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When playing action video games, an optimal experience implies the presence of a head-up display that informs players on their status in regard of their goal like health points or their localisation in the environment. However, how can this type of information can be integrated in new gaming contexts like virtual reality? Should this information be integrated into the game universe (diegetic design) or stay out of it (non-diegetic design)? For this purpose, the performance, presence and enjoyment of 41 players have been measured during a virtual reality first-person shooter game session with a diegetic and a non-diegetic interface. The results showed that diegetic integration has a positive effect on the player's performance but not on the subjective experience (presence and enjoyment). The study also shed light on the moderator role of expertise in action games on this effect because the diegetic interface only benefited novice players.

Keywords: head-up display; action game; diegetic; presence; enjoyment

1. Introduction

Video games have about 2.2 billion adepts around the world that have generated over 73 billion US dollars in turnover during 2019, which could lead to a market volume of 83 billion dollars by 2023 (Statista, 2019). Among US gamers, 26% of PC gamers play between 1 and 2 hours weekly and 21% of console gamers spend more than 10 hours per week (Padilla, 2018). Video gaming is, for sure, part and parcel of many people's life. Given this importance of video games, a certain amount of research in human factors and ergonomics (HF/E) has been focused on the optimization of the player-game interaction. To achieve this goal, one must already understand the effect of the game on the player's cognitive system, especially the effect of visual information sent through the game screen. Given the growing importance of video games in the industry, it is interesting to understand this impact of visual information so that the game's visual architecture alters the player experience as little as possible, especially when it comes to providing players with information on their status (such as score, hit points, remaining ammunition, map of the game environment, etc.). This information, often placed in a head-up display (HUD) with words, numbers or graphics, is very important for players to know if they will be able to achieve their goal and how to adjust their behavior (e.g. increase the caution with which they advance in the game since their hit points are low to avoid dying). In traditional HUDs, this "non-diegetic" information is outside the game's universe and superimposed on the action area, i.e. outside the diegesis, "the game's total world of narrative actions" (Galloway, 2006, p.7). This information can also be integrated into the game's universe and story by being visually materialized in the game space to be accessible to the game characters and make sense to them. The variation in the player's health, for example, could be represented by a change in the number of injuries on the body of the avatar. This latter, so-called "diegetic", way of integrating this information is often considered intrinsically better than other ways (especially for the feeling of presence) and non-diegetic information would distract the player (e.g. Cudworth, 2014; Tach, 2013; Wilson, 2015). Nevertheless, this is a belief among actors of the video game industry that are not based on any human-centered scientific evidence. Moreover, this question is getting more complex considering new types of human-machine interface that include virtual reality headsets. In 2016, gamers have seen the emergence of technologies such as HTC Vive, Oculus Rift or PlayStation VR. These devices offer innovative ways to immerse oneself in a virtual environment but pose new constraints in the information display compared to traditional games with 2D displays. This question of diegetic integration is particularly important with VR because if it is found to have a real effect on presence, it is important to control it in VR, where presence is more central than in traditional games. Despite the current success of this technology, the issue of HUD in these environments remains unexplored. How can all the essential HUD elements be made accessible so that the player can have a good experience in a much less limited field of view than on a standard screen? The current study proposes to scientifically approach these problems in the light of cognitive psychology and HF/E in order to determine the impact of a non-diegetic or a diegetic design choice on players' cognitive processes, especially on their way of distributing attention and their subjective experience with the game.

2. Literature review

2.1. Video game and players

2.1.1. Video game and attention

The visual interface of a video game is often composed of a main action scene, itself composed of objects with which the player must interact, and a complex moving background. The interface also consists of a HUD that provides contextual information on the current situation of the player (such as score or hit points).

Most of the time, this interface is dynamic and complex, therefore the processing of information may not always be easy. In a classic action game, the player may watch for the occurrence of movements in the action scene while monitoring the evolution of its status indicated by the HUD. In this type of environment, attention is therefore very much at work. Theoretical models like the SEEV (Salience, Effort, Expectancy, Value) model (Wickens, Helleberg, Goh, Xu, & Horrey, 2001; Wickens, 2008; Horrey, Wickens, & Consalus, 2006) may help to understand how an individual facing a visual interface distributes its attention between several "areas of interest" or AOIs. In this model, four elements are supposed to influence the probability of directing attention to an AOI: salience (i.e. the degree with which an object automatically captures attention), effort (i.e. the physical distance between two AOIs), expectancy (i.e. the expectation created by the individual on the probability of seeing an event in an AOI) and value (i.e. the relevance of an AOI for the current task).

Although the model was designed to explain the distribution of visual attention among airplane pilots, it can be used in other contexts such as car driving (Horrey et al., 2006). Given this possibility of extension to other contexts, one can easily imagine this model applied to action video games, as it is known that changes in the characteristics of the visual interface can translate into changes in the way to distribute one's attention on this interface. For example, in a Clark and Jie (2007) study, during a shooting task, the complexity of a visual scene (i.e. the entropy of the image) influenced the time the players took to disengage their attention from a certain point (in order to shift this attention to an enemy that appeared on the screen).

A poorly designed interface can therefore generate attentional allocation difficulties that affect the player's performance. This can however be modulated by the level of expertise of the user.

2.1.2. The role of expertise

Expertise is another variable that can influence the processing of visual interfaces in action video games. In their study, Bonny and Castaneda (2016) asked experts in MOBAs (i.e. Multiplayer Online Battle Arenas) and novices to memorize the status and positions of buildings and characters on the mini-map of the game. It turned out that the experts were better than the novices to memorize this information when it corresponded to possible game situations. This superior sensitivity to coherent information is due to the wealth of their knowledge in the field (i.e. probability of occurrence, rules of the game), acquired implicitly over their experiences.

Beyond that, having experience in action video games improves selective attention in general. Indeed, according to Green and Bavelier (2003), experts in action video games have more attentional resources than non-players, as evidenced by their ability to better focus on distracting elements despite the increasing difficulty of a task. They also have a better ability to distribute their attention in space with their larger attentional field that allows them to detect objects without moving their eyes (Green & Bavelier, 2003; 2006). Experts also seem to be able to process more information over time thanks to their smaller attentional blink (Green & Bavelier, 2003). According to a study by Castel, Pratt, and Drummond (2005), action video game players also have a shorter response time than non-players in target visual search tasks and more generally in visual attention tasks.

2.1.3. Video games and player experience

Video games are a special kind of software. Researchers in human-computer interaction have therefore increasingly turned to more appropriate concepts than usability to describe this interaction such as the user/player experience (Caroux, Isbister, Le Bigot, & Vibert, 2015).

Concepts like presence can be part of this experience. Presence is the feeling of being inside the displayed virtual environment (Slater & Wilbur, 1997). For the user, what is displayed gives the feeling of visiting places rather than watching a simple succession of images and the virtual body and its movements are identified as its own body and its own movements. This presence is multidimensional and authors like Makransky, Lilleholt and Aaby (2017) use the concepts of physical presence (e.g. the sense of physical realism, the absence of attention toward the outside world, the non-awareness of physical mediation), social presence (e.g. the feeling of coexisting with other beings) and self-presence (e.g. the sensation of extension and prolongation of the body in the avatar). This presence is a psychological subjective response to immersion (Bowman & McMahan, 2007), the latter being what delivers the technology from an objective point of view (Mestre, 2005), the ability to "cover" our sensory modalities, to faithfully simulate the information of a certain modality (Slater & Wilbur, 1997). Nevertheless, this does not prevent some authors from using the term "immersion" to speak of a psychological phenomenon, which is the case for some works cited in this paper. For our part, we will only focus on the concept of presence.

Presence must be differentiated from other aspects of gaming experience such as the more specific concept of perceived realism, which refers to the subjective realism of the virtual world that users feel (Malliet, 2006). Presence must also be distinguished from the state flow, which is more defined in terms of positive emotions. It is a euphoric state of concentration and involvement, often presented as one of the most enjoyable and valuable experiences one can have (Csikszentmihalyi, 1990). Presence is a sensation of “being there”, flow is associated with an altered state of consciousness (e.g. loss of the notion of time and of one’s own consciousness; Michailidis, Balaguer-Ballester, & He, 2018).

Moreover, presence is linked to attention: according to Witmer & Singer (1998), cognitive involvement is one of the prerequisites of presence. In other words, the attentional focus on a set of coherent and meaningful stimuli would be needed to construct a coherent representation, a mental model. The player should therefore also inhibit inconsistent information. Furthermore, it has been shown that people who have difficulty making mental models would feel less involved in the virtual environment (Lackner & DiZio, 1998).

Enjoyment can also be part of the player experience. It is the degree to which the player has fun while playing the game. According to authors like Fang, Susy, Jacek, and Chitra (2010), enjoyment has an affective dimension that corresponds to emotions and affective states during the game, a cognitive dimension that relates to judgments of the game’s elements (e.g. story coherence, message quality, relevance), and a behavioral dimension, that is, behavioral responses to the game.

It has been shown that the arrangement and the nature of the information provided in the interface has an influence on presence and enjoyment. For instance, Hou, Nam, Peng, and Lee (2012) showed that playing with a large video-projection type display produces more presence than on a traditional TV screen. In the same way, Schuemie, Van Der Straaten, Krijn, and Van Der Mast (2001) indicated that a high resolution and the representation of a virtual body promotes presence. In a study of Yannakakis, Martínez, and Jhala (2010), players had to move a ball through a 3D maze while avoiding predators and retrieving items that increased the score. The results showed that the camera viewpoint above the ball had an impact on specific dimensions of the player's enjoyment like fun, frustration or relaxation.

It has to be kept in mind that presence and enjoyment can be linked. In games based on motion controllers' interactions, high levels of presence appear to be associated with high levels of enjoyment, compared to interactions with simple joysticks (Shafer, Carbonara & Popova, 2011). The same type of link can be found in a study of Skalski, Tamborini, Shelton, Buncher, and Lindmark (2010) where the most realistic interaction modes (i.e. using a wheel in a racing game) produce higher level of presence and thus higher level of enjoyment compared to natural controls. For Tamborini and Bowman (2010), graphics quality, sound, haptic simulations, active participation and natural interaction modes make players more present and lead to a more physically challenging and psychologically stimulating experience.

2.2. Head-Up Display

As mentioned in section 1, for the game experience to be optimal, the player must interact with a carefully designed HUD. Several studies have shown that the nature and the disposition of information in this part of the interface have an influence on the player's experience and performance (Caroux & Isbister, 2016; Sabri, Ball, Fabian, Bhatia, & North, 2007; Caroux, Le Bigot, & Vibert, 2011). Caroux and Isbister (2016) observed more eye fixations on the HUD of a RTS (Real-Time Strategy) game than on the HUD of a FPS (First-Person Shooter) game. The interviews then showed that the players found the RTS HUD more useful. This corroborates the SEEV model (Wickens et al., 2001; Wickens, 2008; Horrey et al., 2006), because the more the HUD was salient (here, larger) and valuable, the more attention was focused on it. Then, for a game where the HUD is important (RTS), the more the player's expertise is high, the more the HUD has an effect on the player experience. The players also prefer when the main and secondary HUD elements are present and when the information is horizontally aligned. This familiarity effect seems particularly present among the experts. It has also been shown that the anticipation is facilitated (i.e. increase in the number of fixations in the anticipation area) and the performance improved when the HUD is located near an area where important information is expected to appear (Caroux et al., 2011).

2.3. HUD and diegesis

Usually, the information in the HUD is non-diegetic (Fig. 1) and according to a rather instinctive postulate, a diegetic interface (Fig. 2) would be preferable and more immersive than a non-diegetic interface. It is for this purpose that some games have totally or partially integrated information classically in HUDs into the narrative. The most famous case is Dead Space (Electronic Arts, 2008), which places the life bar on the armor of the character. Another example can found in Metro 2033 (4A Games, 2010), where players have to look directly at the magazine of the weapon to have access to the amount of remaining ammunition.

Figure 1. Resident Evil 5 (Capcom, 2005) screenshot. This game uses a non-diegetic interface (with a map at the top right and the ammo, the hit points and the equipped weapon at the bottom right).

Figure 2. Dead Space (Electronic Arts, 2008) screenshot. This game uses a diegetic interface to show the health points (on the spine of the avatar).

This diegetic design was mainly chosen for aesthetic reasons, but, because it was not based on scientific decision criteria and models of human information processing, there is no evidence that these artistic choices have no adverse influence on the player. This is what authors like Iacovides, Cox, Kennedy, Cairns, and Jennett (2015) tested. In their study, removing non-diegetic elements increased immersion (their measure of immersion corresponds to the definition of presence we used in the present study in subsection 2.1.3) only from a certain level of expertise. Without HUD, with the diegetic interface, experts were less distracted by peripheral elements than novices were (i.e. higher cognitive involvement scores), they felt the game to be easier to use and their performance was facilitated. However, this was not the case for novices, the presence of a traditional HUD was essential for them, it gave them important information that, if absent, significantly altered their gaming experience. For experts only, Peacocke, Teather, Carette, and MacKenzie (2018) came to relatively similar conclusions for a first-person shooter task: ammo monitoring performance was higher when the ammo count was diegetically incorporated onto the weapon but it was not always the case for tasks with other indicators (e.g. for health monitoring). Babu (2012), found no difference in these experts' presence level between the diegetic or non-diegetic condition. However, the strongest limitation of this study was that the diegetic game was different from the non-diegetic game. Results like those of Fragoso (2014) can also nuance: for participants interviewed after playing a video game with a diegetic or a non-diegetic interface, the non-diegetic HUD was not considered as interfering (and was sometimes preferred to a diegetic interface) as long as it did not break the functional and aesthetic coherence of the interface. This would show that the players prefer a clear and functional interface, which allows information to be "explicit, easy to find and monitor over time". However, since this qualitative study is based on a small sample, these results do not tend to be generalized.

2.4. Specificities of virtual reality

According to Parisi (2014), what is called "virtual reality" (VR) refers to a set of technologies whose primary purpose is to make one believe to be elsewhere, generally by using a stereoscopic display (which gives an illusion of depth) with a headset, a motion tracking device and a conventional joystick or hand and body movement sensors to interact with the virtual environment. The central goal of virtual reality is to maximize the probability of emergence of the illusion of being in the virtual world that is presented while the user is not really there (i.e. a feeling of presence) by using different equipment from traditional gaming.

One of the peculiarities of a VR visual interface is that it offers a much wider field of view (up to 120°) than simple monitors (around 25°). In such interfaces, information clutter can be reduced and spatial understanding can be increased thanks to that larger field of view (Bowman & McMahan, 2007). In video games interfaces with a HUD, it is a bit different. Virtual reality gaming can be categorized as high resolution gaming because the visual interface exceeds the player's visual field, and it is known that this type of display causes specific problems potentially linked to the HUD. Sabri et al. (2007) observed that, on a RTS game with a multi-monitor display, the players had a better battlefield awareness compared to a display on a single screen. However, they were less aware of the HUD elements, which are peripheral to the action scene (i.e. the battlefield). It is therefore necessary to bring this information near the cursor. These HUD awareness deficits can be explained by the SEEV model’s effort: the attentional movements to be made is too high to reach the HUD, which reduces the probability to reach this area and to have a good overall picture of the situation in the game.

Concerning the differences between VR and traditional games, McMahan et al. (2012) found interesting results for a first person shooting task by varying the display fidelity (a projection onto one wall vs 6 walls with stereoscopic display) and the interaction fidelity (a classic mouse and keyboard vs the actual movements of the player). The best performances appeared for low display fidelity with low interaction fidelity (as often in classic FPS games) and for high display fidelity with high interaction fidelity (as in VR games). The high display and interaction fidelity condition also produced the highest level of presence, involvement and usability. For an equally performance-intensive context, Pallavicini, Pepe, and Minissi (2019) found no difficulty differences between VR and desktop display, but VR produced a more intense emotional response (on subjective and physiological measures) and presence.

3. The present study

The aim of the present research was to study how the degree of integration of the HUD information into the game's diegesis impacted the performance and the player experience in new gaming virtual environment like VR where this question remains unexplored. For this purpose, a FPS VR mini-game was created with two types of interface, a diegetic one (i.e. indicators on the weapon) and a non-diegetic one (i.e. indicators in a HUD). In this study, diegetic integration was manipulated by varying the location of information into the game's three-dimensional space, as it is the most common way in video games to integrate information into diegesis (see section 2.3), and a good way to limit the variation of other game elements that could have unpredictable effects on the player.

Because in diegetic interfaces HUD information can be arranged on the character or the player's weapon (unlike non-diegetic ones where information is usually scattered around the screen), the cost of attentional movements between the action scene and HUD information should be reduced and therefore performance should be improved. Moreover, because of what is known about action game experts and their attention skills and memory patterns, only them could benefit from a performance improvement in diegetic interfaces.

H1: Players perform better in diegetic interfaces than in non-diegetic interfaces but only if they are action game experts.

A link between the effect of diegetic integration on performance and its effect on presence can be expected as attention is linked to presence (Lackner & DiZio, 1998; Witmer & Singer, 1998). Players should direct their attention towards elements more coherent with the diegesis of the game than in the case of a non-diegetic interface which could remind players they are in front of an action video game, disengaging them from the diegesis. Furthermore, the literature indicates that classical HUDs in non-diegetic interfaces seem to distract experts and diegetic interfaces would allow them to fully engage in the game and its diegesis, which would increase the level of presence. On the other hand, novices would need conventional non-diegetic interfaces providing help and clear feedbacks, enabling them to create a good mental model.

H2: Players facing a diegetic interface feel more present in the game than those facing a non-diegetic interface but only if they are action games experts.

No study has specifically studied the effect of diegetic integration on the player's enjoyment but it seems that enjoyment is positively predicted by presence (Shafer, Carbonara, & Popova, 2011; Skalski, Tamborini, Shelton, Buncher, & Lindmark, 2010; Tamborini & Bowman, 2010). Therefore, it appears reasonable to expect that enjoyment will vary in the same way as presence.

H3: As presence predicts enjoyment, players facing a diegetic interface have higher levels of enjoyment than those facing a non-diegetic interface but only if they are action games experts.

4. Material and methods

4.1. Participants

Forty-one participants, including 15 women and 26 men, were recruited, with an average age of 22.5 years (SD = 3.39). They were recruited on a voluntary basis through social networks and on the university campus. They were requested to indicate the number of hours spent playing action games over the last 6 months. At least 4 hours of gaming per week were necessary to belong to the action video game expert group and at most 1 hour per month for the novice group in the last 6 months (Castel et al., 2005). The sample was composed of 21 experts and 20 novices. Among the action games mentioned in the questionnaire could be found Counter Strike: Global Offensive, Fortnite, Overwatch, Diablo 3 or the Call of Duty and Battlefield franchises. Only right-handers were selected since the interface was designed to keep the weapon on the right side of the game screen. No participant had VR experience or very little experience (e.g. a single session of 30 minutes).

4.2. Material

For this study, a VR mini-game was created with two different visual interface, a non-diegetic interface and a diegetic interface.

4.2.1. Task

The experimental task was a classic first-person shooter task. This type of performance-intensive task creates enough pressure to engage attentional processes (McMahan et al., 2012). The participants, who had a fixed position in the middle of the virtual environment, had to shoot at targets (i.e. moving black spheres) continuously appearing, rolling then disappearing after a certain amount of time. They were asked to eliminate the targets as quickly as possible. This temporal pressure was materialized by a countdown timer. The task ended when the countdown reached the end. The targets were not necessarily in the players' field of vision, so they had to look at the radar and potentially rotate in order to have the target inside their field of vision and then to shoot. They also had to watch the temperature of their weapon that could stop functioning for a few seconds if it turned red (overheating). It was then necessary for the players to shift their attention to various parts of the interface in order to be able to have a good performance. More particularly, they had to monitor effectively the peripheral elements (i.e. the radar to see where are the targets, the overheating indicator to avoid wasting time, the countdown to monitor the remaining time and the score to monitor the quality of the performance) as well as the action scene where targets appeared. Thus, the task has been designed to direct the players' attention to our characteristics of interest of the interface that are supposed to determine the variations of performance, presence and enjoyment between the conditions.

We made sure to create a task close to what can be found in classic action video games so as to create enough presence and enjoyment to expect significant differences between groups and avoid a floor effect.

4.2.2. Non-diegetic interface

Diegetic integration was manipulated by varying the location of information into the game's three-dimensional space. In the non-diegetic condition, the elements of the HUD were superimposed on the game screen, outside the diegesis (Fig. 3). To comply with the ergonomic criteria from the literature, HUD information was aligned at the bottom of the screen (see familiarity effect in Caroux & Isbister, 2016) and followed the head movements of the player. The HUD was composed of four interface elements. It included a radar indicating the position of the targets, a weapon overheating indicator whose color progressively progressed from green to red as the participant fired without allowing the weapon to cool, a countdown timer, and score bars indicating the number of targets successfully shot.

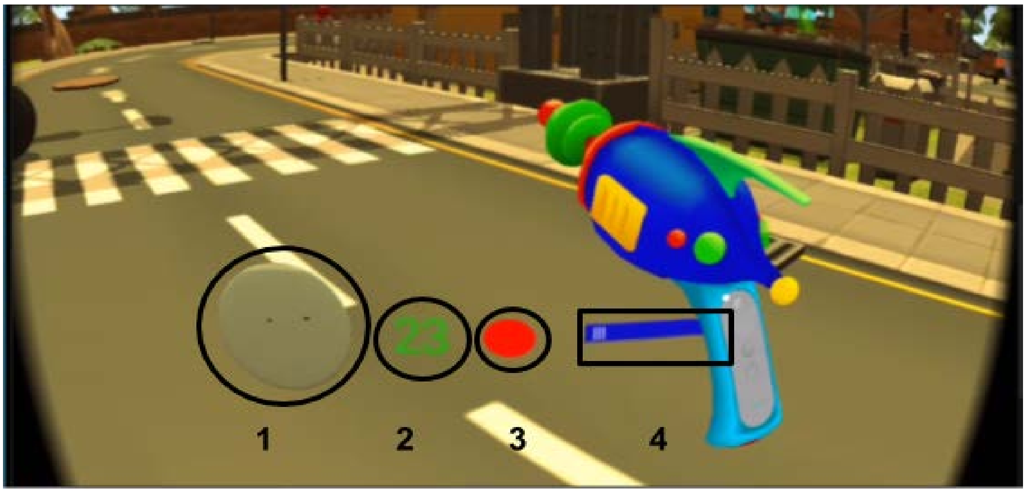

Figure 3. Screenshot of the non-diegetic interface. 1. Radar. 2. Countdown timer. 3. Overheating indicator. 4. Score bars.

4.2.3. Diegetic interface

In the diegetic condition, the interface elements had the same appearance as in the non-diegetic interface, the peculiarity being they were integrated in the game space with the radar hooked on the side of the gun and the overheating indicator on the barrel's end (Fig. 4). In the same way, the countdown and the score were integrated on the back of the weapon. The form of the indicators was carefully controlled between the experimental conditions.

Figure 4. Screenshot of the diegetic interface. 1. Radar. 2. Overheating indicator. 3. Countdown timer. 4. Score bars.

4.3. Experimental design

The experiment was conceived in a 2x2 mixed design with two independent variables, the level of diegetic integration (diegetic vs non-diegetic) as an intra-subject variable, and the expertise (novice vs expert) as an inter-subject variable. Each participant played with the diegetic interface and the non-diegetic interface. To minimize the effects of training, the conditions were balanced between the participants, half of the experts and novices were in the diegetic condition first while the other half were in the non-diegetic first.

4.4. Procedure

4.4.1. Introductory phase

Whatever the experimental condition, participants first had to sign a consent form. A questionnaire asking for demographic information and playing time on action games was administered at the beginning of the experiment to determine their level of expertise.

4.4.2. Familiarization and training phase

All participants went through a familiarization period for 1 minute, where they performed the experimental task without any data collection. The interface elements (*i.e.* radar, timer, score and overheating indicator) were absent from this phase to prevent participants of all groups from reaching maximum performance too quickly, which could make the benefit of each type of interface invisible. This phase was mainly used to familiarize with the controls of the game, the virtual environment and the VR technology. In this phase, players could also practice shooting at targets. Then, just before the first experimental task, the experimenter explained the composition of the interface elements (diegetic or non-diegetic), using a video tutorial. Here, the absence of direct training is justified by the same points mentioned at the beginning of this subsection.

4.4.3. Experimental phase

The participants did the task in one of the two conditions (diegetic or non-diegetic) during which the data collection was carried out during a 5-minute session.

4.4.4. Post-experimental phase

At the end of the experimental task, the presence and the enjoyment questionnaires were administered. The participants then started again the whole procedure (from the video tutorial explaining the diegetic or the non-diegetic interface before the task) for the condition which had not yet been completed (diegetic if they had already passed the non-diegetic and vice versa).

4.5. Measures

4.5.1. Performance

A number of indicators have been taken into account that reflect the way in which the participant distributes the attention on the interface and which can be influenced by the type of interface. We observed the *number of eliminated targets*. The *number of times the weapon overheated* (i.e. each time the overheating indicator became red) and the *number of time the weapon reached an intermediate temperature* (i.e. each time the overheating indicator became orange) were also taken into account. The *number of shots fired* was also observed to find out how the player handled the overheating constraint. The *player-to-target distance* was measured for all shots, for eliminations, when the weapon reached an intermediate temperature and when it overheated. Finally, *reactivity* was measured, that is to say the length between the shot and the appearance of each new target.

4.5.2. Presence

To evaluate the level of presence, we used the Multimodal Presence Scale of Makransky et al. (2017) as described in subsection 2.1.3. This scale was specifically developed and validated for virtual reality environments. In addition, it allows to split and to compare the different types of presence and to potentially detect a difference between the conditions on a particular type of presence. It contains items related to physical presence, social presence and self-presence rated on a 5-points Likert scale (1 = strongly disagree, 2 = somewhat disagree, 3 = neither agree nor disagree, 4 = somewhat agree, 5 = strongly agree). As the present game did not involve social interaction, the choice has been made to focus only on physical presence (5 items) and self-presence (5 items).

4.5.3. Enjoyment

Enjoyment was measured by 11 items from the Fang et al. (2010) questionnaire, which measures the affective, behavioral and cognitive dimensions of this aspect of the player's experience in a video game. Each item is rated on a 7-points Likert scale (1 = strongly disagree, 2 = disagree, 3 = somewhat disagree, 4 = neither agree nor disagree, 5 = somewhat agree, 6 = agree, 7 = strongly agree).

5. Results

All statistical tests were computed using IBM SPSS Statistics Version 20.0 (IBM Corp, 2011).

5.1. Performance

A mixed 2 (expertise) x 2 (type of interface) ANOVA was conducted on each performance measures.

5.1.1. Number of eliminations

As shown in Table 1, the type of interface did not have a significant effect on the number of eliminated targets. On the other hand, the level of expertise had a significant effect. More precisely, as indicated in Table 2, the experts have eliminated more targets than the novices regardless of the type of interface. No significant interaction effect between expertise and type of interface was found for eliminations.

Table 1. ANOVA results for dependent measures of players' performance

Independent variable	**Measure of performance**	***F***	***df***	***p***	**η^2_p**
Level of expertise	Number of eliminated targets	**21.7**	**1,39**	**<.001**	**.357**
	Intermediate temperature (number of occurrences)	**4.31**	**1,39**	**<.05**	**.100**
	Overheating (number of occurrences)	**5.68**	**1,39**	**<.05**	**.127**
	Number of shots fired	.610	1,39	.440	.015
	Player-to-target distance when intermediate temperature	4.04	1,39	.051	.094
	Player-to-target distance when overheating	**5.19**	**1,39**	**<.05**	**.118**
	Player-to-target distance when elimination	**21.8**	**1,39**	**<.001**	**.359**
	Player-to-target distance when shots fired	1.09	1,39	.303	.027
	Reactivity	1.75	1,39	.194	.043
Type of interface	Number of eliminated targets	.375	1,39	.544	.010
	Intermediate temperature (number of occurrences)	1.24	1,39	.272	.031
	Overheating (number of occurrences)	3.79	1,39	.059	.088
	Number of shots fired	3.51	1,39	.069	.082
	Player-to-target distance when intermediate temperature	.930	1,39	.341	.023
	Player-to-target distance when overheating	3.94	1,39	.054	.023
	Player-to-target distance when elimination	.427	1,39	.517	.011
	Player-to-target distance when shots fired	2.65	1,39	.112	.064
	Reactivity	2.74	1,39	.106	.066
Level of expertise * Type of interface	Number of eliminated targets	.413	1,39	.524	.010
	Intermediate temperature (number of occurrences)	1.40	1,39	.244	.035
	Overheating (number of occurrences)	**5.20**	**1,39**	**<.05**	**.118**
	Number of shots fired	**4.47**	**1,39**	**<.05**	**.107**
	Player-to-target distance when intermediate temperature	1.88	1,39	.178	.046
	Player-to-target distance when overheating	**5.00**	**1,39**	**<.05**	**.114**
	Player-to-target distance when elimination	.346	1,39	.560	.009
	Player-to-target distance when shots fired	**6.02**	**1,39**	**<.05**	**.134**
	Reactivity	1.65	1,39	.206	.041

Table 2. Descriptive statistics for dependent measures of players' performance

	Novice players		Expert players	
	Diegetic interface	**Non-diegetic interface**	**Diegetic interface**	**Non-diegetic interface**
Dependent measure	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
Number of eliminated targets	19.8 (11.3)	17.8 (8.5)	30.1 (8.4)	30.2 (8.8)
Intermediate temperature (number of occurrences)	25.8 (10.9)	29 (10.8)	21.5 (9.1)	21.4 (9.5)
Overheating (number of occurrences)	4.8 (3.7)	6.6 (4)	3.3 (3.3)	3.2 (3.1)
Number of shots fired	89.8 (16.4)	95.8 (12)	90.1 (10.5)	89.7 (11.1)
Player-to-target distance when intermediate temperature	263.1 (109.5)	296.3 (115.2)	223 (94.9)	217.2 (100.9)
Player-to-target distance when overheating	51.5 (39.6)	68.7 (43.4)	35.4 (33.6)	34.4 (33.8)
Player-to-target distance when elimination	192.9 (116.7)	172.9 (90.2)	303.1 (85.3)	302.1 (92.9)
Player-to-target distance when shots fired	932.9 (168.6)	998 (124.8)	932.2 (111.2)	919.1 (118.7)
Reactivity	3821.4 (265.5)	3985.4 (224.8)	3818.8 (202.1)	3838.6 (272.9)

5.1.2. Weapon overheating

Intermediate overheating. The type of interface did not have a significant effect on the number of intermediate overheating (see Table 1). However, there was a significant main effect of the level of expertise as the experts tended to reach less the intermediate temperature than novices (see Table 2). No significant interaction effect was found.

Overheating. The ANOVA performed on the overheating number indicated no significant main effect of the type of interface on overheating (see Table 1). However, the level of expertise had significant effect on overheating, experts tended to reach less the overheating level than novices (see Table 2). The interaction between expertise and type of interface was also significant. The diegetic interface reduced the overheating number when the players were novices but not when they were experts as shown in Figure 5.

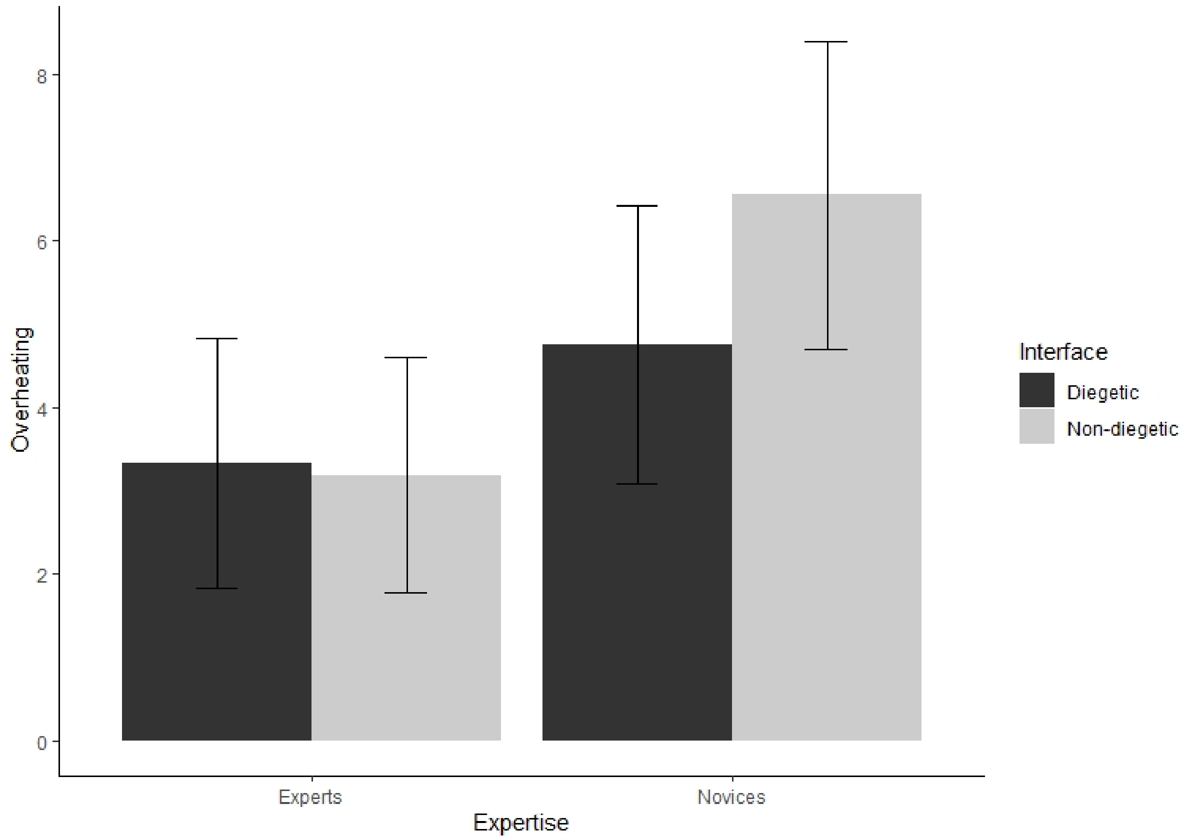

Figure 5. Mean overheating number as a function of expertise and type of interface with 95% confidence intervals.

5.1.3. Number of shots

There was no significant effect of the type of interface on the number of shots with the weapon (see Table 1). This time, the expertise had not a significant effect on this variable either. However, it can be noted that the number of shots was significantly influenced by the interaction between the type of interface and expertise. The type of interface had an impact on the number of shots but only for novice players. There was no significant variation of the number of shots between conditions for experts. This interaction is represented in Figure 6.

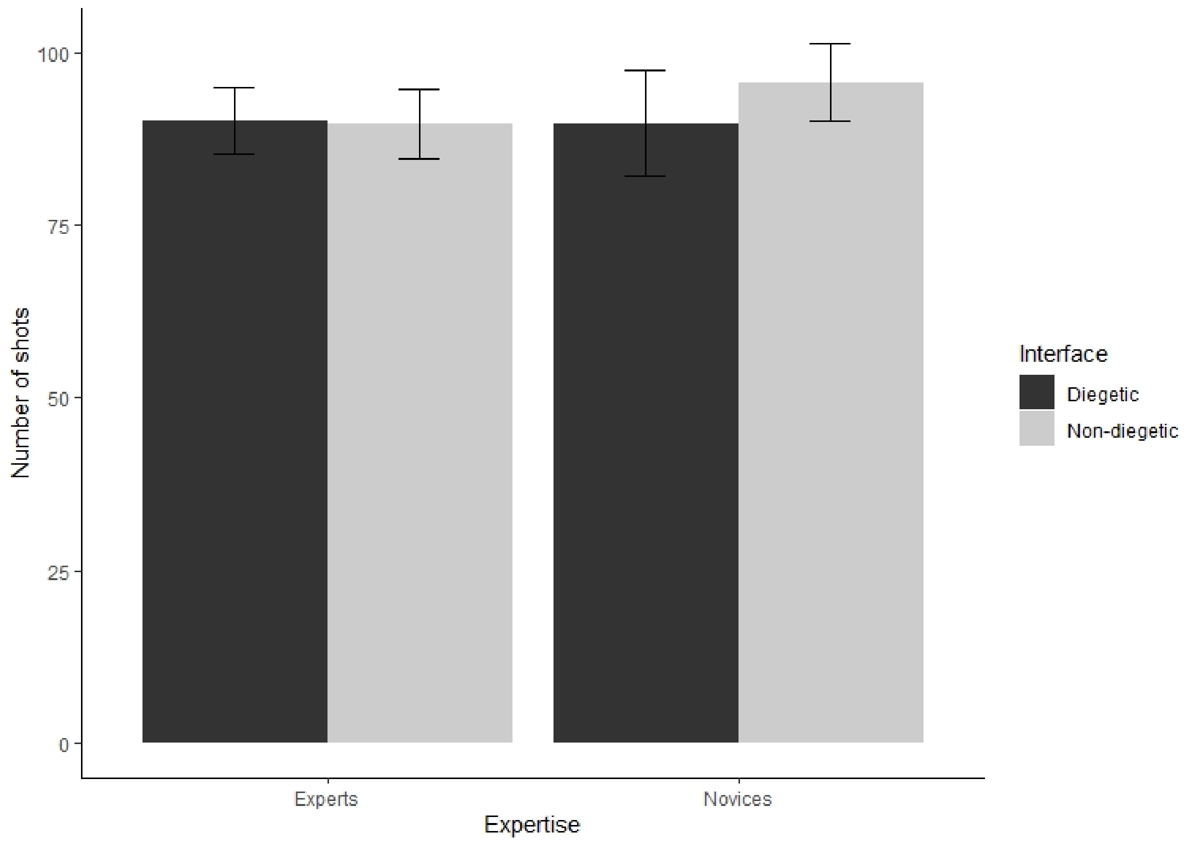

Figure 6. Mean number of shots as a function of expertise and type of interface with 95% confidence intervals.

5.1.4. Player-to-target distance

Player-to-target firing distance when reaching the intermediate temperature was not significantly influenced by the interface, nor by the expertise, nor by an interaction of the two (see Table 1) .

Player-to-target distance during overheating was not significantly influenced by the type of interface. The level of expertise did have an significant effect. Indeed, for the experts, the gun tended to overheat for targets that were nearer than the novices' targets (see Table 2). There was also a significant effect of the interaction between the type of interface and expertise. In the diegetic interface, the novices's gun tended to overheat for targets that were nearer than in the non-diegetic interface. This was not the case for the experts.

For the distance between the player and the eliminated targets, the interface type did not, again, show any significant effect on the distance separating the player from the eliminated targets. However, a significant effect of the expertise was observed on that player-eliminated target distance. The targets eliminated by the experts were significantly further than those eliminated by the novices. There was not any significant interaction effect.

No significant effect of the interface on the target-to-player distance for all shots was found. It was the same for the effect of the level of expertise. Here again, an interaction effect between the type of interface and expertise was highlighted. When the interface was diegetic, the novices fired on targets closer than those on which they fired in the non-diegetic interface. For the experts, the firing distance did not differ much between the two conditions. An illustration of this interaction can be seen in Figure 7.

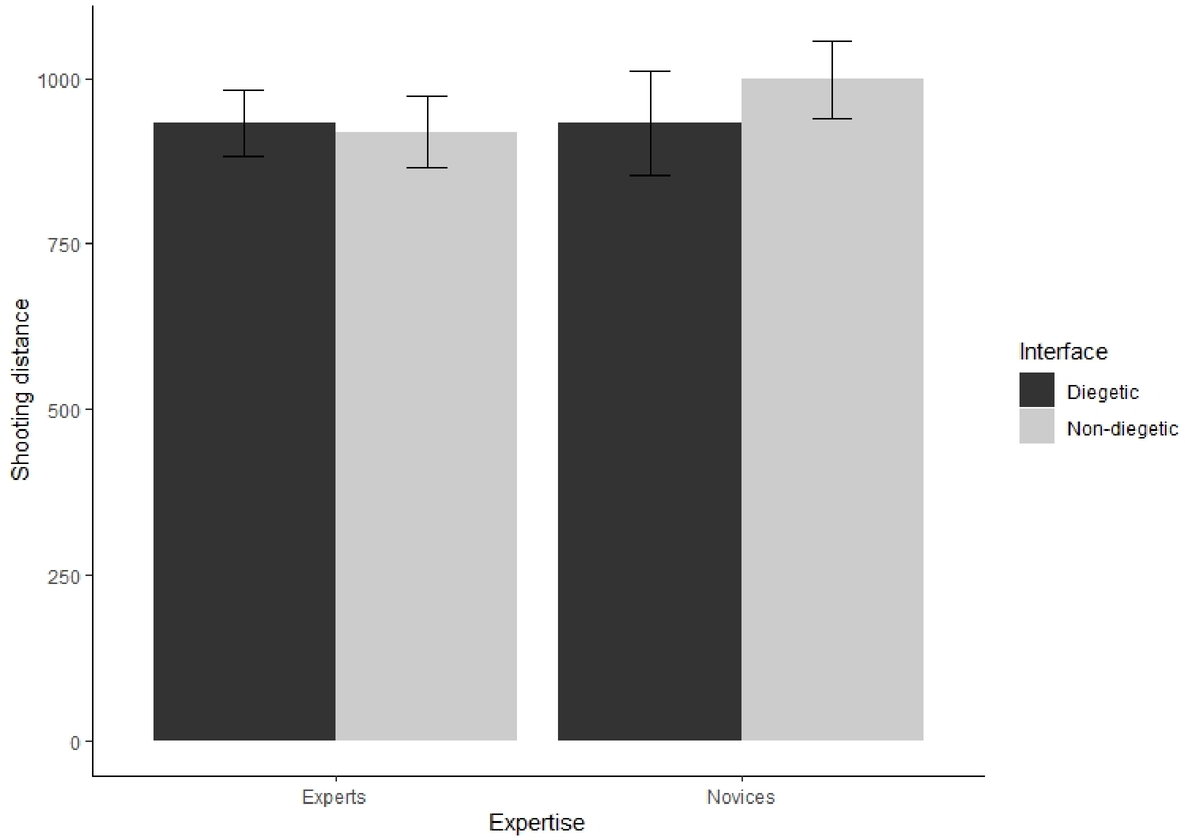

Figure 7. Mean shooting distance as a function of expertise and type of interface with 95% confidence intervals.

5.1.5. Reactivity

No effect on reactivity was found, neither by the type of interface, nor by the expertise, nor by an interaction between the two.

5.2. Presence

A mixed 2 (expertise) x 2 (interface type) ANOVA was conducted on each of the two presence scores.

5.2.1. Physical presence

As shown by the ANOVA results available in Table 3, there was no main effect of the expertise on physical presence. The type of interface did not have any effect either. No interaction effect was found.

5.2.2. Self-presence

The mean differences between conditions observed in descriptive statistics (see Table 4) were not significant as there was no main effect of the expertise on self presence (see Table 3). The type of interface did not have any effect either. No interaction effect was found.

Table 3. ANOVA result for dependent measures of presence

Independent variable	**Presence scores**	***F***	***df***	***p***	η^2_p
Level of expertise	Physical presence score	.215	1,39	.646	.005
	Self-presence score	.001	1,39	.979	.000
Type of interface	Physical presence score	.044	1,39	.835	.001
	Self-presence score	.773	1,39	.385	.019
Level of expertise * Type of interface	Physical presence score	.010	1,39	.920	.000
	Self-presence score	.612	1,39	.612	.015

Table 4. Descriptive statistics for dependent measures of presence

	Novice players		**Expert players**	
	Diegetic interface	**Non-diegetic interface**	**Diegetic interface**	**Non-diegetic interface**
Dependant measure	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
Physical presence score	17 (3.7)	17 (4.4)	17.4 (3.5)	17.5 (2.8)
Self-presence score	14.3 (4.5)	14.4 (6)	13.9 (5.1)	14.7 (4.7)

5.3. Enjoyment

A mixed 2 (expertise) x 2 (interface type) ANOVA was conducted on each of the four enjoyment scores.

5.3.1. Affective dimension

The ANOVA performed on the affective enjoyment scores indicated a main effect of the expertise on the affective dimension of enjoyment (see Table 5). Specifically, expertise had a positive effect on the affective dimension, the experts having a mean score higher than the novices (see Table 6). For the type of interface, no significant effect was found. It was the same for the interaction effect.

5.3.2. Behavioral dimension

There was no main effect of the expertise on the behavioral enjoyment. The type of interface did not have any effect either. No significant interaction effect was found.

5.3.3. Cognitive dimension

There was a main effect of expertise on the cognitive dimension of enjoyment. Indeed, the experts had a higher level of cognitive enjoyment than the novices (see Table 6). On the other hand, the type of interface did not have any effect. No significant interaction effect was found.

5.3.4. Global enjoyment

There was no main effect of the expertise on the behavioral dimension. The type of interface did not have any significant effect either. No significant interaction effect was found.

Table 5. ANOVA result for dependent measures of enjoyment

Independent variable	**Enjoyment scores**	***F***	***df***	***p***	**η^2_p**
Level of expertise	Affective dimension score	**4.59**	**1,39**	**<.05**	**.105**
	Behavioral dimension score	2.93	1,39	.095	.066
	Cognitive dimension score	**4.51**	**1,39**	**<.05**	**.104**
	Global enjoyment score	.682	1,39	.414	.017
Type of interface	Affective dimension score	.003	1,39	.960	.004
	Behavioral dimension score	.099	1,39	.755	.004
	Cognitive dimension score	2.58	1,39	.116	.078
	Global enjoyment score	.087	1,39	.770	.002
Level of expertise * Type of interface	Affective dimension score	.003	1,39	.960	.000
	Behavioral dimension score	1.08	1,39	.304	.029
	Cognitive dimension score	1.03	1,39	.316	.019
	Global enjoyment score	1.15	1,39	.290	.029

Table 6. Descriptive statistics for dependent measures of enjoyment

	Novice players		Expert players	
	Diegetic interface	**Non-diegetic interface**	**Diegetic interface**	**Non-diegetic interface**
Dependant measure	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
Affective dimension score	5.8 (.86)	5.8 (1)	6.2 (.63)	6.2 (.49)
Behavioral dimension score	4.6 (1.7)	4.4 (1.8)	3.6 (1.6)	3.7 (1.9)
Cognitive dimension score	3.7 (1.3)	3.8 (1.3)	4.4 (1)	4.4 (1)
Global enjoyment score	54 (9.5)	53.3 (9.5)	55.1 (7.1)	56.3 (7.8)

5.4. Link between presence and enjoyment

A regression analysis has been computed to know if physical and self presence predicted affective enjoyment. The regression coefficents for physical presence (ß = .063, $t(79) = .399$, $p = .691$) and self presence were not significant (ß = .109, $t(79) = .970$, $p = .335$). This regression model accounted for a non-significant portion of the variance in affective enjoyment, $R^2_{adj} = .008$, $F(2,79) = 1.32$, $p = .274$.

Another regression analysis has been computed to know if physical and self presence predicted behavioral enjoyment. The regression coefficents for physical presence (ß = -.137, $t(79) = -.634$, $p = .528$) and self presence (ß = .159, $t(79) = 1.04$, $p = .300$) were not significant. This regression model accounted for a non-significant portion of the variance in behavioral enjoyment, $R^2_{adj} = -.011$, $F(2,79) = .544$, $p = .582$.

A last regression analysis has been computed to know if physical and self presence predicted cognitive enjoyment. The regression coefficents for physical presence (ß = .049, $t(79) = .325$, $p = .746$) and self presence (ß = .132, $t(78) = 1.24$, $p = .219$) were not significant. Once again, the regression model accounted for a non-significant portion of the variance in cognitive enjoyment, $R^2_{adj} = .019$, $F(2,79) = 1.78$, $p = .175$.

6. Discussion

6.1. Performance

The first hypothesis was about the player's performance. It was expected that the performance would be better for the diegetic interface than for the non-diegetic interface but only for experts. This hypothesis was not confirmed: the beneficial effect of the diegetic interface was not observed for the experts. On the other hand, novice players have benefited from this interface on some aspects (i.e. the overheating number, the number of shots and the shooting distance).

The lack of effect on performance among experts runs counter to earlier findings (Iacovides et al., 2015, Peacocke et al., 2018). However, the superiority of the diegetic interface in terms of performance facilitation tends to confirm what was expected about the attention distribution. In reference to the SEEV model, the diegetic interface seems to have reduced effort between two areas of high expectancy and value: the situation information area (i.e. the performance indicators) and the anticipation zone. These two are characterized by a high expectancy because targets are expected to be seen in the part of the interface before the gun and many changes are happening also in the gun area (e.g. timer, heat indicator). They are also valuable because the indicators are useful to monitor (e.g. where are the targets) and regulate the performance (e.g. being more aggressive because there is no time left) and the anticipation zone is important as it needs to be constantly checked to shoot targets which is the main objective. The effort might be also reduced between each indicator compared to a non-diegetic design where these indicators are spread out horizontally. This effort reduction would especially facilitate the monitoring of the overheating indicator and would result in a more cautious attitude while playing to avoid overheating. Indeed, in the diegetic condition, novices shot less often than in the non-diegetic condition and they chose closer targets, which led to less overheating.

Contrary to our predictions, only novices have been affected by this effect of diegetic interface. This has probably been observed because the experts already have all the skills to effectively distribute their attention on the interface whereas, for the novices, the diegetic integration represents a considerable aid.

Naturally, the performance of the experts was generally better than that of the novices (they have a better score, are less overheating the weapon and can reach further targets). This is explained very well, as it has already been stated, by their knowledge in action games (Bonny & Castaneda, 2016) and their attention skills enhanced by action games (Green & Bavelier, 2003; Green & Bavelier, 2006).

6.2. Presence

Regarding the hypothesis on presence, we expected that the level of presence would be higher in the diegetic condition than the non-diegetic but only for the experts. This hypothesis was not corroborated because we found no significant effect the measures of presence. This goes against some earlier works (Iacovides et al., 2015). Some explanations can be found in qualitative studies such as Fragoso et al. (2014) where non-diegetic interface was not considered intrinsically interfering until it broke the interface coherence. The diegetic integration would not systematically generate a better presence in the virtual environment. Actually, it is emphasized by Llanos and Jørgensen (2011) that the clarity and accessibility of HUD information are the most important factors for the player's presence. Not observing a difference in presence between the two conditions, it could be concluded, from the point of view of these authors, that there was no significant difference in terms of clarity, accessibility, understanding of information between the two interfaces.

6.3. Enjoyment

Regarding the hypothesis on enjoyment, it was expected that the diegetic interface would produce more enjoyment than the non-diegetic interface only for the experts. No aspect of this hypothesis has been corroborated because the type of interface had no effect on any dimension whatsoever.

Only an effect of the expertise was observed on the affective and cognitive enjoyment. The superiority of experts on the hedonic aspects could be explained by the fact that they tamed the controls of the game more quickly and delivered a better performance than novices, which could have led to less frustration.

Complementary regression analyses showed that presence was globally not a good predictor for enjoyment unlike prior works, such as Skalski et al. (2010) and Shafer et al. (2011) where differences in modes of interaction with the game led to differences in levels of presence, which in turn led to differences in levels of enjoyment. This might be due to our measure of enjoyment that is not the same as previous works. The studies we have relied on do not usually use constructs as formalized as those we have used. In addition, we used a multidimensional scale that measured a broad range of aspects of enjoyment; therefore, our measures did not focus on the same aspects of enjoyment as the other studies. Previous studies found an effect maybe by investigating a rather specific aspect of enjoyment and we certainly lost this effect by widening the panel.

Despite these findings, determining the impact of whether or not a diegetic design has an impact on players' cognitive processes and experience remains an important topic. New practices in the development of video games, such as virtual reality, are necessarily exposed to this question: how to integrate status and contextual information in the visual interface? The diegetic/non-diegetic dimension is a crucial aspect to consider, especially because it is tempting to make an intuitive decision, based on beliefs from the video game industry.

This study has attempted to give a scientific answer to this question and has shown that a diegetic design is not inherently better than a non-diegetic design as one might think. We did not find significant differences on a number of measures and the significant differences were due to interaction effects between expertise and type of interface, demonstrating that the answer to the debate on the diegetic versus non-diegetic interface is not simple. Beyond that, this question as theoretical implications. It is an opportunity to test models of human cognition, such as the SEEV model in this study, and assessing their predictive power.

6.4. Limitations

The results remain quite dependent on the environment used, they are not totally generalizable. These results are related to action games because the visual space was arranged in a first-person shooter interface. In other types of game (e.g. strategy games, life simulation games), the HUD may pose different constraints in terms of space arrangement, it may require more space than in FPS games or contain radically different information.

For this experiment, elements of the diegetic interface were always accessible. Another diegetic integration choice might require the player to interact with the HUD elements to gain access to the information (e.g. manipulate the weapon to see the remaining ammunition) but this design would significantly increase the cost of attentional movements and the benefits of the diegetic interface for the performance would not be observable. However, this statement is quite uncertain because such a design could have a positive impact on interaction fidelity and therefore on the player experience (McMahan et al., 2012).

6.5. Perspectives

Measuring presence and enjoyment with questionnaires at the end of tasks can be problematic. With these questionnaires, participants are asked about the memory they have of their experience, a memory that can be altered between the beginning of the task and the beginning of the answers to the questionnaires. An ideal measure should be done during the gameplay with, for example, the adjustable distraction method (Nordahl & Korsgaard, 2010) where the level of presence is an evaluation based on the responses to stimuli during the game experience, which are adjusted in order to find the minimum stimuli strength at which presence can be broken.

Then, only one way of integrating the HUD information in a diegetic way has been tested. Other ways exist (as already mentioned in section 6.4), and they could produce a different effect. A comparison of several diegetic designs could inform about the precise components that affect the performance and the player's experience.

In addition, eyetracking data could add insights about behavioural data and possibly increase the power of the interpretations on attention (if not contradict them). Furthermore, objective measures (e.g. oculometric, electrodermal, cardiovascular, brain imaging) could solve the problems posed by subjective measures (i.e. problems of understanding the questions and the problem of real-time measure).

As player experience was not impacted by manipulating only elements of the display, it would also be interesting to see if the integration of diegetic interactions with the HUD information (e.g. manipulating the weapon to see the remaining ammunition) can influence the player experience more. In particular, it would be interesting to observe this impact in light of results such as those of McMahan et al. (2012) on interaction fidelity and those of Skalski et al. (2010) and Shafer et al. (2011) regarding the impact of interactivity on presence and enjoyment. Actually, diegetic integration may be multidimensional, location may just be one of its dimension and interactivity might be another one. For the sake of experiment control, variations in the level of diegetic integration have been operationalized as variations in the integration into the game’s three-dimensional space. Nevertheless, studying the game’s diegesis focusing on spatial characteristics of the information in the interface may not give the complete picture of what diegetic integration can do on players. Other studies are necessary to understand the impact of each dimension of diegetic integration on players while controlling the others dimensions.

6.6. Design recommendation

Thanks to the results of this study, some recommendations may be prescribed for potential action video game visual interface designers. Although none of our hypotheses has been fully corroborated, interesting effects have been highlighted. Furthermore, none of these effects showed a negative impact of a diegetic interface compared to a non-diegetic interface, which allows us to make a recommendation regarding the design of visual action video game interfaces:

> In VR environments, the information of the HUD must be spatially integrated as much as possible into the game's diegesis so that they remain close to the action scene, while remaining always accessible to the player's eye, if the goal is to promote the performance of novices to action games.

7. Conclusion

The purpose of this study was to determine the impacts of visual interface design choices, diegetic or not, in a VR environment. The integration of common HUD information into the diegesis of the game seems to have beneficial effects on performance that are nevertheless limited for expert players. However, the attentional differences between a diegetic and non-diegetic design do not seem large enough to create a difference in presence. Moreover, the link between diegetic integration and enjoyment remains unclear. Overall, diegetic integration of the HUD information may have a (beneficial) effect on the performance of novices but not on their subjective experience.

According to the literature, the diegetic integration of a traditional action video game HUD can have a beneficial influence on the player's performance. This is also what seems to indicate our results in VR. VR environments occupy more field of view than traditional games, which makes it more difficult to access a conventional HUD and divide the attention with the action scene. Diegetic integration in VR is perhaps more important than in non-VR games as it seems to shorten the distance between HUD elements and the action scene. It may therefore be more likely to have beneficial performance effects due to diegetic integration in VR than in other non-VR games environments.

This study highlighted the moderator role of expertise in the player-video game interaction. There was almost no main effect of the type of interface on the player's behavior and experience. Most of the effects of the type of interface are only observed when interacting with expertise, which indicates the important weight of context. A particular type of interface does not have a universal effect: the type of player needs to be taken into account to have a chance to predict its effect.

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