While the present paper aims by no means to solve the requirement of a clear definition and distinction of these terms, it is important to clarify what immersion means in the context of this research.

Nilsson et al. proposed a taxonomy of three types of immersion: Immersion as a property of a system, as a subjective response to narrative contents, or as a subjective response to challenges within the virtual environment [1]. This taxonomy shows that apart from the audio-visual presentation also narrative and challenge factors might impact mental immersion.

The concept of presence has often been described as the sense of "being there". Slater distinguishes two types of perceptual illusions associated with presence, namely place illusion and plausibility illusion [3]. Furthermore, the suspension of disbelief is considered to be a mediator for presence. However, most research on presence is linked to virtual reality systems. Slater therefore argues that presence for desktop systems "requires deliberate attention and is not simply a function of how the perceptual system normally works, but is something that essentially needs to be learned, and may be regarded as more complex" [3].

Ermi et al. state that while there might be a link between the audio-visual implementation of a game and immersive experience, this is not the most important factor. Therefore, for digital desktop games, typically the term immersion is used, "because it more clearly connotes the mental processes involved in gameplay" [2]. The act of involvement due to the interactive nature of games causing challenge-based and narrative immersion seems to be more dominant in a gaming experience than different types of presence. Quite the contrary, the abandonment of the "displacement" can be a requirement for gaming immersion [7].

With respect to game immersion, Jennett argues that immersion results from "self-motivated attention which is enhanced through feedback from the game", which is not solely influenced by selective attention or cognitive load. She also argues that games with simple graphics may not involve presence, as users of Tetris unlikely experience being in a world of falling blocks, but can nonetheless feel highly immersed [8].

B. Assessment of Immersion

The need for reliable and valid measures of immersion and presence has long been recognized and discussed in the literature, leading to a basic taxonomy of subjective, behavioral and physiological methods [9].

Past research has traditionally relied on subjective methods like questionnaires. Despite being widely considered as ground truth, subjective assessments are often very time consuming and intrusive, thereby potentially altering the to-be-measured phenomena. A variety of different questionnaires on immersion and presence have been developed based on different theories and sub-dimensions. An overview of questionnaires used to assess engagement concepts is given in ITU Rec. P.809 [10]. Finally, the IEQ [8] was specifically developed to measure immersion in gaming.

More and more frequently, subjective methods are complemented by various non-invasive physiological methods that involve the placement of electrodes on standardized positions of the body surface [11]. These include the measurement of electrical brain activity, electro-encephalography (EEG), as well as measurements of the electrical activity of the heart, electro-cardiography (ECG), and electrical effects of varying eccrine sweat gland activity, electro-dermal activity (EDA).

Physiological signals can be recorded continuously, without any conscious effort from the participant side. By contrast, subjective methods require participants to explicitly introspect on their experience and derive descriptions on predefined psychometric rating scales; thus, inadvertently, subjective measurement outcomes are to some degree biased by distortions in human cognitive judgment and memory [11].

Earlier studies have already employed ECG and EDA to assess immersive experiences, e.g. to distinguish QoE between of virtual reality and desktop environments [12], between virtual and augmented reality interactions [13] and different affective video content presented in virtual reality (in addition to EEG and electro-oculography, EOG) [14]. A recent, extensive study by Chessa et al. attempted to evaluate the immersivity of the Oculus Rift and other head-mounted displays for different virtual scenarios (e.g. in view of presence and simulator sickness) by using subjective questionnaires, ECG measurements of heart rate and head movements [15].

C. Influence of screen size and network on immersion

When researching the impact of image quality on video gaming experience, Bracken and Skalski found a significant link between immersion and image quality. Specifically they compared the experience playing video games in standard definition (SD) and high definition (HD) [16].

In a study about immersion in mobile gaming, Beyer et al. [17] demonstrated a link between immersion and screen size when comparing small smart phones to bigger phones and tablets. However, no linear link seemed to exist between gaming QoE and display size; rather, QoE and its sub-dimensions are not influenced by screen sizes larger than a threshold of roughly 5-in.

Huo et al. investigated the effect of two screen sizes, 12.7-in. and an 81-in., and found differences in assessed character evaluation, mood change as well as physical presence and self-presence. However, no significant covariate effect for immersion tendency on players' evaluation of game characters, arousal, or enjoyment of game could be shown [18].

Burns et al. researched gaming immersion assessed with the IEQ for two difference displays, a 40-in. LCD TV and head-mounted display, as well as differences in challenge. They reported significantly higher immersion ratings for an optimal challenge, but no effects due to the used display [19].

Also Lombard and Ditton linked presence to screen size [20] and advised research on physiological measures of presence.

EEG was used in a study by Beyer et al. [21], who examined the influence of very strongly reduced video quality for a first person shooter game in a cloud gaming setup. They suggested significant differences for overall gaming QoE, flow, immersion, tension, positive and negative affects, valence rating as well as in alpha frequency band power.

III. METHODS

A. Participants

To answer the research questions stated in Section I, a subjective experiment was conducted. A total number of 30 participants (10 female, M = 26.7 years, range between 20 to 36 years), with normal or corrected-to-normal vision were tested. Asked about their gaming expertise, 60 % of participants described themselves as "intermediate", 20 % as "novice" and 20 % as "expert" gamers. The majority of participants were foremost PC gamers.

B. Experimental Design and Manipulations

The experiment followed a within-subject design with two within-subject factors. The first factor, *screen size*, was manipulated by presenting the game either on a smartphone display (small), a computer monitor (medium) or on a television monitor (large). The second factor, *network condition*, was manipulated by inducing either bit rate reduction, delay or packet loss. Dependent variables included both subjective measures (overall gaming QoE, video quality, and IEQ) and physiological features extracted from ECG (average heart rate, heart rate variability) and EDA (peaks in skin conductivity, amplitudes of skin conductivity).

Due to reasons summarized in the previous Section, the focus of the present work lies on mental immersion, i.e. immersion related to the mental state of a user caused by the interaction with a game. Therefore, prominent presence questionnaires such as the Presence Questionnaire, ITC Sense of Presence Inventory, and Igroup Presence Questionnaire (IPQ) (see [10]) were not considered suitable. Instead, the Immersive Experience Questionnaire (IEQ) was selected as measuring instrument, which was specifically designed for the subjective assessment of immersion in gaming and is covering several features related to mental immersion. According to Jennett, immersion in the application domain of gaming can be decomposed into cognitive involvement, real world dissociation, emotional involvement, challenge, and control; each dimension of gaming immersion can be captured via IEQ [8].

In addition, overall gaming QoE and video quality were assessed using the extended 7-point continuous rating scale (with labels "extremely bad", "bad", "poor", "fair", "good", "excellent", "ideal"), as proposed in [10]. To avoid confusion by using differently designed scales, we adjusted the discrete 7-point IEQ scale by also applying the extended continuous scale. An example of this scale design is shown in Figure 1.

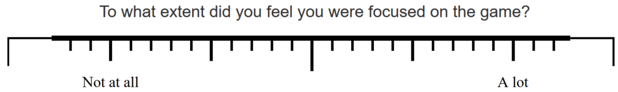

Fig. 1: Seven-point extended continuous rating scale for IEQ. The example shows an item to assess cognitive involvement.

By following a multi-method approach, the present paper complements subjective assessment using the IEQ with two physiological methods, ECG and EDA, to gauge gaming experience through post-hoc ratings and recorded emotional responses. Corresponding effects and correlations between subjective IEQ measures and physiological features promise to improve the convergent validity of the derived interpretations.

C. Experimental Setup

During the experiment, participants played a game called Rogue Legacy™. This game is an action platformer positioned in the Rogue-like genre. As such, the game is moderately delay-sensitive, with abstract graphics. It offers a tutorial level that includes all necessary information about the gameplay controls, which further give an introduction about the game's story, aiming for emotional attachment of the player. Like most rogue-like games, Rogue Legacy™utilizes procedurally generated levels, that is, it uses a building block pattern to generate the game world. Thus, the world is functionally different for each run of the game, while still being very similar. Apart from the interesting story and well-known mechanics, this characteristic was a major reason for the selection of the game, as comparable scenarios are generated which would not be entirely known to the players (potentially leading to boredom), but also not be entirely new for each interval.

The game was always played using a regular keyboard as input device. For the experiment, the game was executed on a server machine. This machine was a sufficiently powerful Windows PC, running on an Intel i5 4460 processor, 32GB RAM and an Nvidia GeForce GTX 1060 graphics card. The client machine was equipped with the same specifications as the Server PC, but using an Nvidia GeForce GTX 960. The two machines were connected via a local LAN network and all input and output took place on the client.

As a cloud gaming system, Steam™'s In-Home Streaming was used. For the *reference* network condition, a bit rate of 50.000 kbps and 1080p resolution at a frame rate of 60 fps was used. For simulations of a limited bandwidth, Steam™'s console on the client was used to reduce the *bit rate* to 1000 kbps. For the remaining network impairments we wanted to simulate, the network emulator Clumsy was utilized to introduce a *delay* of 200 ms (round-trip time) to the network or to simulate a *packet loss* rate of 10 %. For the latter, a small initial delay of 20 ms was induced to prevent an unrealistic error concealment available due to the use of a local network.

The packet loss condition caused strong jerkiness in the video but did not influence the amount of control packets send. Even though, using Clumsy and constant values for delay and packet loss does not represent real network very well, we considered these simulations to be sufficient as we solely attempted to create a noticeable difference in video and interaction quality. The following three screen sizes were used in the experiment: 5" (Sony Xperia XZ), 24" (Asus VG248QE) and 40" (Samsung UE40D6500). The phone display was connected to the PC using a USB 3 cable and the app Wired XDisplay. The screens were positioned at different distances from the participant, the 40" being the farthest and the 5" the nearest, adhering to ITU-T Rec. P.910.

To record ECG and EDA signals, medical-grade g.tec hardware and software (g.USBamp, g.TRIGbox, g.Recorder) were employed. ECG electrodes were placed according to Einthoven lead I, on wrists and the side of the neck. EDA was recorded from the middle and ring finger to enable better flexibility in finger movements during gameplay.

D. Experimental Procedure

The experimental procedure followed the ITU-T Rec. P.809 [10]. It started with general questions about demographics and video gaming preferences. Next, the participants were hooked up to the physiological measurement equipment and told to sit still and relax for the physiological baseline measurement. Afterwards, they played the tutorial level of Rogue Legacy™ to learn the controls of the game. They were told to ask questions about the gameplay while playing the tutorial, to avoid interrupting the evaluated play intervals later on. After finishing the tutorial, participants played the game under all four network conditions for a selected screen size. The procedure was then repeated for the remaining screen sizes. The order of conditions was randomized across participants. Each play interval was five minutes long to allow enough time to fully engage in the game. Participants started a condition via keypress. Each condition ended with the screen fading to gray and pausing the game to avoid an abrupt break potentially influencing immersion-related aspects. After each interval, participants answered digital questionnaires on a separate laptop.

IV. Results

To examine the influence of *screen size* and *network condition* on subjective ratings of gaming QoE, video quality and IEQ scales as well as physiological features (ECG, EDA), multiple two-way repeated-measures analyses of variance (ANOVAs) were computed. Post-hoc pairwise comparisons were calculated and Bonferroni-adjusted for multiple testing. It must be noted that for the calculation of the IEQ scores, mean values of all items for the corresponding factors (cf. [8]) were calculated. Furthermore, a correlational analysis was performed to interrelate subjective and physiological measures; the p values of Pearson correlation coefficients were adjusted for multiple tests with the Holm correction. Results from the ANOVAs are listed in Table I, the arithmetic mean (M) and standard error of the mean (SEM) values for gaming QoE and IEQ total are depicted as a bar plot in Figure 2.

A. Impact on subjective measures

Gaming QoE: Mean ratings of gaming QoE for all conditions using the small screen (M = 3.848, SEM = 0.149) are significantly lower compared to the medium screen (M = 4.244, SEM = 0.128), but not compared to the large screen (M = 4.074, SEM = 0.155). However, this main effect is solely caused due to significantly lower ratings while using the small screen size compared to the medium screen sizes ($p < .05$) and compared to the large screen size ($p < .01$) during the reference network condition. Independent of screen size, mean ratings of gaming QoE for the reference condition (M = 4.620, SEM = 0.160) are not significantly higher than those of the reduced bit rate condition (M = 4.301, SEM = 0.153), but a statistically significant difference exists between the reference condition and the packet loss (M = 3.343, SEM = 0.201) as well as the delay (M = 3.958, SEM = 0.169) condition. Especially for the packet loss condition, significantly lower gaming QoE ratings are observable compared to the other conditions for all screen sizes. Interestingly, due to lower ratings of the references condition for the small monitor, no significant differences compared to the delay condition can be seen for this screen size.

Video Quality: While no main effects of screen size can be found for the video quality ratings, the ANOVA implied a tendency for an interaction between screen size and network condition, $F(6,174) = 1.932$, $p = 0.078$, $\eta^2 = 0.06$. Pairwise comparisons revealed a difference between the small and large screen size for reduced bit rate, $p = 0.011$. All network conditions are significantly different from each other.

IEQ total: For the means of total IEQ immersion score, no main effect of the screen size can be found. Yet, once again, a tendency for an interaction between screen size and network condition can be seen, $F(5.51,159.72) = 1.883$, $p = 0.086$, $\eta^2 = 0.06$. Pairwise comparisons show significant lower immersion ratings for the small screen size compared to the medium size ($p < .01$) as well as to the large size ($p < .01$). For the network conditions, a main effect can be found which is caused by the significant differences between the reference condition and the packet loss condition ($p < .01$) as well as compared to the delay condition ($p < .05$). Also, between the low bit rate condition and packet loss condition, a significant difference was revealed ($p < .01$).

IEQ Cognitive: While the ANOVA did not yield a main effect for the screen size, it revealed a main effect of the network condition due to significant differences between the packet loss condition (M = 4.190, SEM = 0.138) and the reference condition (M = 4.729, SEM = 0.131) as well as with the reduced bit rate condition (M = 4.596, SEM = 0.127).

IEQ Dissociation: The ANOVA yielded a small yet significant main effect of real-world dissociation ratings for the small screen size (M = 3.835, SEM = 0.143) and the medium screen size (M = 4.165, SEM = 0.149), $p < .001$, for the reference network condition.

TABLE I: Main effects of screen size and network condition based on results of two-way repeated measure ANOVA. Significant differences are highlighted in bold. In cases of violation of sphericity based on Mauchly's test, degrees of freedom are corrected using Greenhouse-Geisser (for epsilon smaller .75) or Huynh-Feldt correction. The effect size is denoted by η^2.

Factor	Screen Size					Network Condition				
	F	df_1	df_2	p	η^2	F	df_1	df_2	p	η^2
Gaming QoE	3.83	2	58	**.028**	.117	14.43	2.02	58.58	**<.001**	.332
Video Quality	0.44	2	58	.648	.015	24.26	2.54	73.60	**<.001**	.455
IEQ total	2.55	2	58	.087	.081	10.49	1.84	53.46	**<.001**	.266
IEQ Cognitive	0.67	2	58	.514	.023	8.26	2.17	62.80	**<.001**	.222
IEQ Dissociation	3.74	2	58	**.030**	.114	4.09	1.81	52.44	**.026**	.124
IEQ Involvement	2.37	2	58	.102	.076	10.47	1.91	55.34	**<.001**	.263
IEQ Challenge	1.81	1.66	47.05	.181	.059	4.67	1.78	51.55	**.017**	.139
IEQ Control	1.64	2	58	.203	.054	11.68	1.89	54.73	**<.001**	.286

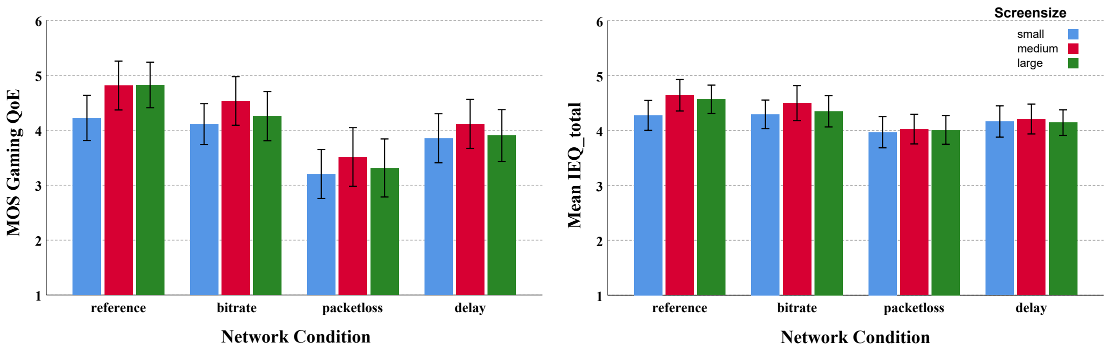

Fig. 2: Bar plots of means and 95 % confidence interval for gaming QoE (left) and IEQ total (right) for different screen sizes (small, medium, large) and network conditions (reference, i.e. no impairment, reduced bit rate, added packet loss, added delay).

IEQ Involvement: Significant differences were also shown for the involvement ratings between the reference network condition (M = 4.504, SEM = 0.163) compared to the packet loss condition (M = 3.887, SEM = 0.161, p = 0.003) and delay condition (M = 4.107, SEM = 0.143, p = 0.012). However, main effects resulted due to a change in the screen size.

IEQ Challenge: For the challenge ratings, no main effect for the screen size was observed. However, a small main effect of the network conditions was shown due to significant differences between the reference condition (M = 4.461, SEM = 0.100) and the packet loss condition (M = 4.246, SEM = 0.104), p = 0.026.

IEQ Control: A significant main effect of the control ratings was found for the comparison of the reference condition (M = 4.584, SEM = 0.130) with the packet loss condition (M = 3.905, SEM = 0.139, p < .001) as well as with the delay condition (M = 4.162, SEM = 0.123, p = .016).

B. Impact on physiological measures

Statistical analysis of the gathered physiological data demonstrated only a single statistically significant effect of *network condition* on heart rate variability, $F(3,87) = 4.925$, p = .008, $\eta^2 = .02$. Pairwise comparisons yielded a significant contrast between the reference (M = 0.006, SEM = 0.001) and packet loss condition (M = 0.002, SEM = 0.001, p = .017).

The correlational analysis suggested significant relationships between heart rate variability and subjective measures for *IEQ total* (r = .21, p < .01), *IEQ Cognitive* (r = .22, p < .01), *IEQ Involvement* (r = .19, p < .01), *IEQ Challenge* (r = .16, p < .01) and *IEQ Control* (r = .23, p < .01). Besides, a significant correlation with *Gaming QoE* was found (r = .12, p = .02).

V. Discussion and Conclusion

Overall, our work confirms findings by Beyer et al. in 2014 [17], as all screen sizes used in our research were larger than 5-in. and no significant differences of *screen size* on immersion was observed—apart from real world dissociation, which is a construct not covered by the GEQ used in [17].

However, our findings are not in line with the work of Beyer et al. in 2015 [21], who reported significant differences for overall gaming QoE and immersion caused by a reduction of video quality. While the video quality was also significantly lower due to bit rate reduction and packet loss in our research, the impact was much lower than in the study presented in [21]. In both studies, a bit rate of 1000 kbps was chosen, leading to a video quality MOS of 1.4 in [21] and 3.0 in the present study. This deviation is presumably caused by the fact that different cloud gaming systems were used, especially with different presets (ultrafast compared to llhq) and resolutions, and as the encoding complexity of both games was different.

Apparently, the impact on immersion in [21] was not solely caused by a reduction in video quality but rather in interaction quality; under such low video quality, the usability of the system would be strongly harmed, which was not the case in our study. This explanation seems plausible, given that the strongest influence on immersion was caused by packet loss leading to strong jerkiness and thus unreliable visual feedback from the game. It also confirms findings by Burns et al. [19], who reported an impact of challenge, but not of screen size on immersion (assessed via IEQ). Therefore, the content and playability of a game might contribute more to gaming immersion than network conditions which still allow for sufficient interaction with the system. This insight might have consequences for the development of prediction models of gaming QoE in the context of cloud gaming services, such as ITU-T Rec. G.1072, because an in-depth assessment of different screen sizes would not be required. Accordingly, a model developed for desktop monitors might as well be applicable to other screen sizes.

From all extracted physiological features, only heart rate variability turned out to be significantly affected by *network condition*. This main effect was further substantiated by significant correlations of heart rate variability with various subjective measures, including total IEQ and gaming QoE. Therefore, this ECG feature might prove useful for future studies on mental immersion, complementing more traditional subjective measures in a multi-method assessment approach.

In general, the identified effects of *screen size* and *network condition* on mental immersion were rather small, as indicated by low effect size values reported ($\eta^2_{max} = .27$) and only minor differences in means for IEQ between the reference condition using the medium screen ($M = 4.641$) and the packet loss condition using the small screen ($M = 3.967$). When comparing this difference with the much larger differences in means for gaming QoE between the reference condition using the large screen ($M = 4.82$) and the packet loss condition using the small screen ($M = 3.20$), it appears that immersion alone is not sufficient as a single predictor for gaming QoE.

It must be noted that the generalizability of the present findings remains limited, since only a single game was used, which was not highly complex and unknown to participants. Moreover, the need for active gameplay caused considerable manual motor activity, which most likely increased noise levels in the recorded physiological signals. As a consequence, the statistical power to detect smaller effects on other physiological features besides heart rate variability might have been reduced. To induce a higher variability in immersion ratings, alternative game contents might be considered to eventually allow for an improved investigation of the relationship between subjective and physiological measurements. In addition, interaction in a controlled lab environment might have limited the degree of evoked immersion; also, only a small range of possible technical parameters was investigated. Addressing these important limitations and taking other related concepts like flow into account could lead to more insightful future research.

ACKNOWLEDGEMENTS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 871793.

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