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Head-up displays in action video games: The effects of physical and semantic characteristics on player performance and experience

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Abstract

This study aimed to investigate how different characteristics of head-up displays (HUDs) can impact the performance and subjective experience of players in action video games. HUDs are a very common way to display contextual information. However, very few studies have empirically investigated the influence of HUD design on player performance and experience from a human information processing perspective. Four experiments were conducted in which players of different levels of expertise played commercial action video games. The physical characteristics of HUD, i.e. the physical appearance of the information on screen such as size and color (Experiments 1-2), and the semantic characteristics, i.e. the composition (nature and content) of the information (Experiments 3-4), were manipulated. Player performance and subjective experience were systematically assessed. The results showed that players' performance and experience were impacted when the semantic characteristics of the HUD elements were manipulated and when their nature was relevant to the main task players have to perform within the game. The performance of more experienced players was particularly affected in this case. In contrast, the results did not show that altering physical or semantic characteristics that were less relevant to the game main task would affect players' performance and subjective experience.

Keywords

Contextual information; Expertise; Composition; Size; Color.

1. Introduction

Visual interfaces are the most important parts of virtual environments such as video games. Most of the information the player needs to interact with the virtual environment is displayed visually (see Caroux et al., 2015 for a review). Traditionally, the visual interface of a video game is composed of three types of elements: the main action scene, the background, and contextual information (Caroux & Isbister, 2016). The main action scene contains objects that the player must interact with (e.g. avatars, enemies or targets). They are displayed against a complex, moving background (e.g. interiors, landscapes). Contextual information is typically overlaid on the main action scene in a head-up display (HUD) (Jørgensen, 2012; Peacocke et al., 2018). Contextual information provides information about the current situation in the game, such as the score, the health status of the avatar, the map of the virtual world, warning messages, etc. This information can be provided in the form of words, numbers or symbols (Brooksby, 2008).

HUDs can be used in real-world environments. Their main purpose is to facilitate operator activities such as driving and piloting, for the most studied (e.g., Park & Park, 2019; Stanton et al., 2019), and more generally in activities that can benefit from augmented reality systems, such as surgery or rescue operations (e.g., Lovreglio & Kinatader, 2020; Toyooka et al., 2018). In these situations, HUDs typically augment the user's perception of the environment by overlaying contextual information onto the actual scene. Unlike HUDs used in real-world environments, most of the elements used in video game HUDs can be opaque and have no real association with the part of the screen they are superimposed. In particular, they can hide elements present in the main game scene (Caroux et al., 2011).

While HUDs are a very common way to display contextual information in commercial video games, very few studies have empirically investigated the influence of HUD design on player performance and subjective experience. They have shown that the spatial organization of HUD elements on the interface (e.g., Caroux et al., 2011; Caroux & Isbister, 2016; Sabri et al., 2007), the diegetic way in

which contextual information is displayed (i.e., integrated into the action scene, rather than superimposed) (e.g., Iacovides et al., 2015; Peacocke et al., 2018), or the composition of the HUD (i.e., the nature of the elements that are displayed) (e.g., Caroux & Isbister, 2016), are characteristics that have a strong impact on player performance and experience.

Even if the results of these studies are very useful for the HCI field, including game user researchers and game designers, a major limitation is that most of them are essentially descriptive. They mostly assessed the impact of HUD characteristics without considering the cognitive functioning of the players (e.g., Peacocke et al., 2018; Sabri et al., 2007). In other words, the results of these studies are limited because they could not be predicted or explained from the perspective of human cognitive processing. Yet, several models based on knowledge on human information processing in cognitive sciences, can be applied to study interface design (e.g., Wickens & Carswell, 2012; Wickens & McCarley, 2008).

Another limitation of some of the previous studies on HUD in video games is that the situations of play that were used were not genuinely ecological. The experimental methodology used in some studies made situations in which the material was quite simple and not fully representative of the actual commercial games (e.g., Caroux et al., 2011; Peacocke et al., 2018). Also, some studies have based their data collection solely on the preference or perception of players without actually playing (e.g., Caroux & Isbister, 2016). This may limit the external validity of the methods and the generalizability of the findings.

The goal of the present article is to further investigate how different characteristics of HUDs can impact the performance and subjective experience of players. Four experiments were conducted, in which players of different levels of expertise played commercial action video games. The physical characteristics of the HUD, i.e. the physical appearance of the information on screen such as size and color, and the semantic characteristics, i.e. the composition (nature and content) of the information, were manipulated. The design of these experiments were conducted in accordance with the

theoretical framework of the SEEV model (Salience-Effort-Expectancy-Value) (Wickens et al., 2003), which is a model of visual attention that is particularly relevant when designing visual displays (Wickens, 2015). To the best of our knowledge, the present study is the first to examine the impact of different HUD features in action video games on player performance and subjective experience, using commercial games, and applying human factors/ergonomics models, such as the SEEV model, to predict and explain this impact.

2. Related work

2.1. Influence of video game design choices on player performance and experience

The influence of video game design choices on player performance and experience has been well documented over the past two decades. According to a recent systematic review of the scientific literature by Caroux et al. (2015), these design factors can be grouped into three main categories: input and output interfaces (i.e. visual and auditory displays; ways of game control), game content (i.e. challenge, difficulty, narrative and gameplay) and multiplayer aspects of games (i.e. competition/collaboration, nature of the game partner, etc.). This review showed that, in addition to player performance, two overall aspects of player experience may be influenced by these game factors: engagement and enjoyment. In the context of video games, player performance can be viewed as a quantitative outcome to a given task in the game, which is typically measured by a score (e.g., number of points earned), time taken to complete the task, etc. (e.g., Bergonse, 2017; Stenros, 2017). Player experience can be considered as the feelings held by the player during and immediately after the playing of the game, such as engagement (e.g., immersion, presence) and enjoyment (e.g., flow, emotions), which are usually subjectively assessed using questionnaires or interviews (e.g., Caroux et al., 2015; Vanden Abeele et al., 2020; Wiemeyer et al., 2016).

Visual interfaces have been one of the most studied factors due to their prevalence in the video game system. Several studies have shown how isolated features of visual interfaces can influence player performance and experience (and more generally, user performance and experience), and how these features can be manipulated by designers to optimize player-video game interactions. Some of these studies focused on global features such as the player's point of view (first or third person) (Bae et al., 2012; Black, 2017), the quality of the game's graphics (Claypool & Claypool, 2007), or the stereoscopic 3D displaying (Rousset et al., 2018; Takatalo et al., 2011). Other studies have investigated the influence of visual background features on player performance and experience. Color (Wolfson & Case, 2000), luminosity (Knez & Niedenthal, 2008), motion (Caroux et al., 2013; Kuiper et al., 2019) and visual complexity (Jie & Clark, 2008) are factors that may have a particular influence. Finally, some studies have focused on more local features regarding the displaying of contextual information, usually within a HUD. Their characteristics such as their spatial organization (e.g., Caroux et al., 2011; Caroux & Isbister, 2016; Sabri et al., 2007), their integration or not within the main action scene (i.e., diegesis) (e.g., Iacovides et al., 2015; Marre et al., 2021; Peacocke et al., 2018), and their composition (e.g., Caroux & Isbister, 2016) have been particularly studied. The influence of HUD design choices on player performance and experience is elaborated below.

2.2. Influence of HUD design choices on player performance and experience

Displaying contextual information in a permanent HUD in video games is useful for players to understand the game environment (Caroux & Isbister, 2016; Jørgensen, 2012). However, the performance and subjective experience of players may differ depending on the game genre and player expertise (Caroux & Isbister, 2016). Several studies have shown interesting findings for specific characteristics of HUDs.

First, the spatial organization of HUD elements on the interface has been shown to be a characteristic that impacts player performance and experience (Caroux et al., 2011; Caroux &

Isbister, 2016; Sabri et al., 2007). Caroux and Isbister (2016) designed an experiment in which players were asked to judge statements about their feeling (mainly preference) on screenshots of commercial first-person shooter (FPS) and real-time strategy (RTS) games with different HUD spatial organizations. The results showed that original HUDs (i.e. without modification by the experimenters) were preferred over all other modified HUDs. For the modified HUDs, those in which the main elements were displayed near the main action area (rather than at the ends of the interface) were better evaluated. Furthermore, for the RTS game, where HUDs were perceived as highly useful, the higher the expertise of the players, the greater the differences in feel between HUDs. Sabri et al. (2007) manipulated the display of contextual information around the player's on-screen cursor in an experimental RTS game. The full HUD (which contained, for example, the mini-map, resources, notifications, etc.) could be displayed in different configurations around the cursor or at the ends of the screen. The results showed that player preferences were better when the HUD was displayed near the cursor, although game performance was not impacted. Caroux et al. (2011) investigated the influence of the location of an isolated HUD element, the score, on player performance and visual attention in an experimental arcade game. The results showed that performance (i.e. game score) was best when the score display was located near the main action area, but just outside the anticipation zone of the obstacles. This finding could be explained using eye-tracking data, which showed that positioning the score in this way maximized the allocation of attention to this anticipation area.

Second, the diegetic way in which contextual information is displayed could have a particular impact on player experience and performance (Iacovides et al., 2015; Peacocke et al., 2018). Iacovides et al. (2015) studied the impact of the presence or absence of a HUD (i.e. non-diegetic elements) on player immersion in a commercial FPS game. The results showed no difference in immersion for novice players. However, immersion was higher for expert players in the diegetic-only condition (i.e. without HUD) than in the HUD condition. Peacocke et al. (2018) also investigated the impact of diegetic presentation of contextual information, isolating the HUD elements. Players were asked to

play an experimental FPS game in four experiments in which a different element was manipulated (i.e. ammunition, health, weapon type, navigation aid). Interestingly, the results were different in the different experiments, depending on the manipulated element. Performance and preference were better with a diegetic display for ammunition. There was no difference in performance or preference between the diegetic display and HUD conditions for all other manipulated elements.

Third, HUD composition can also have an impact (Caroux & Isbister, 2016). In the same experiment as presented above, Caroux and Isbister (2016) investigated the influence of HUD composition of commercial FPS and RTS games on player preference. The results showed that the original full HUDs were preferred over all other modified HUDs. This was independent of the nature of the elements of the HUDs for the FPS game. The nature of the elements was more important for the RTS game. HUDs in which the main elements (i.e. more related to the game main task) were removed were rated lower than HUDs without secondary elements. As with spatial organization, for the RTS game, the more expert the player, the greater the differences in feel between HUDs.

2.3. The SEEV model: a human information processing-based model for visual interface design

Several models based on knowledge on human information processing in cognitive science, can be applied to study interface design (e.g., Wickens & Carswell, 2012; Wickens & McCarley, 2008). When designing visual displays, the theoretical framework of the SEEV model is particularly relevant (Horrey et al., 2006; Wickens, 2015; Wickens et al., 2003). The SEEV model (Saliency-Effort-Expectancy-Value) is a model of visual attention that predicts the visual scanning on the different areas of a scene. The allocation of visual attention to each of these areas is determined by four factors: the visual saliency of the area, the effort required to shift attention to the area, the expectancy that information appears or changes within the area, and the value of the information in the area. Saliency and effort are typically defined in terms of physical features of the information. Expectancy and value depend more on the task performed by the user. The SEEV model is usually

studied in complex workplaces, such as aircraft cockpits or operating rooms. However, interfaces for everyday or leisure applications can also be studied and designed following this kind of model. For example, Caroux et al. (2011) experimentally showed that the player performance can be impacted by the location of the score information display within the game interface. This impact on performance could be predicted and explained by applying the SEEV model. Because the value of such information is high in an arcade game, the effort to scan it should be at the minimum for the player. As a result, the player performance was higher when the score display was located near to the main part of the action scene than when it was at other ends of the interface.

3. The present study

The goal of the present article is to study in more detail how different characteristics of HUDs can impact the performance and subjective experience of players. Four experiments were conducted. In each of them, participants had to play commercial games, mainly categorized in the action genre. This genre of game is one of the most represented among commercial games and one of the most popular among players (Entertainment Software Association, 2020). The physical characteristics of HUD, i.e. the physical appearance of the information on screen (Experiments 1-2), and the semantic characteristics, i.e. the composition (nature and content) of the information (Experiments 3-4), were manipulated. The size of HUD elements on the screen was manipulated in Experiment 1. The color of HUD elements was manipulated in Experiment 2. The composition of HUD was manipulated in Experiments 3 and 4. As explained below, the difference between these two last experiments was about the value of HUD elements that were displayed or removed. Elements of game control mapping were manipulated in Experiment 3, while elements directly related to the player's main task within the game world were manipulated in Experiment 4. The HUD characteristics manipulated in the present study were chosen because of their importance in more conventional HUDs (i.e. in domains other than video games). For example, some studies about HUDs in automotive

applications have focused on size, color or composition of HUDs and have shown their influence on driver performance (see for a review Park & Park, 2019). Similarly, composition has been shown as a main feature of HUDs in video games regarding the player experience (Caroux & Isbister, 2016).

In each experiment, the expertise of participants in action video games, i.e. their current and past experience playing action video games, was also manipulated. Performance and subjective experience were systematically assessed with respect to these manipulations of HUD and player expertise. The dimensions of player performance and experience that were assessed in each experiment depended on the type of HUD manipulation and the main task of the game played.

For each experiment, the hypotheses about player performance and experience were made accordingly with the theoretical framework of the SEEV model (Wickens et al., 2003). The general hypothesis was that each of HUD manipulation (physical or semantic) has an effect on player performance and experience, and that it is modulated by player expertise. Semantic manipulations may modify HUDs' expectancy or value regarding the game task. Physical manipulations may modify only their salience or effort required to reach them. Therefore, semantic manipulations should have more impact on the game task performing than physical manipulations. Because more experienced players are more familiar with the tasks proposed by the game, their performance and experience should be more impacted by semantic manipulations than physical manipulations, compared to the performance and subjective experience of less experienced players. The hypotheses for each experiment, as well as their justification, are detailed in each experiment section accordingly the given manipulation.

4. Overview of the methods used in each experiment

The experiments included in the present study were designed in essentially the same pattern.

Similar elements in each experiment are presented in the following paragraphs. Specific elements are presented below, within each experiment section.

4.1. Participants

Participants were young adult volunteers (mean ages between 20.8 and 24.0 years old) with normal or corrected-to-normal vision. They were recruited via advertisements on the university campuses, in gaming cafés, on online social networks, and through snowball sampling. They were not compensated for their time. They were recruited based on their expertise in one or more sub-genres of action video games related to the game used in the study (e.g., action-role-playing game, action-adventure, first-person shooter). In Experiments 1-3, the expertise was determined through a socio-demographic questionnaire, asking participants the number of hours they played these games per week over the past 6 months. This type of categorization of video game expertise is commonly used in the literature on the topic (e.g., Bediou et al., 2018). In addition, previous play time would be a good predictor of player expertise and game performance (Röhlcke et al., 2018). In experiments 1 and 3, participants who played the given sub-genre(s) more than 4 hours per week on average over the past six months are categorized as more experienced players, those who played less than one hour per week are considered as less experienced players. Participants in the less experienced group may have been used to playing other types of games (puzzle, adventure, etc.). In Experiment 2, participants who played more than 1 hour per week in the past six months were categorized as more experienced players, those who played less than one hour per week were considered as less experienced players. This lower minimum number of hours of play to be included in the more experienced group than in Experiments 1 and 3 (1 hour instead of 4 hours per week) was mainly due to some difficulty in finding enough players who had played more than 4 hours per week in the past 6 months at the time of participant recruitment. However, previous studies have shown that

comparisons between more and less experienced players with such distinction would still be valid (e.g., Caroux & Isbister, 2016; Iacovides et al., 2015). In Experiment 4, expertise was assessed with objective data, as detailed in the related sub-section below. All experiments complied with the tenets of the Declaration of Helsinki. Informed consent was obtained from each participant.

The sample sizes for each experiment were calculated based on the main effect of HUD characteristics, and its interaction with participants' expertise. All statistical power calculations were done using the G*Power software (Faul et al., 2007). Since the present study was not a replication, we had no hint of the expected effect sizes for these effects, and thus we used the mean effect size, $d = .5$ (Cohen, 1988). The analyses performed with G*power suggested a minimal sample size of 34 participants to reach a statistical power of 80% ($\alpha = .05$), for both the main and the interaction effects of interest. Thus, the number of participants recruited for each experiment was at least 34 (see the "Participants" section of each experiment for more details).

4.2. Material, design, procedure and dependent measures

A fairly recent commercial action video game with excellent reviews was used in each experiment. The game was different for each experiment. The HUD was manipulated for each game based on the purpose of the experiment. The game was chosen based on the appropriateness of the HUD manipulation and the technical feasibility offered by the game settings. Two HUD conditions (Experiments 1-3) or three (Experiment 4) were presented. Changes to HUD characteristics were made directly in the game settings (such as "display settings") (Experiments 1-3), or in the game configuration files (Experiment 4). The HUD was always manipulated within-participant. The expertise of the players was always manipulated between-participants.

Participants first went through the game's tutorial to familiarize themselves with the game's controls and mechanics. During the tutorial, participants could ask any questions they had about the game mechanics. Afterwards, all participants had to complete two games (or missions) (Experiments 1-3) or three games (Experiment 4). They played one game (or mission) per HUD condition. The order of

the HUD conditions was counterbalanced. Participants had to complete an objective with specific constraints related to the given game (e.g., in a limited time, with as few deaths as possible, etc.). At the end of each game, participants completed one or more questionnaires that were used to assess players' subjective experience. The dimensions of player experience assessed were different in each experiment depending on the purpose of the experiment.

Two types of measures were defined for all experiments: player performance and player experience. The variable(s) calculated for each measure, as well as the corresponding analyses, were specific to each study based on the given game objective.

5. Experiment 1: Size

5.1. Goal and hypotheses

The objective of this experiment was to assess the effect of the size of the HUD elements on player performance and experience. The size of the HUD elements relates to the amount of space they take up on the screen.

According to the SEEV model (Wickens et al., 2003), the size of the HUD elements could influence their salience and the effort required to reach them. The larger the HUD, the greater its salience and the lower the effort required to reach it. To the best of our knowledge, no study has investigated HUD size in video games, or in other application areas, in terms of the impact of player expertise. However, studies on interface diegesis in action video games could shed some light on this issue. Iacovides et al. (2015) showed that expert players of these games would have a better experience (specifically greater immersion) when the HUD is minimal or even removed. This was not the case for novice players.

Therefore, according to the SEEV model framework, the first hypothesis (H1) was that when the HUD is larger on the screen, player performance is higher. No hypothesis could be made about the

influence of player expertise. Thus, a research question (RQ) was how this effect can be modulated by player expertise.

The subjective experience of players was assessed along with the immersion dimension, which is a common dimension of player experience when studying the influence of interface display in video games (e.g., Iacovides et al., 2015). In line with previous studies (e.g., Iacovides et al., 2015), the second hypothesis (H2) was that when the HUD is larger on the screen, player immersion is lower, but only for more experienced players.

5.2. Methods

5.2.1. Participants

A total of 40 volunteers (28 men, 12 women) participated in the experiment. They were aged from 18 to 36 years old ($M = 23.2$, $SD = 3.6$). They were recruited on the basis of their expertise in the following (sub-)genres of video games: action games, action-role-playing games (A-RPG) and role-playing games (RPG). Because A-RPG games, action games and RPGs share many similarities, in terms of game design, but also in terms of visual interface design, the expertise in one or more of these (sub-)genres of games could easily be transposed when using games of the same genre. 20 participants were categorized as more experienced players. 20 participants were considered as less experienced players. Participants who have already played the specific game used in the present experiment were not included in the study.

5.2.2. Material, design and procedure

The A-RPG video game "*The Witcher III: Wild Hunt - Blood and Wine*" (CD Projekt RED, 2016) was used. The proportion of HUD was 9% of the screen in the small HUD condition and 15% in the large HUD condition (a 40% difference between the two conditions). The size was in the same ratio for each HUD element (see Figure 1). Note that the large HUD configuration corresponds to the default configuration of the commercial game.



Large HUD

Small HUD

Figure 1. Screenshots of the game interface in the two conditions of HUD size in Experiment 1.

Two different missions, with equal characteristics, were used in order to avoid a learning bias. The order of the missions and, consequently, the combinations of mission and type of HUD were counterbalanced. The two missions were originally included in the commercial game ("Equipment of the Grand Master's Griffin School" and "Equipment of the Grand Master's Wolf School"). The main goal of both missions was to collect scrolls ("wizard diagrams") to create an armor. To do so, players mainly had to follow the indications on the mini-map and to fight while monitoring the player avatar's health bar (see Figure 1). The participants were asked to complete the requested goal as quickly as possible and with as few deaths of their avatar as possible. At the end of each mission, participants completed the "Immersive Experience Questionnaire" (IEQ) (Jennett et al., 2008), which was used to assess players' immersion. The IEQ has 31 items that assess different components of immersion (i.e. cognitive involvement, emotional involvement, real world dissociation, challenge and control). The participants were asked to rate each item with a 5-point Likert scale. The experiment was conducted on an Xbox One console with a 32-inch TV and headphones. Participants interacted with the video game via an Xbox One controller. Participants were seated 1.50 m from the screen.

5.2.3. Dependent measures and data analysis

The player's performance was measured with the time needed to complete each mission and the number of times the player's avatar died for each mission. Player immersion was given from the IEQ total score after each mission. The IEQ total score was calculated by summing each item rating. The score could range from 31 to 155.

Data were analyzed using ANOVAs with the type of HUD as a within-participant factor and player expertise as a between-participants factor. One factorial mixed ANOVA was performed for each of both performance score and IEQ total score. Statistical analyses were performed with R-Studio 1.0.136.

5.3. Results and discussion

As shown in Table 1, there was no significant effect of the type of HUD on the time of mission completion ($F(1, 38) = 0.62, p = .43, \eta^2_p < .01$), nor significant interaction between the type of HUD and player's expertise ($F(1, 38) = 0.04, p = .84, \eta^2_p < .01$). In the same line, there was no significant effect of the type of HUD on the number of deaths ($F(1, 76) = 1.56, p = .22, \eta^2_p = .02$), nor significant interaction between the type of HUD and player's expertise ($F(1, 76) = 0.51, p = .48, \eta^2_p < .01$). The first hypothesis (H1) was not supported. The results did not show an effect of HUD size on players' performance, regardless of their expertise (in response to the research question, RQ). The results were not in line with the framework of the SEEV model (Wickens et al., 2003). Since a larger HUD would be more salient and could be reached with less effort than a smaller one, one would expect it to be more usable (at least for a less experienced player).

Table 1. Scores for each dependent measure with respect to HUD size and players' expertise in Experiment 1.

Dependent measure	More experienced players		Less experienced players	
	Large HUD	Small HUD	Large HUD	Small HUD
Completion time in seconds	368.3 (145.4)	388.7 (146.7)	541.9 (171.0)	576.4 (157.6)
Number of deaths	0.35 (0.81)	0.50 (0.83)	0.70 (1.13)	1.25 (1.92)
Immersion (IEQ)	105.1 (13.7)	104.8 (13.2)	106.0 (9.7)	104.5 (9.4)

Note. Standard deviations are shown in parentheses.

There was no significant effect of the type of HUD on player immersion ($F(1, 76) = 0.39, p = .54, \eta^2_p < .01$), nor significant interaction between the type of HUD and player's expertise ($F(1, 76) = 0.01, p = .93, \eta^2_p < .01$). The second hypothesis (H2) was not supported either. The results did not show an effect of HUD size on players' immersion, regardless of players' expertise. It was not in line with previous literature, which have shown that minimizing or removing HUD could improve more experienced players' immersion (e.g., Iacovides et al., 2015).

The next experiment investigated another case of a physical characteristic of video games' HUD: color.

6. Experiment 2: Color

6.1. Goal and hypotheses

The objective of this experiment was to assess the effect of the main color of the HUD elements on player performance and experience. The color of HUD elements relates to the color of the text or symbols used to display contextual information on the screen.

It has been widely shown that color can have an influence on psychological functioning in humans (see Elliot & Maier, 2014 for a review). Different colors may generate different emotions in humans (Valdez & Mehrabian, 1994), and have an impact on user experience in video games (Knez & Niedenthal, 2008; Roohi & Forouzandeh, 2019; Wolfson & Case, 2000). To the best of our knowledge, no studies have investigated HUD color in video games. However, predictions about player performance and experience can be based on studies that have investigated the color of the entire interface. For example, Knez & Niedenthal (2008) and Wolfson & Case (2000) showed that the red color would provide better player performance than the blue one. This was mainly explained by the fact that red color is more physiologically arousing (i.e. exciting and stimulating) than blue color. These studies did not give any results on the impact of player expertise. In the present study, we have chosen to manipulate red and blue colors because of their predominance in previous color studies.

Therefore, the first hypothesis (H1) was that when the main color of HUD is red, players' performance is higher than when it is blue. No hypothesis could be made about the influence of player expertise. Thus, a research question (RQ1) was how this effect can be modulated by player expertise.

The subjective experience of players was assessed with the arousal and emotional states, which are common dimensions of player experience when studying the influence of color interface display in video games (e.g., Wolfson & Case, 2000). In line with the performance hypothesis, the second hypothesis (H2) was that when the main color of the HUD is red, the arousal and emotional states of players is more impacted than when it is blue. Again, no hypothesis could be made about the influence of player expertise. Thus, a research question (RQ2) was how this effect can be modulated by player expertise.

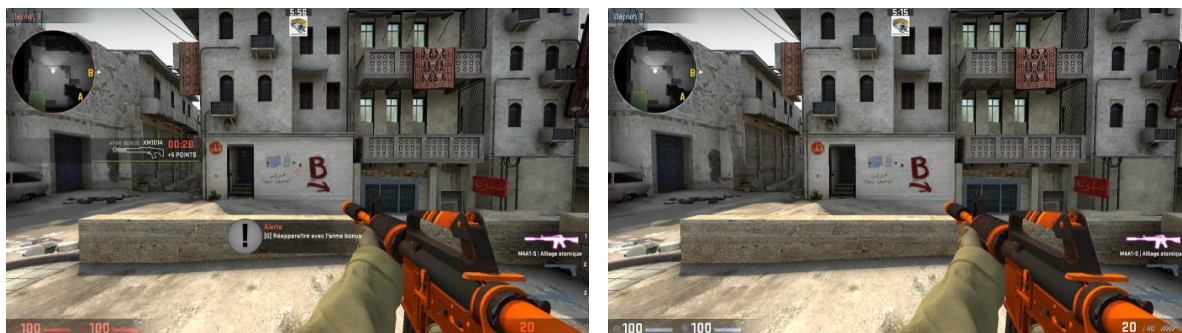
6.2. Methods

6.2.1. Participants

A total of 36 volunteers (31 men, 5 women) participated in the experiment. They were aged from 21 to 28 years old ($M = 24.1$). They did not suffer from colorblindness. They were recruited on the basis of their expertise in first-person shooter games (FPS) (sub-genre of action video game). 18 participants were categorized as more experienced players. 18 participants were considered as less experienced players. Having playing experience with the game used in the present experiment was not a criterion for exclusion from recruitment.

6.2.2. Material, design and procedure

The FPS video game “*Counter Strike: Global Offensive*” (Valve Corporation, 2012) was used. Two versions of the HUD of this game were designed according to its main color: blue or red. The color change concerned elements displayed at the ends of the screen (health status, armor status, ammunition, mini-map frame) and in the center of the screen (warning messages, viewfinder) (see Figure 2). Note that none of both color configurations corresponds to the default configuration of the commercial game.



Red HUD

Blue HUD

Figure 2. Screenshots of the game interface in the two conditions of HUD size in Experiment 2.

The participants had to play two games of 10 minutes each. The goal of the participants was to shoot at as many targets as possible in the game while being hit as little as possible by the other avatars. All participants played with the same set of weapons and were not allowed to change them during the game. At the end of each game, participants completed the Positive and Negative Affect Schedule (PANAS) (Watson et al., 1988) and the Self-Assessment-Manikin (SAM) (Bradley & Lang, 1994), which were used to assess the arousal and emotional states of players. The PANAS was composed of 20 items that assess the positive affect (10 items) and the negative affect (10 items). The participants were asked to rate each item with a 5-point Likert scale. The SAM was composed of three items that assess pleasure, arousal and dominance. The participants were asked to rate each item with a 9-point Likert scale. At the end of the experiment, the participants were asked whether they perceived any differences between the interfaces in the two game sessions. The experiment was conducted on a laptop with a 14-inch screen and headphones. Participants interacted with the video game via the keyboard of the laptop and an external mouse.

6.2.3. Dependent measures and data analysis

The player's performance was measured with the score at the end of each game. The score was calculated by the video game according to its original rule (i.e. without modifications by the experimenter). This score was mainly based on the number of successfully shot targets and the frequency of elimination of the player's avatar. Players' emotional states and arousal were given from the PANAS and SAM scores after each game session. Two scores of positive affect and negative affect were computed (from 5 to 50) from the PANAS scale. Three scores of pleasure, arousal and dominance were computed (from 1 to 9) from the SAM scale.

Data were analyzed using ANOVAs with the color of HUD as a within-participant factor and player expertise as a between-participants factor. One factorial mixed ANOVA was performed for the performance score. Also, one factorial mixed ANOVA was performed for each of both scores of the

PANAS scale scores as well as for each of the three scores of the SAM scale. Statistical analyses were performed with TIBCO Statistica 13.5.

6.3. Results and discussion

As shown in Table 2, there was no significant effect of the main color of HUD on the scores ($F(1, 34) = 0.17, p = .68, \eta^2_p < .01$), nor significant interaction between the color of HUD and player's expertise ($F(1, 34) = 1.34, p = .25, \eta^2_p = .04$). The first hypothesis (H1) was not supported. The results did not show an effect of HUD main color on players' performance, regardless of players' expertise (in response to research question RQ1). These results are not in line with previous literature that has shown a difference in player performance between mainly red and blue interfaces (Knez & Niedenthal, 2008; Wolfson & Case, 2000).

Table 2. Scores for each dependent measure with respect to HUD color and players' expertise in Experiment 2.

Dependent measure	More experienced players		Less experienced players	
	Red HUD	Blue HUD	Red HUD	Blue HUD
Score of performance	314.3 (73.5)	331.5 (83.1)	151.5 (77.43)	143.3 (92.8)
<i>PANAS</i>				
Positive affect	32.2 (9.7)	34.2 (9.1)	34.1 (6.3)	32.3 (7.7)
Negative affect	18.4 (5.3)	18.2 (5.4)	21.2 (5.6)	22.5 (6.6)
<i>SAM</i>				
Pleasure	5.9 (2.1)	6.8 (2.2)	6.3 (1.5)	6.1 (1.6)
Arousal	5.0 (2.4)	4.8 (2.1)	6.3 (1.7)	6.5 (1.7)
Dominance	4.6 (2.5)	5.1 (2.6)	4.1 (2.1)	3.8 (2.3)

Note. Standard deviations are shown in parentheses.

There was no significant effect of the color of HUD on subjective scales, namely the dimensions of positive ($F(1, 34) = 0.01, p = .92, \eta^2_p < .01$) and negative affect ($F(1, 34) = 0.55, p = .47, \eta^2_p = .02$), as well as pleasure ($F(1, 34) = 1.46, p = .24, \eta^2_p = .04$), arousal ($F(1, 34) = 0.00, p = 1.00$) and dominance ($F(1, 34) = 0.06, p = .80, \eta^2_p < .01$). There was no significant interaction between HUD color and expertise for any of the subjective scales, namely the dimensions of positive ($F(1, 34) = 3.27, p = .08, \eta^2_p = .08$) and negative affect ($F(1, 34) = 1.07, p = .31, \eta^2_p = .03$), as well as pleasure ($F(1, 34) = 4.07, p = .052, \eta^2_p = .11$), arousal ($F(1, 34) = 0.27, p = .61, \eta^2_p < .01$) and dominance ($F(1, 34) = 1.21, p = .28, \eta^2_p = .03$). The second hypothesis (H2) was also not supported. The results did not show an effect of HUD main color on players' arousal and emotional states, regardless of players' expertise (in response to research question RQ2). This was not in line with previous literature that has shown that the main color of the interface can impact the human's psychological functioning (Elliot & Maier, 2014), and the player experience, including their emotional state (Knez & Niedenthal, 2008; Roohi & Forouzandeh, 2019; Wolfson & Case, 2000).

The type of manipulation in the following Experiments 3 and 4 were quite different from that of Experiments 1 and 2. Instead of modifying a physical characteristic of the HUD, which could result in a cosmetic change, the nature of information contained within the HUD was investigated. For example, Caroux & Isbister (2016) showed that the composition of HUD had an impact of players' preference, but only on the basis of judging interface screenshots. The following experiments investigated whether the composition would also have an impact on player performance and experience in situations of actual playing.

7. Experiment 3: Composition – Number of elements

7.1. Goal and hypotheses

The objective of this experiment was to assess the effect of the HUD composition on player performance and experience. The HUD composition relates to the nature and the number of the elements of contextual information that are displayed within the interface (Caroux & Isbister, 2016). According to the SEEV model (Wickens et al., 2003), the HUD composition could influence the value of HUD and the expectancy that information will appear or change within the HUD. The HUD composition is more directly related to the task the player has to perform than physical characteristics such as color or size, which were manipulated in Experiments 1 and 2. Composition is a semantic characteristic of HUDs, meaning that the nature of the information elements could be more or less useful for the player during the execution of their task. A higher number of these elements could improve the value and expectancy of the HUD. To the best of our knowledge, no studies have investigated the impact of HUD composition on performance in video games, or in other application areas, regarding the impact of player expertise. However, as explained in the rationale of Experiment 1, studies of interface diegesis in action video games could shed some light on this issue regarding player experience. For example, Iacovides et al. (2015) showed that expert players of these games would have a better experience (more precisely, greater immersion) when the HUD is minimal or even removed. This was not the case for novice players. On the other hand, Caroux and Isbister (2016) showed that players preferred full HUDs to HUDs with less information displayed in an action game. However, this finding was based only on the evaluation of screenshots (i.e. not on actual playing).

Therefore, according to the SEEV model framework, the first hypothesis (H1) of the present experiment was that when the number of elements of contextual information displayed in the HUD is higher, players' performance is higher. No hypothesis could be made about the influence of player expertise. Thus, a research question (RQ) was how this effect can be modulated by player expertise.

As in Experiment 1, the subjective experience of players was assessed with the immersion dimension, which is a common dimension of player experience when studying the influence of interface display in video games (e.g., Iacovides et al., 2015). In line with previous studies (e.g., Iacovides et al., 2015), the second hypothesis (H2) was that when the number of elements of contextual information displayed in the HUD is higher, player immersion is lower, but only for more experienced players.

7.2. Methods

7.2.1. Participants

A total of 41 volunteers (24 men, 17 women) participated in the experiment. They were aged from 19 to 35 years old ($M = 24.0$, $SD = 3.8$). They were recruited on the basis of their expertise in action-adventure and RPG video games. 21 participants were categorized as more experienced players. 20 participants were considered as less experienced players. Having playing experience with the game used in the present experiment was not a criterion for exclusion from recruitment. Three participants had previously played the present game (all were included in the more experienced group).

7.2.2. Material, design and procedure

The action-adventure video game "*The Legend of Zelda: Skyward Sword*" (Nintendo, 2011) was used. Two versions of HUD composition were used (see Figure 3). They differed in terms of nature of elements of contextual information. The full version displayed all the original information that was presented by default in the game. It included elements of information that permanently notify on the status of the avatar (health, shield, activated shield, etc.) controlled by the player. Also, it included all the information of game controls that the player has with the controller. The light version displayed only the information of the avatar status. Information about the game controls were removed. By this way, the light version displayed less contextual information than the full

version. Note that the full HUD configuration corresponds to the default configuration of the commercial game.



Full HUD

Light HUD

Figure 3. Screenshots of the game interface in the two conditions of HUD composition in Experiment 3.

Two different missions, with equal characteristics, from the original game were used in order to avoid a learning bias. The order of the missions and, consequently, the combinations of mission and composition of HUD were counterbalanced. The main goal of both missions was the same. The players were placed at the beginning of a dungeon, which was composed of several rooms. They had to solve puzzles and/or fight with enemies in each room in order to progress to the end of the dungeon. The duration of each mission was 15 minutes. At the end of each mission, participants completed the "Immersive Experience Questionnaire" (IEQ) (Jennett et al., 2008), which was used to assess players' immersion, as in Experiment 1. The experiment was conducted on a Wii U console with a 27-inch TV. Participants interacted with the video game via a Wii controller, which included motion recognition sensors.

7.2.3. Dependent measures and data analysis

The player's performance was measured in terms of progress within each mission, by calculating the ratio of the number of passageways unlocked by the player to the total number of passageways (ranged from 0 to 1). Player immersion was given from the IEQ total score after each game session (see Experiment 1 for details).

Data were analyzed using ANOVAs with the type of HUD as a within-participant factor and player expertise as a between-participants factor. One factorial mixed ANOVA was performed for each of both performance score and IEQ total score. Statistical analyses were performed with IBM SPSS Statistics 25.

7.3. Results and discussion

As shown in Table 3, there was no significant difference of progression between the full ($M = 0.21$, $SD = 0.21$) and light HUD conditions ($M = 0.24$, $SD = 0.18$), $F(1, 39) = 1.11$, $p = .30$, $\eta^2_p = .03$. The interaction between HUD composition and player expertise did not reach significance, $F(1, 39) = 2.14$, $p = .15$, $\eta^2_p = .05$. The first hypothesis (H1) was not supported. The results did not show an effect of HUD composition on players' performance, regardless of players' expertise (in response to the research question RQ). This was not in line with the SEEV model framework (Wickens et al., 2003). According to this framework, more information in the full HUD should have improved the value or the expectancy of the HUD elements, making it more useful (even for a less experienced player).

Table 3. Scores for each dependent measure with respect to HUD composition and players' expertise in Experiment 3.

Dependent measure	More experienced players		Less experienced players	
	Full HUD	Light HUD	Full HUD	Light HUD
Score of performance	0.33 (0.23)	0.32 (0.21)	0.09 (0.06)	0.15 (0.07)
Immersion (IEQ)	150.1 (18.6)	155.0 (19.9)	148.0 (21.4)	152.0 (20.4)

Note. Standard deviations are shown in parentheses.

There was no significant effect of the composition of HUD on player immersion ($F(1, 39) = 2.41, p = .13, \eta^2_p = .06$). There was no significant interaction between HUD composition and player expertise ($F(1, 39) = 0.03, p = .86, \eta^2_p < .01$). The second hypothesis (H2) was not supported either. The results did not show an effect of HUD composition on players' immersion, regardless of players' expertise. It was not in line with previous literature, which showed that minimizing or removing HUD could improve more experienced players' immersion (e.g., Iacovides et al., 2015). This was also not in line with the study of Caroux & Isbister (2016), which showed that full HUDs in an action game were preferred by players to HUDs with less information displayed.

In this experiment, the elements that were removed in the light HUD condition concerned the mapping of the game controls, i.e. the correspondence between each controller button and the possible actions on the avatar. This kind of information could be considered as little related to the main task within the game, which was to solve puzzles and fight with enemies in order to progress to the end of the mission. The elements of game controls did not provide any information to guide or help the player to effectively pursue the mission. As a result, the value of these HUD elements could be considered quite low.

This limitation has been addressed in the next experiment. The goal of Experiment 4 was similar to that of the present experiment, i.e. investigating HUD composition. However, care was taken to

ensure that the nature of the elements displayed or was directly related to the player's main task, in order to clearly modify the value and expectancy of the HUD.

8. Experiment 4: Composition – Main and secondary elements

8.1. Goal and hypotheses

As in Experiment 3, the objective of this experiment was to assess the effect of HUD composition on player performance and experience. However, elements of HUD were manipulated according to their level of relevance regarding the main task that the players have to perform within the game. As in Experiment 3, the different conditions of HUD composition were designed by displaying or removing elements of the HUD. In the present experiment, the nature of the display or removal of elements was of two kinds, following the taxonomy of Caroux and Isbister (2016): main elements, which contain contextual information necessary for the execution of the main task within the game (i.e. of high value); secondary elements, which contain little or no information necessary for the execution of the main task (i.e. of low value).

According to the SEEV model framework, the first hypothesis (H1) was that players' performance is lower with a HUD without main elements than with a HUD without secondary elements and with a full HUD (displaying all elements). Because more experienced players are more familiar with the tasks proposed by the game, their performance and experience should be more impacted by the manipulation of contextual information directly related to these tasks, compared to less experienced players. Therefore, the second hypothesis (H2) was that the effect of HUD composition on performance is accentuated for more experienced players.

Given that in the present experiment, the manipulation of HUD elements is more related to the relationship between the nature of contextual information and the game task, the findings of Caroux and Isbister (2016) may be more relevant for hypothesizing about player experience than in

Experiment 3. These authors showed that players preferred full HUDs to HUDs with less information displayed in an action game. This effect was accentuated for expert players. Thus, the third hypothesis (H3) was that players' experience is higher with a full HUD than with a HUD without main elements or without secondary elements. The fourth hypothesis (H4) was that the effect of the HUD composition on player experience is accentuated for more experienced players. In this experiment, player experience was assessed more broadly than in Experiment 3, in which only immersion was assessed. The aim was to observe whether other dimensions than immersion could be impacted by HUD manipulation, using a general game experience questionnaire, which included immersion.

8.2. Methods

8.2.1. Participants

A total of 40 volunteers (33 men, 7 women) participated in the experiment. They were aged from 18 to 34 years old ($M = 20.8$, $SD = 1.9$). They were recruited on the basis of their expertise in Multiplayer Online Battle Arena (MOBA) games, which is a sub-genre of action video games. Contrary to the previous studies in which expertise was assessed on the basis of a declarative questionnaire, expertise was assessed with objective data. We took advantage of the existence of an official player ranking of the "League of Legends" game (Riot Games, 2009), one of the most played MOBA games in the world, to determine the expertise of MOBA players. The use of this ranking allowed a more accurate qualification of the players' expertise than a declarative questionnaire. All participants were regular players of this genre of game. More experienced participants ($N = 18$) were players who were ranked at a level equal or higher than "platinum V" (high rank in the game). The ranks for the more experienced participants were: 4 platinum V, 3 platinum IV, 2 platinum III, 1 platinum II, 1 platinum I, 4 diamond V, 1 diamond III, and 1 diamond I. Less experienced participants ($N = 22$) were players who were ranked at a level equal or lower than "silver I" (low rank in the game). The ranks for the less experienced participants were: 3 bronze V, 1 bronze IV, 2 bronze II, 5 silver V, 2 silver IV, 3 silver III, 3 silver II, and 3 silver I.

8.2.2. Material, design and procedure

The MOBA video game "*League of Legends*" (Riot Games, 2009) was used. Three versions of HUD composition were used (see Figure 4). They differed in terms of nature of elements of contextual information. The full version displayed all the original information that was presented by default in the game. On the one hand, it included elements of information that continuously inform on the status of the avatars (e.g., health and resource points) and the orientation in the game world (e.g., real-time position of the different game elements in the mini-map). These elements were considered main elements of HUD. On the other hand, the HUD included elements concerning game statistics (e.g., score, players' pseudo, number of items of interest). They were considered secondary elements of HUD. Two alternative versions of HUD were designed: one version without main elements and one version without secondary elements. In these two conditions, the objects concerned were simply removed from the interface.



Full HUD



HUD without secondary elements



HUD without main elements

Figure 4. Screenshots of the game interface in the three conditions of HUD composition in Experiment 4.

The participants played against a human player who was an accomplice in the experiment. The second author of the present article took the role of the accomplice. This accomplice was always the same for each participant. Their level was Platinum III (high rank). The games were played with the character “Ezreal” in the “Summoner’s rift” map from the original game. Participants had to achieve the highest possible overall score. In the “League of Legends” game, the overall score calculated by the game is best when the player has eliminated as much as possible of the avatar controlled by the other player and the units controlled by the computer while being eliminated as little as possible. The accomplice was in a different room from the participant. They could not communicate verbally. The accomplice was instructed to play as well as possible (i.e., to get the highest possible score) and

in the same way for each participant. The duration of each game was 10 minutes. The experiment was conducted on a computer with a 24-inch screen. Participants interacted with the video game via a classic keyboard and a mouse.

At the end of each game, participants completed two questionnaires, which were used to assess general player experience. The first one was the questionnaire used by Caroux and Isbister (2016) on feelings about HUD, consisting of two statements to be rating by the participants (feelings about HUD composition and global feelings about HUD). An additional statement concerned familiarity with the HUD. The participants were asked to rate each statement with a 10-point Likert scale.

The second one was the “In-game” version of the “Game Experience Questionnaire” (GEQ) (Ijsselstein et al., 2013), which assesses the general subjective experience of players. This questionnaire was composed of fourteen items categorized within seven dimensions (sensory and imaginative immersion, flow, competence, positive affect, negative affect, tension, and challenge). Participants were asked to rate each statement on a 5-point Likert scale. This questionnaire was chosen because of the wide range of dimensions of player experience that are assessed, unlike the IEQ questionnaire used in experiments 1 and 3, which only assesses immersion. In addition, this questionnaire has been used extensively in previous studies on player experience (e.g., Law et al., 2018). However, recent studies have shown that the GEQ has serious problems of empirical validity (Johnson et al., 2018; Law et al., 2018). Some of the items and dimensions of the structure are not sufficiently discriminating. The GEQ could be supported empirically using a revised factor structure (Johnson et al., 2018). We have chosen to follow the recommendations of Johnson et al. (2018) to analyze the GEQ data, as explained below in the following section on data analysis.

8.2.3. Dependent measures and data analysis

The player's performance was measured for each game with two measures: the number of eliminations of the other player's avatar by the participant and the number of computer's units eliminated by the participant.

Feelings about HUD were measured using scores on all three questions (feeling of composition, global feeling, and familiarity). Each of these scores could range from 1 to 10. The general player experience was measured using the in-game version of the GEQ. All these subjective data were measured after each game session. As explained above, the original structure of the GEQ has problems with non-discriminatory items and dimensions (Johnson et al., 2018; Law et al., 2018). To address this problem, we chose to follow the recommendations of Johnson et al. (2018) in analyzing the data from this questionnaire. Johnson et al. validated a model in which items were removed (i.e. 8 items that cross-loaded mainly with the “positive affect” dimension) and with three dimensions merged into a new one (i.e. the “negative affect”, “tension” and “challenge” factors were merged into the “negativity” factor). This revised structure has been empirically validated with the original GEQ. Although a lighter version of the GEQ was used (the “in-game GEQ”, 14 items vs. 33 items for the original GEQ), following this revised structure could substantially improve the validity of the results of this questionnaire. The result was a revised structure of the “in-game GEQ” with 8 items divided into 5 factors (competence, sensory and imaginative immersion, flow, positive affect, negativity). A score was calculated for each of these 5 factors. It is an average of the scores of each item that make up the factor. Each of these scores could range from 0 to 4.

Data were analyzed using ANOVAs with the type of HUD as a within-participant factor and player expertise as a between-participants factor. One factorial mixed ANOVA was performed for each of both performance scores as well as for each score of the three feelings’ statements and the five factors of the GEQ. When the Mauchly sphericity test was significant, Greenhouse-Geisser correction was applied. Post-hoc analyses used Tukey’s HSD. Statistical analyses were performed with IBM SPSS Statistics 25.

8.3. Results and discussion

Figures 5 and 6 show that the HUD composition had an effect on the scores of performance, namely the number of eliminations of the other player’s avatar by the participant, $F(2, 76) = 26.28, p < .001$,

$\eta^2_p = .41$, and the number of computer's units eliminated by the participant, $F(2, 76) = 76.11$, $p < .001$, $\eta^2_p = .67$. Post-hoc analyses showed that these two scores were lower in the condition of HUD without main elements (respectively $M = 0.05$, $SD = 0.22$ for the number of eliminations of the other player's avatar; $M = 45.75$, $SD = 24.31$ for the number of computer's units eliminated) than in the conditions of full HUD (respectively $M = 0.93$, $SD = 1.14$; $M = 54.55$, $SD = 25.48$) and HUD without secondary elements (respectively $M = 0.58$, $SD = 0.93$; $M = 54.30$, $SD = 25.46$) ($p < .001$ for all comparisons). The number of eliminations of the other player's avatar was also lower in the condition of HUD without secondary elements than in the condition of full HUD ($p < .01$).

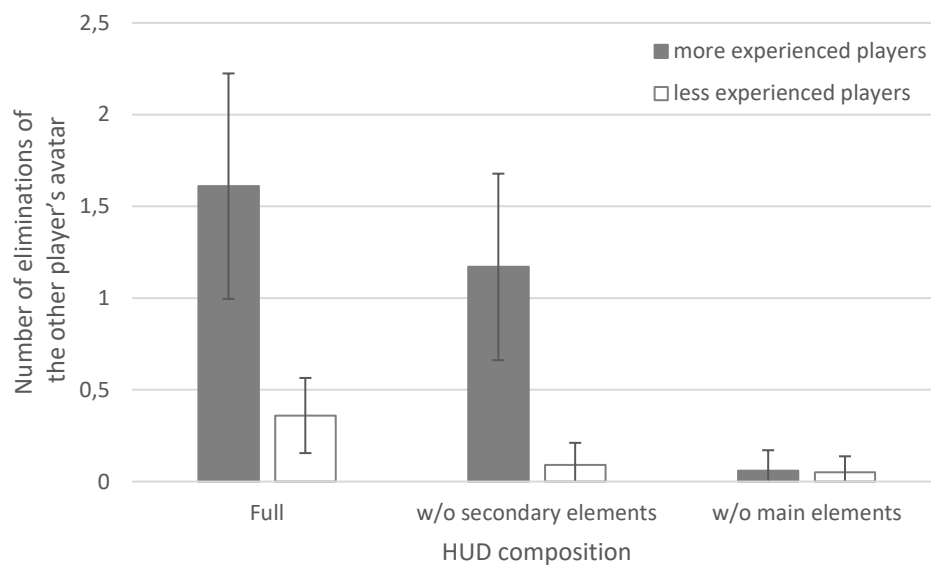


Figure 5. Number of eliminations of the other player's avatar with respect to HUD composition and players' expertise in Experiment 4.

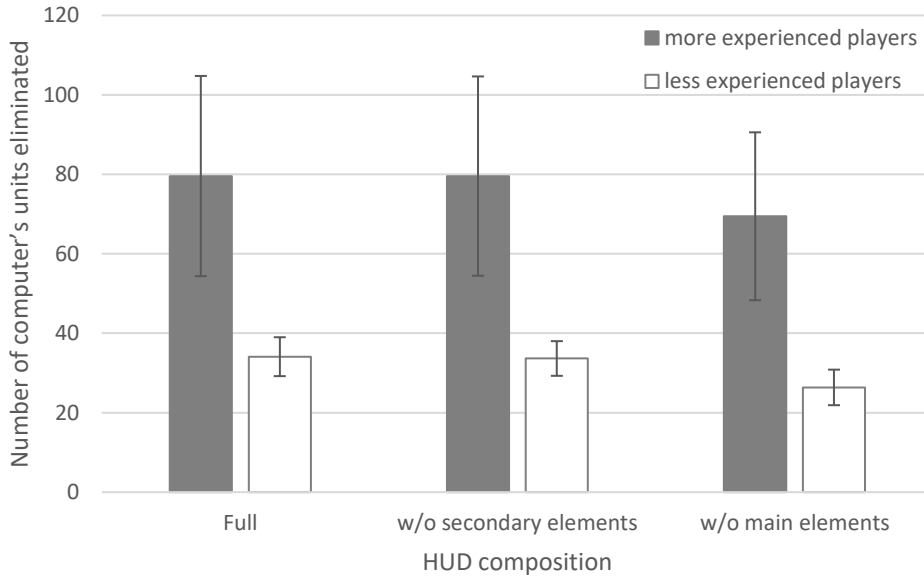


Figure 6. Number of computer's units eliminated with respect to HUD composition and players' expertise in Experiment 4.

The interaction between HUD composition and player expertise was significant for the number of eliminations of the other player's avatar by the participant, $F(2, 76) = 13.21, p < .001, \eta^2_p = .26$. The score was higher for more experienced than less experienced players in the full HUD and HUD without secondary elements conditions ($p < .001$ for both comparisons), but it was not significantly different in the HUD without main elements condition ($p = .89$). However, there was no significant interaction for the number of computer's units eliminated by the participant, $F(2, 76) = 1.71, p = .19, \eta^2_p = .04$.

The first hypothesis (H1) was supported. More and less experienced players' performance was impacted by the modifications of HUD composition, but only when the main elements were removed. These results are in line with the SEEV model (Wickens et al., 2003). Displaying elements of information of high value or expectancy (main elements) would improve the utility of HUD, and therefore the task performance. Also, more experienced players performed better than less experienced players, except when main elements were removed (for the score "number of

eliminations of the other player's avatar", which is the more important one regarding the game main task), which supported hypothesis 2 (H2). More experienced players' performance would be more sensitive to the presence or absence of elements of high value in the HUD. This was not in line with previous studies like Iacovides et al. (2015) that showed that the player experience was better for more experienced players when the HUD was minimal or removed. Note, however, that in their experiment, Iacovides et al. (2015) manipulated the presence or absence of contextual information in the HUD without distinguishing the nature of information (i.e. main or secondary elements).

Table 4 shows that the HUD composition had an effect on the three dimensions of HUD feelings. The composition feeling ($F(1.3, 49.8) = 109.53, p < .001, \eta^2_p = .74$, after Greenhouse-Geisser correction), global feeling ($F(1.3, 49.5) = 107.62, p < .001, \eta^2_p = .74$, after Greenhouse-Geisser correction) and familiarity ($F(1.3, 49.4) = 93.45, p < .001, \eta^2_p = .71$, after Greenhouse-Geisser correction) were rated higher by the players in the full HUD condition than in the other conditions ($p < .001$ for all comparisons). Also, they were better rated in the HUD without secondary elements condition than in the HUD without main elements condition ($p < .001$ for all comparisons).

In the same line, this factor had also an effect on 3 out of 5 factors of the revised in-game version of the GEQ. Competence ($F(2, 76) = 29.36, p < .001, \eta^2_p = .44$) and positive affect ($F(1.7, 64.5) = 89.30, p < .001, \eta^2_p = .70$, after Greenhouse-Geisser correction) were rated higher in the full HUD and HUD without secondary elements conditions than in the HUD without main elements condition ($p < .001$ for all comparisons). Negativity ($F(1.7, 65.1) = 150.88, p < .001, \eta^2_p = .80$, after Greenhouse-Geisser correction) was rated higher in the HUD without main elements condition than in the full HUD and HUD without secondary elements conditions ($p < .001$ for all comparisons). There was no significant effect of HUD composition on flow ($F(1.5, 55.4) = 1.57, p = .22, \eta^2_p = .04$, after Greenhouse-Geisser correction) and immersion ($F(1.3, 47.9) = 1.28, p = .28, \eta^2_p = .03$, after Greenhouse-Geisser correction) dimensions of the GEQ.

Table 4. Scores for each dimension of questionnaires with respect to HUD composition and players' expertise in Experiment 4.

Questionnaires' dimensions	More experienced players			Less experienced players		
	Full HUD	HUD w/o secondary elements	HUD w/o main elements	Full HUD	HUD w/o secondary elements	HUD w/o main elements
<i>HUD judgement</i>						
Composition	8.89 (1.32)	7.56 (0.70)	3.56 (2.33)	8.86 (0.99)	7.59 (1.59)	4.32 (2.30)
Familiarity	8.17 (1.86)	6.61 (1.50)	3.33 (2.06)	8.68 (1.09)	7.50 (1.34)	4.64 (1.68)
Global feeling	8.72 (1.71)	7.56 (0.70)	3.78 (2.32)	8.86 (0.94)	7.50 (1.44)	4.05 (2.08)
<i>General Experience</i>						
Immersion	1.83 (1.58)	1.72 (1.64)	1.83 (1.58)	1.68 (1.36)	1.68 (1.32)	1.73 (1.32)
Flow	3.78 (0.43)	3.83 (0.38)	3.33 (0.69)	2.91 (1.41)	2.82 (1.65)	2.86 (1.21)
Competence	2.22 (1.00)	2.17 (1.10)	0.83 (0.92)	1.18 (1.01)	1.18 (0.73)	0.36 (0.58)
Positive affect	2.97 (0.58)	3.06 (0.70)	1.36 (1.00)	2.27 (0.61)	2.30 (0.63)	1.09 (0.48)
Negativity	1.04 (0.70)	1.19 (0.68)	3.31 (0.80)	1.48 (0.90)	1.52 (0.71)	3.30 (0.66)

Note. Standard deviations are shown in parentheses.

There was no significant interaction between HUD composition and player expertise on any dimension of subjective experience, namely composition ($F(1.3, 49.8) = 0.80, p = .41, \eta^2_p = .02$, after Greenhouse-Geisser correction), familiarity ($F(1.3, 49.4) = 0.70, p = .44, \eta^2_p = .02$, after Greenhouse-Geisser correction), global feeling ($F(1.3, 49.5) = 0.11, p = .81, \eta^2_p < .01$, after Greenhouse-Geisser correction), immersion ($F(1.3, 47.9) = 0.61, p = .48, \eta^2_p = .02$, after Greenhouse-Geisser correction), flow ($F(1.5, 55.4) = 1.67, p = .20, \eta^2_p = .04$, after Greenhouse-Geisser correction), competence ($F(2, 76) = 1.84, p = .17, \eta^2_p = .05$), positive affect ($F(1.7, 64.5) = 2.36, p = .11, \eta^2_p = .06$, after Greenhouse-Geisser correction), negativity ($F(1.7, 65.1) = 1.60, p = .21, \eta^2_p = .04$, after Greenhouse-Geisser correction).

Hypothesis 3 (H3) was supported. In line with previous results, player experience was globally lower when the main elements of HUD were removed, compared with a full HUD. In addition, it was also globally lower than when secondary elements of HUD were removed. These results obtained with an actual playing situation support previous results that were only obtained with subjective judgements of screenshots (Caroux & Isbister, 2016). However, contrary to the performance results, the results did not show that more and less experienced players' experience would be impacted differently by HUD composition, which did not support hypothesis 4 (H4). These results were not in line with previous literature, which showed that subjective experience would be different regarding player expertise (e.g., Caroux & Isbister, 2016; Iacovides et al., 2015). The operationalization of players' expertise was not strictly similar between the present experiment and those of this previous literature. In the present experiment, both more and less experienced players were regular players of the game concerned. In other studies (e.g., Caroux & Isbister, 2016; Iacovides et al., 2015), only the more experienced players were regular players of the game (or even the genre of game) concerned. In particular, less experienced players could be non-players of video game. Therefore, we could make the hypothesis that the difference in player's subjective experience would only be observed when there is a large difference in expertise between players, but not when it concerns different levels of expertise between regular players.

9. General discussion

The results of the four experiments provided different results on the influence of HUD characteristics on the performance and experience of players in action video games. Player performance and experience would be impacted when the semantic characteristics of the HUD elements are manipulated and when the nature of these elements is directly related to the main task the player has to perform within the game. The impact of modifying physical characteristics or semantic characteristics less relevant to the game main task on player performance and experience

has not been shown. In more detail, in Experiments 1 and 2, there was no significant effect of size or color of HUD elements (physical characteristics). In Experiment 3, there was no significant effect of the presence or absence of some HUD elements that are not directly related to the main task within the game (mapping of game controls, in this experiment), which is nevertheless a semantic characteristic. In contrast, Experiment 4 showed that the presence or absence of elements of contextual information necessary for the game main task (avatar status and orientation in the game world, in this experiment) did have a significant influence on player performance and experience. Performance and experience were impaired when these elements were removed.

Considering the framework of the SEEV model (Wickens et al., 2003), the results showed that changing the value or expectancy of HUD elements in action video games had an impact on players' performance and experience. In contrast, the present study did not show that changing the salience of HUD elements or the effort required to reach them (e.g., size) would have an impact. This does not seem to be consistent with previous studies that have shown that the spatial organization of HUDs, which is another way to change the value of HUD effort, can have an impact on player performance and experience (e.g., Caroux et al., 2011; Sabri et al., 2007). These previous studies used experimental games. In such experiments, the game interface typically only displayed the elements being studied. In this sense, the value or expectancy of the manipulated elements were automatically of high value regarding the game main task. The games used in the present experiments were commercial games with HUDs containing much more information with elements of various values (i.e., not always specifically relevant to the game main task).

In addition, player expertise may have played a role in modulating this effect. Experiment 4 interestingly showed that the performance of the more experienced players was superior to that of the less experienced only when all elements of the original HUD were displayed or when secondary elements were removed. However, this experiment did not show significant modulation of expertise on player experience.

Considering the framework of the SEEV model, the present study did not show that more experienced players would be influenced differently than less experienced players by the salience of HUDs or the effort required to reach them. However, they were more sensitive to the manipulation of the value or expectancy of HUD elements. Because more experienced players are more familiar with the main task within the game, the manipulation of HUD elements that are specifically relevant to the game main task, i.e. high value or expectancy, had a greater impact on their performance than for less experienced players.

9.1. Limitations

As with all multi-experiment studies, the comparison of the results between the four experiments should be made cautiously. In particular, this series of experiments was conducted using quite different material. Each experiment used a different video game. Even if all the games can be categorized in the action genre, they have quite different gameplay rules and mechanics. Some results might have been slightly different if the physical and semantic characteristics had been manipulated in a similar way for each game. The actual utility of HUDs in action video games could depend on the sub-genre of the game (i.e., action-adventure, FPS, A-RPG), as discussed in the literature (e.g., Caroux & Isbister, 2016; Jørgensen, 2012). The video games that were chosen in the first three experiments may be video games for which the overall HUD is of low value to the players. In contrast, the game used in Experiment 4, which is categorized within the MOBA sub-genre includes gameplay elements from action games, but also strategy games. HUDs may be considered more useful in strategy games than in action games (Caroux & Isbister, 2016). This may be an alternative explanation for the fact the modification of the HUD had a significant impact on player performance and experience in this experiment.

In the same line, player performance and experience were not assessed with the same variables throughout the four experiments. As explained in each experiment section, the measures were chosen according to the game goals and the expected dimension of experience that would be

impacted by the HUD manipulation. The fourth experiment was the only one for which a global experience questionnaire was used. This questionnaire assessed several dimensions of player experience, while the other experiments examined a few dimensions. Since such a questionnaire increased the chance of observing an effect, this could be an alternative explanation of the significant impact of the HUD modification on player experience only in this experiment. For instance, note that the results did not show an effect of HUD manipulation on immersion in any of the three experiments in which this dimension of player experience was assessed (Experiments 1, 3 and 4). It would be possible that the HUD manipulation would affect other dimensions of player experience (e.g., competence, positive affect, etc.) if they had been assessed as they were in Experiment 4. However, this speculation should be taken with caution as immersion was not assessed using the same questionnaire (IEQ in Experiments 1 and 3, GEQ in Experiment 4). This precaution should be all the greater as the GEQ poses validity problems, as explained in the method section of Experiment 4.

Finally, the choices of operationalizing the modalities of the HUD characteristics made in each experiment could also be considered as limitations. For example, the difference in size of the HUDs in Experiment 1 could have been different. A larger HUD could enlarge its space on the interface and be more salient. The distance between the HUD elements and the central area of the main action scene could make it easier for players to use them. The color difference in Experiment 2 could also have been more salient. When asked at the end of the experiment, the more experienced players mainly detected the difference in HUD color between the two conditions (78% of them). This was not the case for less experienced players (6%). Note that the players did not see the experimenter changing the HUD color in front of them. Further studies should continue to investigate these HUD manipulations by testing other ways to operationalize these features.

9.2. Perspectives

Although the objective of the present article was to investigate the influence of characteristics of HUDs on player performance and experience in action video games, the generalization of the findings of the present experiments to all kinds of HUD characteristics and all kinds of games may be limited. Because of the wide variety of commercial video games, the topic of the present study was limited to action video games, which are one of the most popular genres of games. Future studies should investigate other genres of games. For example, and as noted above, HUDs would be used and experienced differently in genres such as strategy games, where the HUD elements may be more useful to players during the game task (Caroux & Isbister, 2016). In the same way, three types of HUD characteristics were manipulated in the present study: size, color and composition. Other important characteristics could also influence player performance and experience. For example, spatial organization within the game interface could influence player preferences and performance (Caroux & Isbister, 2016; Sabri et al., 2007). It would be interesting to study the overall impact of spatial organization on player experience in commercial games. In addition, each characteristic was studied in isolation in different experiments. Some combinations of these characteristics may have an influence on performance and experience. For example, although the present study did not reveal an isolated significant effect of size or color, these physical aspects of the HUD may have a multiplicative effect on its salience or the effort required to be reached (in accordance with the SEEV model). Finally, Experiment 4 investigated composition by manipulating main or secondary elements as groups of elements. It might be interesting to have a more fine-grained approach by isolating specific elements among these groups. For example, the mini-map in a MOBA game might have an even more important role than the other main elements of contextual information. Further studies should specifically examine these points.

Also, the present study assessed player experience using quantitative measurement (i.e. with scales). The experiments were designed so that comparisons between different HUD design conditions were facilitated in terms of quantitative data. For example, the different player

experience scales provided data that were easily compared with inferential statistics. However, given that player experience can be considered as the feelings held by the player during and immediately after the playing of the game, a more qualitative assessment (e.g., interviews, verbalizations during playing, etc.) could provide more information about player experience with the different HUD designs. Future studies should be designed to collect data from a qualitative assessment.

Future studies should also further explore the diversity of players in terms of visual disabilities, cognitive styles, or attentional capacities. As with all visual displays, users and players are not equal in processing visual information. First, manipulating the visual features of game interfaces could have different impacts depending on the ability to discriminate different sizes or color contrasts (e.g., Wang et al., 2020). For example, the way colors are manipulated in Experiment 2 could be more or less disruptive for people with color blindness. Second, players may have different cognitive processing styles when processing complex visual scenes. For example, Raptis et al. (2018) used a theory of individual differences in visual information processing (the Field Dependence-Independence style, (Witkin et al., 1975)) to study the impact of visual displays (mixed reality vs. conventional display) on player behavior and immersion. Further experiments could investigate the interaction of such cognitive style with the visual characteristics of game interfaces on player performance and experience. Third, the attentional abilities of action video game players appear to differ from those of non-players of action video games (e.g., Bediou et al., 2018). It would be interesting to further explore how players' attentional abilities relate to their performance and experience when manipulating visual video game interfaces.

The present study, like most of those published in the literature, focused on game interfaces displayed on conventional flat screens (TV or desktop computers). However, the diversity of devices to display video games is increasing, with the most important ones being mobile devices and virtual reality headsets (e.g., Pallavicini et al., 2019). It would be interesting, but also important, to

investigate whether and how the manipulation of HUD characteristics would have the same influence on player performance and experience as with conventional configurations.

Finally, the present study aimed to investigate action video games' visual interfaces from the point of view of a human information processing model: the SEEV model (Wickens et al., 2003). Some of the results were in line with the predictions made according to this model framework (Experiment 4). Other results were not in line, as in Experiments 1 and 3. Even if it is possible to predict the performance of players with this model, as shown in this or previous studies (e.g., Caroux et al., 2011), this is not the primary aim of this model. The SEEV model is a model of visual attention that predicts visual scanning over different areas of a scene. The present results that may or may not support the hypotheses of performance could be better understood if direct measures of visual attention had been made. Researchers or game designers conducting their work within such a theoretical framework should study the visual and attentional processes of players in parallel with their performance. Future studies about the effects of visual interfaces on player performance and experience should rely on the measurement of visual attention, for example, using eye-tracking.

9.3. Design recommendations

The findings from the present study can be used as recommendations for the design of action video game interfaces, but also for interfaces of environments and systems that share the characteristics of these games (i.e. complex and dynamic visual interfaces).

Changing the composition of the HUD could have a significant impact on player performance and experience. Adding contextual information related to the main task that players must perform in the game (i.e. providing any information to guide or assist players in completing their main task) can improve player performance and experience, especially when the game is played by more experienced players. On the contrary, removing this main information may decrease player performance and experience.

Since the present study did not reveal any significant influence of the presence or absence of other, more secondary elements of HUDs (i.e. elements not directly related to the game main task) on player performance and experience, no recommendation can be made about this feature. The same is true for the physical characteristics of HUDs, such as size and color. Designers should adjust them carefully.

10. Conclusion

The goal of this study was to investigate how different characteristics of the HUDs can impact the performance and subjective experience of players, using commercial games. The results of the four experiments showed that player performance and experience are impacted when the semantic characteristics of the HUD elements are manipulated and when the nature of these elements is relevant to the main task the player has to perform within the game. The performance of more experienced players is particularly affected in such a case. Further studies are needed to explore the influence of physical or semantic characteristics less relevant to the game main task on player performance and experience, regardless of player expertise. This study also showed that applying human factors/ergonomics models such as the SEEV model makes it possible to predict and explain the impact of HUD design on player performance and experience in action video games. Even if HUDs in games do not have the same role as in other systems, more related to efficiency or safety (e.g., airplane, car, operating room, etc.), they can be studied from a human information processing perspective. Future studies need to investigate whether and how the present findings can be generalized to the wide variety of game genres and display devices that exist in the video game world.

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