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Title:

Influence of head-up displays' characteristics on user experience in video games

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Abstract

Head-up displays (HUD) are important parts of visual interfaces of virtual environments such as video games. However, few studies have investigated their role in player-video game interactions. Two experiments were designed to investigate the influence of HUDs on player experience according to player expertise and game genre. Experiment 1 used eye-tracking and interviews to understand how and to what extent players use and experience HUDs in two types of commercial games: first-person shooter and real-time strategy games. Results showed that displaying a permanent HUD within the visual interface may improve the understanding of this environment by players. They also revealed that two HUD characteristics, namely composition and spatial organization, have particular influence on player experience. These critical characteristics were manipulated in experiment 2 to study more precisely the influence of HUD design choices on player experience. Results showed that manipulation of design of these HUD characteristics influences player experience in different ways according to player expertise and game genre. For games with HUDs that are perceived as very useful, the higher player expertise is, the more player experience is influenced. Recommendations for video game design based on these results are proposed.

Keywords

Virtual environments; visual interface; game design; player experience; eye movements; eye tracking.

Highlights

- Permanent HUD may improve players' understanding of game environment
- Composition and spatial organization are critical characteristics of HUDs
- HUD design choices have influence on user experience in video games
- This influence is different according to player expertise and game genre

1. Introduction

Virtual environments such as video games, are environments simulating the physical presence of a user in a place that imitates the real world, or represents an imaginary world (Stanney et al., 1998).

Two elements must be taken into account to describe the interface of this type of environment: the way that the user can interact with the environment, and information displayed by the interface that allows interaction with the user (Stanney et al., 2003). This information can be displayed according to different sensorial modalities, but the visual mode is generally the most used (Stanney et al., 2003).

The visual interfaces of video games generally consist of a main action scene containing objects with which the player can interact (e.g. avatars, enemies or targets) and a complex, moving background (e.g. interiors, landscapes). Traditionally, a *head-up display* (HUD) is often superimposed on the main action scene (see Caroux et al., 2015a for a review). This display provides contextual information associated with the current situation in the form of words, word lists, numbers or symbols (Brooksby, 2008). In most cases, the more-or-less permanent information is arranged around the edge of the screen (e.g., score, life points, map of the virtual world). In contrast, the non-permanent information is often displayed in the central area (e.g., warning messages). HUDs vary as a function of context. Some of them augment the user's perception of the game environment by superimposing context information over a real scene. HUDs can be used in real environments to assist, for example, piloting or driving activities (e.g., Charissis and Papanastasiou, 2008; Crawford and Neal, 2006). However, in contrast with HUDs in planes or cars, most of the elements used in head-up displays in video games could be opaque and have no real association with the part of the screen on which they are superimposed. They may therefore hide elements present in the game's main scene (Caroux et al., 2011).

The influence of specific elements of the video game visual interfaces, such as point of view or background characteristics, on player performance or experience has been investigated in several

studies (e.g., Bae et al., 2012; Browne and Anand, 2012; Caroux et al., 2015b, 2013, 2011; Dyson, 2010; Hou et al., 2012; Jie and Clark, 2008; Knez and Niedenthal, 2008; Sabri et al., 2007; Takatalo et al., 2011; Wolfson and Case, 2000; Yannakakis et al., 2010). However, only a few of them investigated the influence of HUDs on player behavior, and more specifically on player experience.

The aim of the present research was to understand how HUD design choices influence player experience and to propose solutions to optimize player-video game interaction. The present study was composed of two experiments. Experiment 1 aimed to understand how and to what extent players use and experience HUDs in existing commercial games. Experiment 2 aimed to understand more precisely the influence of the most essential HUD characteristics on player experience by manipulating them.

The current state of knowledge about HUDs in player-video game interaction is introduced in the following paragraphs. Then, user-centered theoretical frameworks useful to design HUDs are presented.

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

HUDs are important parts of video game visual interfaces. They provide contextual information to the player, such as a score or health bar (Brooksby, 2008). However, few scientific studies have investigated the benefits of HUDs to player-video game interaction. Actually, this issue has been mostly debated in the industrial community. For example, Wilson (2006) proposed several reasons to abandon classical HUDs. This game designer claimed that HUDs decrease player immersion in the game environment and increase unnecessarily the amount of information to be processed by the player, particularly by a beginner. He suggested integrating all contextual information within the main action area. Elements would be displayed in a “diegetic” way. In such a way, contextual information would be directly integrated within the game world, and not superimposed on, as if virtual characters could see and use it. For example, in a shooter game, remaining ammunition could

be displayed directly on the gun used by the virtual character (and the player). In contrast, Breda (2008), suggested that these arguments are not valid because HUDs have always been a conventional way to display contextual information in a game. However, these opinions were not proven with empirical results.

More recently, researchers conducted scientific studies about HUDs in video games. Jørgensen (2012) investigated the acceptance of HUDs in games by players. Contrary to certain game designer opinions, the author showed that HUDs are accepted, and even desired. That was true for all kinds of HUDs, even the most intrusive. In contrast, HUDs entirely integrated within the action scene or invisible are not always desired. The author also showed that the main condition for high acceptance is that displayed information should be useful for the player. Other studies investigated the influence of isolated characteristics of HUDs on the player performance and experience. Sabri et al. (2007) and Caroux et al. (2011) studied the effects of the spatial organization of contextual information in video games. Sabri et al. (2007) have shown that in the interfaces of high-resolution video games, spread across several monitors, the important context information that is most frequently consulted or used should be as close as possible to the cursor controlled by the player. In multi-monitor configurations, players have been found to perform their best when the context information is displayed on the monitor that is actually used. Caroux et al. (2011) studied the influence of the screen position of important context information (the score) on players' performance in a game requiring the visual anticipation of moving obstacles. The authors showed that positioning the score close to the area in which the obstacles were expected to move did facilitate the anticipation of these movements. Furthermore, players' performance was better when the score was positioned just outside, rather than even partially superimposed on, the area of anticipation.

In sum, there are still rather few findings from scientific research. It would be difficult for game designers to know what they have to do exactly to design a perfect HUD from these results only.

Thus, it may also be useful to take into account general user-centered theoretical frameworks for interface design that exist in the HCI literature.

1.2. User-centered theoretical frameworks for the design of visual interfaces and head-up displays

Several theoretical frameworks for interface design exist in the HCI literature. These models are based on the fact that users must, to realize their tasks, divide their attention between the different sources of information, acquire the necessary information, and integrate that information. Two frameworks are especially relevant to designing visual interfaces and HUDs.

First, the proximity-compatibility principle can be used to explain and optimize information integration. Wickens and Carswell (1995) demonstrated that two information sources requiring divided attention in service of integration during a common task or mental operation should be placed close to each other in the display. In contrast, pieces of information used in isolation can be placed farther apart. Maximizing the spatial or temporal proximity reduces the amplitude of attentional moves in divided attention situations.

Second, the framework of the salience, effort, expectancy, and value (SEEV) model (Wickens et al., 2003; Wickens and McCarley, 2008) can help predict users' eye movements on the areas of interest (AOIs) of dynamic visual displays. The model claims that the probability of attending to each particular AOI results from four factors. The visual salience of the area and the effort needed to access the information (i.e., the distance between the AOI and other information sources) depend on the physical characteristics of the display. The two additional factors are the user's expectancy to find relevant information in each AOI (which is linked to the frequency of information changes in this area) and the value of the information for the user.

These two frameworks are usually applied to the design of productivity systems, in which users' performance is essential. However, they can also be used for the design of entertainment systems, such as video games. For example, Caroux et al. (2011) showed that the proximity-compatibility principle could be adapted to design interactive environments, such as video games, that require visual anticipation. They showed that the main elements of contextual information should be located in the expected direction of anticipation but should not overlap with the main action and anticipation zones.

1.3. The present research

The aim of the present research was to understand how HUD design choices influence player experience. The present study was composed of two experiments. Experiment 1 was an exploratory experiment on HUDs in existing commercial games. More precisely, the goal was to understand how and to what extent players use and experience HUDs. The characteristics of HUDs that are essential and that potentially have the highest influence on player experience were extracted and manipulated in Experiment 2. The goal of this experiment was to understand more precisely the influence of HUD characteristics on player experience. Findings can be used to propose some recommendations for design of video games and, more generally, virtual environments. The first general hypothesis for the present study was that choices of HUD design influence player experience. In each experiment, player expertise and game genre were manipulated to measure variations of player experience according to these elements. Thus, the second general hypothesis was that choices of HUD design influence player experience in different ways according to player expertise and game genre.

2. Experiment 1

2.1. Goal and hypotheses

The goal of experiment 1 was to understand how HUDs in existing video games are used and experienced by players. More precisely, the goal was to understand how and to what extent players use and experience HUDs according to their expertise (novice or expert) and the game genre. Two types of existing commercial games were selected: a first-player shooter (FPS) game and a real-time strategy (RTS) game. In an FPS game, players are engaged in battles, in general with firearms, in which the action is experienced through the eyes of the protagonist. In an RTS game, players are engaged in battles in which they issue orders to several units simultaneously to gain control of the battlefield. The action is displayed from a top-down perspective of the whole action. The selection of these games was based on their high difference of HUD design, especially in terms of amount of information (see Figure 1). In modern games, HUDs of these two game genres tend to follow radically different visual styles. More precisely, HUDs in FPS games are much more minimalist than HUDs in RTS games. In FPS games, HUDs generally display a few elements of information about the status of weapons and ammunitions and orientation within the virtual world. In contrast, HUDs in RTS games display a lot of elements and look visually more complex. This is linked to the high complexity of the virtual game world and the large number of possible actions offered to the player. HUDs of RTS games generally displayed elements of management and status of units, management of possible actions, and virtual world status.

Two methods of investigation were used in the present experiment. Eye tracking was used to measure the use of HUDs by players during the game. This method is usually used to reveal visual processing of interfaces in real-time (e.g., Rayner, 2009 for a review). Post-game interviews (e.g., Hoonhout, 2008) were used to measure players' HUD experiences.

The nature of this experiment was exploratory. However, several hypotheses based on the literature, and more specifically on the SEEV model (Wickens et al., 2003), were formulated in addition to one research question. Since the number of HUD elements is higher in RTS games than in FPS games, then:

H1 - Players' gaze is more frequently present and for a longer time on HUDs.

H2 - Players judge RTS HUD more useful than FPS HUD.

Moreover, the visual attention of novice players should be more focused on the main action of the game, since they are still discovering it. Then:

H3 - Novice players' gaze is less frequently present and for a shorter time on HUDs than expert players' gaze.

H4 - Novice players judge HUDs less useful than expert players.

Finally, one of the purposes of this experiment was to identify the critical characteristics of these typical HUDs. The research question was:

RQ - What are the critical characteristics of HUDs in FPS and RTS games for player experience?

2.2. Method

2.2.1. Participants

A total of fifteen volunteers (6 women) aged $M = 27.5$ years ($SD = 5.5$) took part in the experiment. All participants had normal or corrected-to-normal vision. The participants were recruited according to their expertise in playing two specific genres of video games: FPS and RTS. Table 1 shows the number of participants within each group of expertise. Expertise was determined by asking the participants the number of hours per week they played games of a given genre in the last 6 months.

This method was selected because of its wide use in the literature (e.g., Castel et al., 2005; Green and Bavelier, 2003; West et al., 2013). More precisely, in the present experiment, participants who played *more* than an hour per week on average in the six last months were categorized as expert players. Participants who played *less* than an hour per week on average in the six last months were categorized as novice players. Note that the participants were asked about their experience with the genre of games in question. They were not asked about their expertise with the specific games that were used in the present study (i.e. *Call of Duty* or *Starcraft*, see the “material” section below for details). As RTS games or FPS games share many similarities between them, in terms of game design but also in terms of visual interface design, the expertise in one or several RTS or FPS games could be easily transferred when playing other games of the same genre.

[Insert Table 1 near here]

2.2.2. Apparatus

A head-free SMI RED eye-tracker with a 17-inch screen (1280 x 1024 pixels) was used to mimic, as accurately as possible, natural interaction with a virtual environment. A single computer controlled the eye-tracker and collected all the data. Gaze positions were obtained at 50 Hz with an average precision of 0.4 degrees of visual angle (4 to 5 mm on the screen depending on the distance between the eye-tracker screen and the participants). Eye movements were analyzed using SMI BeGaze 3.2.28 software. Eye fixations were defined as any period where the gaze remained focused for 60 ms (three successive gaze points) or more within an area of 30 pixels in diameter (about 10 mm or 0.9 deg of visual angle). The participants interacted with the video game with a keyboard and a mouse. A microphone and audio recording software were used to collect verbal data during the interview phase of the experiment.

2.2.3. Material

Two fairly recent, critically well-received, commercial video games were used: an FPS game and an RTS game. The FPS game was *Call of Duty 4: Modern Warfare* (Activision, 2007). The RTS game was *Starcraft 2: Wings of Liberty* (Blizzard Entertainment, 2010). The games and their HUDs were not modified. A semi-directed interview was also designed. The questions were based on the main characteristics of HUD that were studied in the literature. Participants were asked about their feelings during the game about the composition of the HUD, the spatial organization of the HUD, the integration of the HUD in the main action area, their overall feeling about the HUD, and the perceived help the HUD provided.

2.2.4. Design and procedure

Genre of video game, FPS or RTS, and player expertise for each genre, novice or expert, were manipulated between-participants. Three participants were in the FPS expert group. Five participants were in the FPS novice group. Three participants were in the RTS expert group. Four participants were in the RTS novice group. Whatever the experimental condition, participants played two existing missions of the game. They played the first mission for 5 minutes as a practice game. No measure was done during this mission. Then, they played the second mission for 15 minutes. Eye movements were recorded during this mission. After a short pause, the participants answered the interview questions orally.

2.2.5. Dependent measures

Two sets of measures were defined. The first set of measures was computed from eye movement data. Each game HUD was divided into several areas of interest (AOI). The number of these AOI depended on the game genre.

The FPS game HUD was divided into six AOIs (Figure 1). The first three AOIs concerned permanently displayed information and covered the locations of compass (size 300 x 94 pixels), available guns (size 153 x 301 pixels) and ammunition (size 238 x 133 pixels). The total size of the HUD AOIs that covered permanently displayed information represented 8.08 % of the game's visual interface. The three other AOIs concerned occasionally displayed information and were activated only when some information was actually displayed. They covered two locations of messages to the player (first one: size 1132 x 106 pixels; second one: size 583 x 219 pixels) and the location of missions (size 911 x 122 pixels).

The RTS game HUD was divided into eight AOIs (Figure 1). The first five AOIs concerned permanently displayed information and covered the locations of map (size 320 x 309 pixels), units' management (size 611 x 202 pixels), action buttons (size 349 x 227 pixels), missions (size 250 x 118 pixels) and resources (size 327 x 100 pixels). The total size of the HUD AOIs that covered permanently displayed information represented 27.75 % of the game's visual interface. The three other AOIs concerned occasionally displayed information and were activated only when some information was actually displayed. They covered the locations of messages to the player (size 254 x 100 pixels), tip buttons (size 186 x 143 pixels) and action buttons help (size 349 x 173 pixels).

[Insert Figure 1 near here]

The first gaze-related dependent variables were the mean number of eye fixations made during the game in the whole game screen, the whole HUD AOIs and in each AOI. The second ones were the mean duration of fixation in the whole game screen, the whole HUD AOIs and in each AOI.

The second set of measures was composed of five variables that were computed from the interview data (composition, spatial organization, integration, global, help). The answers given by the participants for each topic of the interview were split into three categories of valence: good feeling (1), neutral feeling (0) and bad feeling (-1). One and only one category was attributed for each participant and for each of the five topics of the interview. Furthermore, qualitative analyses of interview scripts were realized to find the specific elements of the HUD that influenced the participants' feelings.

2.3. Results

2.3.1. Eye movements

Data were analyzed using ANOVAs with the game genre and player expertise as between-participants factors. Then, further analyses were made for each game genre with player expertise as a between-participants factor and the type of AOI as a within-participants factor.

2.3.1.1. Number of eye fixations

Table 2 shows that there was no significant difference in number of eye fixations made on the whole game screen with respect to the game genre, $F(1, 11) = 1.29, p = .28$, or player expertise, $F(1, 11) = 3.16, p = .10$. Interaction between game genre and player expertise was not significant either, $F(1, 11) < 1$.

In contrast, Table 2 shows that the number of eye fixations made by participants was higher within the RTS HUD than in the FPS HUD, $F(1, 11) = 14.62, p < .01, \eta^2_p = .57$. There was no significant difference between expert and novice players, $F(1, 11) < 1$, and the interaction between game genre and player expertise was not significant, $F(1, 11) < 1$.

Regarding the FPS HUD, Table 2 shows that the number of eye fixations made by participants in each AOI were different, $F(5, 30) = 7.78, p < .001, \eta^2_p = .57$. There were more fixations on the compass AOI

than on the other AOIs. There was no significant difference between expert and novice players, $F(1, 6) < 1$, and the interaction between AOI and player expertise was not significant, $F(5, 30) < 1$.

Regarding the RTS HUD, Table 2 shows that the number of eye fixations made by participants in each AOI were different, $F(7, 35) = 10.30, p < .001, \eta^2_p = .67$. There were more fixations on the map or units management AOIs than on the other AOIs. Then, there were more fixations on the action buttons AOI than on the remaining AOIs. There was no significant difference between expert and novice players, $F(1, 5) < 1$, and the interaction between AOI and player expertise was not significant, $F(7, 35) < 1$.

[Insert Table 2 near here]

Regarding the non-permanent elements of HUDs, such as messages, the results showed that they were not fixated much. However, since they were not displayed during the whole session of play, it is delicate to compare their amount of use and their impact on player experience with those of the permanent elements of HUDs. Consequently, mean ratios of number of fixations per element of information actually displayed in each non-permanent area of HUD were calculated and displayed in Table 3. Descriptive analyses showed that in FPS HUDs novice players fixated more the “messages” AOIs than expert players. In RTS HUDs the “tips buttons” and “action button help” AOIs were more fixated by novice players than by expert players.

[Insert Table 3 near here]

2.3.1.2. Mean duration of fixations

Table 2 shows that the mean duration of fixations made on the whole game screen was higher for novice players than for expert players, $F(1, 11) = 6.47, p < .05, \eta^2_p = .37$. There was no difference with respect to game genre, $F(1, 11) = 2.53, p = .14$. The interaction between game genre and player expertise did not reach significance, $F(1, 11) < 1$.

Table 2 shows that the mean duration of fixations made on the whole HUD was higher for novice players than for expert players, $F(1, 11) = 6.99, p < .05, \eta^2_p = .39$. There was no difference with respect to game genre, $F(1, 11) = 1.90, p = .20$. The interaction between game genre and player expertise did not reach significance, $F(1, 11) < 1$.

Regarding the FPS HUD, Table 2 shows that there was no significant difference of mean duration of fixations with respect to the type of AOI, $F(5, 30) = 2.22, p = .08$, or player expertise, $F(1, 6) = 3.24, p = .12$. Interaction between game genre and player expertise was not significant either, $F(5, 30) < 1$.

Regarding the RTS HUD, Table 2 shows that the mean duration of fixations made by participants in each AOI were different, $F(7, 35) = 4.54, p < .01$. The higher mean duration of fixations was on the actions AOI. In contrast, the lower mean duration of fixations was on the missions and resources AOIs. There was no significant difference between expert and novice players, $F(1, 5) = 1.92, p = .23$, and the interaction between AOI and player expertise was not significant, $F(7, 35) < 1$.

2.3.2. Interviews

The five variables were analyzed using log-linear analyses with the score of valence, the genre of game and the player expertise as predictors. For each variable, a qualitative analysis of the interview scripts was added to the analysis of the scores of valence.

2.3.2.1. HUD composition

The three-way loglinear analysis indicated that the three-way interaction (genre x expertise x composition interaction) was significant, $\chi^2 (2) = 6.67, p < .05$. To break down this effect, separate chi-square tests were performed separately for FPS and RTS games. However they did not show significant effect of expertise on the score, $\chi^2 (2) = 4.8, p = 0.09$ for FPS game, and $\chi^2 (2) = 4.28, p = 0.12$ for RTS game. A visual analysis of the results showed that the RTS HUD composition was better perceived by expert players than novice players (Figure 2a). There was no difference of feeling for FPS between novice and expert players.

The qualitative analysis of the interview scripts showed that, for the FPS game, the compass was considered as an important element of the HUD, and that ammunition and available guns were not important elements. Several novice and expert players shared this feeling. Regarding the RTS game, several novice and expert players considered the map as an important element of the HUD. Several expert players considered action buttons as not important. Several novice players estimated that there were too many information elements within the HUD.

[Insert Figure 2 near here]

2.3.2.2. HUD spatial organization

The three-way loglinear analysis indicated that the three-way interaction (the genre x expertise x spatial organization interaction) was significant, $\chi^2 (2) = 9.17, p < .05$. To break down this effect, separate chi-square tests were performed separately for FPS and RTS. Figure 2b showed that for RTS, expert players better perceived the HUD spatial organization than novice players, $\chi^2 (2) = 7.00, p < .05$. For FPS, there was no difference between expert and novice players, $\chi^2 (2) = 4.59, p = 0.10$.

The qualitative analysis of the interview scripts showed that, for the FPS game, several novice and expert players estimated that HUD elements were too far from the main action area. Regarding the RTS game, several novice players disliked the horizontal layout of elements at the bottom of the screen and suggested to organize them vertically on the side of the screen.

2.3.2.3. HUD consistency

The three-way loglinear analysis did not indicate that the three-way interaction (the genre x expertise x consistency interaction) was significant, $\chi^2(2) < 1$. However the two-way interaction expertise x consistency was significant, $\chi^2(2) = 7.32, p < .05$. Figure 2c shows that expert players better perceived the HUD consistency than novice players. The two-way interaction game genre x consistency was not significant, $\chi^2(2) = 1.27, p = .53$. No specific elements were extracted from the qualitative analysis of interview scripts.

2.3.2.4. Global feeling of the HUD

The three-way loglinear analysis did not indicate that the three-way interaction (genre x expertise x global feeling interaction) was significant, $\chi^2(2) < 1$. The two-way interactions were not significant either, $\chi^2(2) = 2.44, p = .29$ for expertise x global feeling, and $\chi^2(2) < 1$ for game genre x global feeling. No specific elements were extracted from the qualitative analysis of interview scripts.

2.3.2.5. Perceived helpfulness of HUD

The three-way loglinear analysis did not indicate that the three-way interaction (genre x expertise x perceived helpfulness interaction) was significant, $\chi^2(2) = 2.12, p = .34$. The two-way interactions were not significant either, $\chi^2(2) = 2.97, p = .23$ for expertise x perceived helpfulness, and $\chi^2(2) = 1.78, p = .41$ for game genre x perceived helpfulness. The qualitative analysis of the interview scripts showed that, for the FPS game, several novice players said that they did not actually use the HUD during their game session.

2.4. Discussion

2.4.1. HUD use and experience by players

The hypotheses regarding differences between RTS and FPS HUDs were that (H1) players' gaze is more frequently present and for a longer time on HUDs, and (H2) players judge RTS HUD more useful than FPS HUD. They were mainly supported. Eye movements and interview results were in line. Results showed that the RTS HUD was more fixated (looked at more often) than the FPS HUD. Participants said that the RTS HUD displayed more important and useful information than the FPS HUD. These results can be explained by two points, in relation with the SEEV model (Wickens et al., 2003; Wickens and McCarley, 2008). On the one hand, the size of the RTS HUD was larger than the FPS HUD (27.75% vs. 8.08% of the screen). The probability of fixation on HUD was higher for the RTS game, in line with the "salience" aspect of the SEEV model. On the other hand, the RTS HUD contained more useful information for players than the FPS HUD, in line with the "value" aspect of the SEEV model. For example, action buttons, which can be clicked to give orders to the game or display more information, were displayed within the RTS HUD. In contrast, the FPS HUD did not display clickable information. However, results did not show that the RTS HUD elements were longer fixated than the FPS HUD ones, as was expected.

Regarding differences between novice and expert players, hypothesis 3 was that novice players' gaze is less frequently present and for a shorter time on HUDs than expert players' gaze. It was not supported. There was no significant difference of number of fixations between novice and expert players, regardless of the game genre. Contrary to expectations, the duration of fixation was higher for novice players than for expert players. The reason could be that information processing was higher because of the novelty of information for novice players. In contrast, hypothesis 4, which was that novice players judge HUDs less useful than expert players, was supported, but for the RTS HUD only. Interviews results showed differences of feelings for the RTS HUD. Novice players had a quite negative feeling, while expert players had a quite positive one. The high complexity of the RTS HUD

could make comprehension difficult by novice players. Expert players would not be impacted because of their familiarity with the design standards of this genre.

Regarding the relation between the objective eye tracking data and the subjective interview data, we noted that they were substantially in line. In particular, data about the amount of eye fixations on the different elements of HUDs and the subjective feelings showed similar results. For example, findings about the critical characteristics of HUDs are quite identical (see next section for details). However, findings between objective and subjective data were not similar regarding the influence of player expertise on player experience. Interview data showed clear differences of subjective feelings between expert and novice players while eye-tracking data revealed almost no influence of player expertise on players' visual behavior. The most interesting example was that several novice players said that they did not use the HUD when playing the FPS game. Eye tracking data analyses showed that novice players actually used HUDs (or at least fixated them), and that there was no significant difference with expert players.

Finally, from a global point of view, these results were in line with those of Jørgensen (2012). HUDs in video games are useful for players and are actually used regardless of game genre and player expertise.

2.4.2. Critical characteristics of HUDs

The research question was: What are the critical characteristics of HUDs in FPS and RTS games for player experience? The present experiment revealed two critical characteristics of HUDs, which should be cautiously considered by designers: composition and spatial organization. These characteristics were used and experienced differently according to game genre and player expertise.

Regarding the composition of HUDs, results from analyses of eye movement data and interviews showed that, among permanently displayed elements, the compass should be considered as the main element for FPS games. In contrast, ammunition and available guns should be considered as

secondary elements. For RTS games, the map should be considered as the main element, and the units and action buttons as secondary elements. Other permanent elements can be considered as negligible elements since they were rarely used. Regarding the non-permanent elements of HUDs, the results showed that they were not fixated much, but ratios of number of fixations per items actually displayed showed that some of them were actually used. However, the low number of data and the high variability between participants limit strong conclusions about their impact on player experience. These results suggest that further studies should be designed to specifically investigate the impact of non-permanent elements on player experience. Therefore, experiment 2 focused only on permanent elements of HUDs.

Regarding the spatial organization of HUDs, results from qualitative analyses of the interview scripts suggested that FPS HUDs could be optimized by displaying elements as close as possible to the main action area for FPS games. The results also suggested that RTS HUDs could be optimized by arranging elements vertically on one side of the screen.

2.4.3. Rationale of experiment 2

The aim of experiment 2 was to understand and optimize the influence of choices of design of HUD characteristics on player experience, according to game genre and player expertise. The manipulated characteristics, HUD composition and spatial organization, were extracted from the results of Experiment 1. The experimental conditions were designed from the eye movement and interviews results of Experiment 1, as they were discussed in the previous sub-section, but also according to the literature (e.g., Caroux et al., 2011; Wickens and Carswell, 1995).

Several HUD screenshots with different composition or spatial organization were presented to players of different levels of expertise. For each HUD, players had to share their feelings on several dimensions: feeling about the HUD composition, feeling about the spatial organization, and global feeling about the HUD. Manipulated HUDs were designed from HUDs of existing commercial games.

To keep the present study as homogeneous as possible, the games used in experiment 2 were the same games used in experiment 1. Several hypotheses were proposed in line with the general hypotheses of the present study.

3. Experiment 2

3.1. Goal and hypotheses

The goal of experiment 2 was to understand the influence of HUD composition and spatial organization on player experience, according to player expertise and game genre. For each game genre (FPS or RTS), two sets of HUDs were designed following the results of experiment 1 and literature (Caroux et al., 2011; Wickens and Carswell, 1995). The first set was composed of four types of HUD designed by manipulating their composition: without modifications (original version), without main element, without secondary element, without any elements (considered as a “control” version) (see Figure 3). Main and secondary elements were determined according to the results of experiment 1. The second set was composed of five types of HUD designed by manipulating their spatial organization: the original HUD, two HUDs with the main element position modified, and two HUDs with the secondary element position modified. The first modified position was on the top center of the screen, and the second one was on the right center of the screen (see Figure 4). In line with the results of experiment 1, the top center position was specifically designed to optimize the player experience with FPS game, while the right center one was specifically designed to optimize the player experience with RTS game. For each HUD, the other position, i.e. top center for RTS game and right center for FPS, was used as a control condition in the experimental design.

Hypotheses 1 and 2 were designed regarding the manipulation of HUD composition, and were based on the results of experiment 1:

H1 - HUD composition has an effect on player experience.

H2 - The interaction between HUD composition and player expertise has an influence on player experience.

More precisely, we expected that player experience is higher with original HUD and HUD without secondary element than on control HUD and HUD without main element. We also expected that these differences are augmented with player expertise.

Hypotheses 3 and 4 were designed regarding the manipulation of HUD spatial organization, and were based on the results of experiment 1 and literature:

H3 - HUD spatial organization has an effect on player experience.

H4 - The interaction between HUD spatial organization and player expertise has an influence on player experience.

More precisely, we expected that for FPS games the player experience is better when the HUD is designed in accordance with the proximity-compatibility principle adapted by Caroux et al. (2011), i.e. when the main element is displayed on the top of the screen, since in FPS games the direction of anticipation is generally expected on the top part of the screen. For RTS games, we expected that the player experience is better when HUD is organized vertically, i.e. when the main element is located on a side of the screen (right side in the present study), in accordance with results of Experiment 1.

3.2. Methods

3.2.1. Participants

A total of forty-eight volunteers (6 women) aged $M = 22.8$ years ($SD = 5.55$) took part in the experiment. They were categorized on the one hand in three groups according to their expertise in FPS playing, and on the other hand in three other groups according to their expertise in RTS playing. Table 4 shows the number of participants within each group of expertise, which was measured by the average time played per weeks for the previous 6 months.

[Insert Table 4 near here]

3.2.2. Material

Four sets of screenshots were designed based on both commercial games used in experiment 1, namely *Call of Duty 4: Modern Warfare* (Activision, 2007) and *StarCraft 2: Wings of Liberty* (Blizzard Entertainment, 2010). The first two sets (FPS-compo and RTS-compo sets) were designed by manipulating the HUD composition (figure 3). The two other sets (FPS-spatial and RTS-spatial sets) were designed by manipulating the HUD spatial organization (figure 4).

[Insert Figure 3 near here]

[Insert Figure 4 near here]

FPS-compo and RTS-compo sets were composed of 4 screenshots each, designed as following. The first screenshot (Full HUD) was the original version of the screenshot; no modifications were made on this HUD. The second one was the same as the original one without the main element display (i.e. compass for FPS, mini-map for RTS). The third one was the same as the original one without the secondary element display (i.e. ammunition for FPS, action buttons for RTS). The fourth one was the same as the original one without all the HUD elements (empty HUD). Only the permanent, peripheral elements were removed. Elements integrated in the main action area or occasionally displayed (e.g., crosshair, units' health) were not removed.

FPS-spatial and RTS-spatial sets were composed of 5 screenshots each, designed as following. The first screenshot (Full HUD) was the original version of the screenshot; no modifications were made on the HUD. The second one was the same as the original one with the main HUD element displayed

on the top center of the screen. The third one was the same as the original one with the secondary HUD element displayed on the top center of the screen. The fourth one was the same as the original one with the main HUD element displayed on the right center of the screen. The fifth one was the same as the original one with the secondary HUD element displayed on the right center of the screen. To obtain a graphically coherent HUD, in this last condition for the RTS game, the mini-map (main HUD element) was displayed in the original location of the action buttons display (secondary HUD element).

A questionnaire composed of three statements was designed. The subject of these statements was the characteristics that were manipulated: feelings about HUD composition, feelings about HUD spatial organization and global feelings about HUD. For each statement, a 10-point Likert-type scale was proposed to collect the feelings of participants (from 1 = Strongly Disagree to 10 = Strongly Agree). The three statements were: “I like the composition of this HUD (e.g., nature, number of elements, ...)”, “I like the spatial organization of this HUD (e.g., layout, elements’ location, ...)” and “Overall, I like this HUD”. Screenshots and questionnaire were displayed on a computer screen. Participants answered using a cursor controlled with a mouse.

3.2.3. Design and procedure

Player expertise was manipulated between-participants (3 groups for FPS and 3 other groups for RTS). HUD composition (4 conditions) and spatial organization (5 conditions) were manipulated within-participants. One screenshot by condition was presented to the participants. All the screenshots were presented to each participant. The order of their presentation was randomized to avoid any biases linked to ordering effects. For each screenshot, participants had to judge the three statements about their feeling on the HUD composition, the HUD spatial organization and their general feeling.

3.2.4. Dependent measures

The three measures used in the present experiment were the rating given by the participants for the HUD composition, HUD spatial organization and global feeling statements for each HUD condition (i.e. for each screenshot). Each score was given on a Likert-type scale from 1 to 10.

3.2.5. Statistical analyses

Differences of manipulations of HUDs (composition and spatial organization) and differences of expectations of effects between games genres (FPS and RTS) required specific statistical analyses for each set of screenshots. Consequently, four different sets of analyses were performed by using ANOVAs:

HUD composition (FPS-compo or RTS-compo sets). The scores of feeling about composition and global feeling statements were analyzed with players' FPS or RTS expertise as between-participants factor and HUD composition as within-participants factor. The score of feeling about spatial organization was not analyzed because spatial organization was not manipulated in these sets of screenshots.

HUD spatial organization (FPS-spatial or RTS-spatial sets). The scores of feeling about spatial organization and global feeling statements were analyzed with players' FPS or RTS expertise as between-participants factor and HUD spatial organization as within-participants factor. The score of feeling about composition was not analyzed because composition was not manipulated in these sets of screenshots.

3.3. Results

The results of the ANOVAs that were performed to analyze the data, and the significant effects and interactions are displayed in Table 5.

[Insert Table 5 near here]

HUD composition in the FPS game. Figures 5a and 5b show that the HUD manipulation had a significant effect on the HUD composition statement and the general feeling statement ratings. The full HUD was rated more highly than the other HUDs. Player expertise had no significant effect on the ratings. Interaction between the two factors did not reach significance.

[Insert Figure 5 near here]

HUD composition in the RTS game. Figures 6a and 6b show that the HUD manipulation had a significant effect on the HUD composition statement and the general feeling statement ratings. The full HUD was preferred to the other HUDs. Then, HUDs without secondary element or main element were rated more highly than the empty HUD. Player expertise did not have a significant effect on the ratings. However, interaction between the two factors reached significance for the general feeling statement rating. The higher player expertise was, the larger the differences of ratings between HUD conditions were. This interaction did not reach significance for the HUD composition statement rating.

[Insert Figure 6 near here]

HUD spatial organization in the FPS game. Figures 7a and 7b show that the HUD manipulation had a significant effect on the HUD spatial organization statement and the general feeling statement ratings. The original HUD was rated more highly than the other HUDs. Then, the HUD with the main

element at the top of screen was rated more highly than the remaining HUDs. Finally, the HUDs with the secondary element at the top or right side of screen were preferred to the HUD with the main element at the right side of screen. Player expertise did not have a significantly effect on the ratings. Interaction between the two factors did not reach significance.

[Insert Figure 7 near here]

HUD spatial organization in the RTS game. Figures 8a and 8b show that the HUD manipulation had a significant effect on the HUD spatial organization statement and the general feeling statement ratings. The original HUD was rated more highly than the other ones. Then, the HUDs with the elements on the right side of screen were preferred to HUDs with the elements on the top of screen. Player expertise did not have a significantly effect on the ratings. However, interaction between the two factors reached significance for the general feeling statement rating. The higher player expertise was, the larger the differences of ratings between HUD conditions were. This interaction did not reach significance for the HUD spatial organization statement rating.

[Insert Figure 8 near here]

3.4. Discussion

3.4.1. HUD composition

Hypothesis 1 was that HUD composition has an effect on player experience. It was supported. In general, full HUDs were preferred to the other ones. HUDs whose permanent elements were removed were the least preferred. In line with results of experiment 1, players wanted to get access to all contextual information to play. However, contrary to our expectations, there was no difference between the HUDs without main or secondary element, whereas results of experiment 1 showed that the compass (FPS game) or the map (RTS game) were the most important elements in their respective HUDs. The explanation could be that composition is not a characteristic strong enough to reveal thin differences with this type of manipulation.

Hypothesis 2 was that the interaction between HUD composition and player expertise has an influence on player experience. It was supported only for the RTS HUD. The higher player expertise was, the better the full HUD and the worse the empty HUD were experienced. This can be explained by the fact that the higher player expertise is, the more familiar the original HUD is, and then the higher it is preferred to the other ones. However, this was not observed for the FPS HUD. This can be explained by the fact that this HUD was not useful enough for players to reveal this kind of result.

3.4.2. HUD spatial organization

Hypothesis 3 was that HUD spatial organization has an effect on player experience. It was supported. However, contrary to our expectations, original HUDs (i.e. without modification) were rated more highly than the other ones for both game genres. If we analyze the common feature between both original HUD layouts, the explanation could be that participants preferred HUDs where all contextual information was displayed in a line at the bottom of the visual interface. Indeed, both original HUDs displayed most of their elements, including main and secondary ones, in a line at the bottom of the screen. Thus, displaying all permanent contextual information at the bottom of the screen would be

preferred by players, regardless their expertise, even if that doesn't entirely follow design guidelines given by the literature. The two following paragraphs discussed differences of rating between the modified HUDs (i.e. without the original HUD).

Regarding the remaining HUDs for the FPS game, i.e. the non-original HUDs, the HUD with the main element displayed on the top of the screen was rated more highly than the three other remaining HUDs. This result seems to be in line with the proximity-compatibility principle adapted by Caroux et al. (2011). Similarly, the HUD with the main element displayed on the right of screen, i.e. that doesn't follow this principle, was the least liked HUD. Finally, the non-significant difference of player experience between HUDs with modified position of the secondary element seemed to be also in line with the proximity-compatibility principle adapted by Caroux et al. that recommends its application only for the main elements of HUD.

Regarding the remaining HUDs for the RTS game, i.e. the non-original HUDs, HUDs in which elements were vertically displayed (on the right side of screen) were preferred to those in which elements were displayed on the top of the screen. This could be explained by the fact that the different HUD layouts left different shapes of action area on the screen (see figure 4). When the elements were vertically displayed, contextual information was only displayed in the bottom right corner of the screen. When some elements were displayed on the top of the screen, the result was that HUD was scattered in different place of the screen. In this last case, the shape of the action area was more complex than in the first case.

Hypothesis 4 was that the interaction between HUD spatial organization and player expertise has an influence on player experience. It was supported only for the RTS HUD. The higher player expertise was, the better the original HUD and the worse HUDs with elements displayed on the top of the screen were rated. As for RTS HUD composition, this can be explained by the fact that the higher player expertise is, the more familiar the original HUD is, and thus the more it is preferred to the

alternate HUDs. Again, this was not observed for the FPS HUD. This can be explained by the fact that this HUD was not useful enough for players to reveal this kind of result.

4. General discussion

4.1. HUD design choices and player experience

The present study is, to the best of our knowledge, the first one to experimentally investigate the influence of HUD design choices and player expertise on player experience in commercial video games. Both experiments raised several findings about HUD design and player experience. Four noteworthy points can be extracted from the results of these experiments.

First, choices of HUD design influence player experience in different ways according to player expertise and game genre. For games with HUDs that are perceived as very useful (i.e. in RTS games for the present study), the higher player expertise is, the more effect the HUD has on player experience.

Second, composition and spatial organization are characteristics of HUDs that have particular effects on player experience.

Third, Experiment 2 showed that original HUDs were preferred over all others. This kind of result was not in line with our expectations, which were that HUDs that respect ergonomic principles of information integration, such as the proximity-compatibility principle, would optimize player experience. As explained in the discussion section of Experiment 2, it seemed that participants generally preferred when the majority of contextual information was displayed in a line at the bottom of the visual interface. This observation was particularly true for expert players and RTS HUDs.

Fourth, regarding the non-original HUDs (i.e. modified ones), HUDs that were designed in accordance with ergonomic principles of information integration were better experienced than those that do not respect them. More precisely, for games that require visual anticipation in a specific direction on the screen (e.g., FPS game), displaying the main element of HUD in this direction and close to the main

action area could optimize player experience. Thus, the present study showed that the proximity-compatibility principle, which concerns the influence of HUD design choices on user performance, may be also applicable for player experience.

The last two points together suggest that further studies are needed to investigate how and to what extent the design of video game HUDs could combine the facts that most of contextual information should be displayed in a line at the bottom of the visual interface and that two information sources (from action area and HUD) requiring integration should be placed close together.

4.2. Limitations of the present study

There were some limitations in the present study that could attenuate these findings. First, some elements could explain the lack of generalization of effects of player expertise in each experiment. In experiment 1, a larger sample size could have revealed other effects, in particular more differences of visual behaviors between novice and expert players. Another explanation for both experiments could be that the method used in the present study to qualify video game expertise in a specific game genre (number of hours/week of gameplay for the previous 6 months) was not accurate enough. While this method is widely used in the literature (e.g., Castel et al., 2005; Green and Bavelier, 2003; West et al., 2013), it doesn't take in account, for example, the historical experience of the player, especially the game experience during childhood and adolescence when the human brain is most malleable (see for example Latham et al., 2013 for a detailed discussion about this topic).

Second, only two genres of video games were used in the present study, namely FPS and RTS games. This may limit the generalization of the findings. Furthermore, only one game was used per genre, in particular in experiment 2. Further studies should replicate the findings of the present study by using other screenshots of other games.

Finally, in experiment 2, material was composed of screenshots of video games where HUDs were modified. Even if participants were placed in situation to judge these HUDs as if they were actually

playing games, they were not really in interaction with them. The consequence is that it was difficult (if not impossible) to know whether participants indicated their aesthetic or functional preference and feelings. Further studies should investigate the influence of HUD characteristics within real player-game interaction to have a more complete understanding of player experience. Such studies could reveal specific information about their functional preference (and performance) and aesthetic preference. In particular, we could expect a greater impact of the proximity-compatibility principle on user experience than in the present study. Above all, this kind of principle was originally designed to improve actual use of displays.

4.3. Perspectives

This study opens perspectives for future work. For example, the present study focused on contextual information displayed in typical, current video games. These games are generally displayed on TV or computer screens where a virtual environment is represented in a 2D perspective. The rise of new approaches to display a video game, such as stereoscopic displays, virtual reality head-mounted displays or augmented reality displays, may change the way the design of visual interfaces affects user experience. Best choices of design of HUDs for these new approaches may also be different. Further studies should investigate how contextual information can be displayed in these situations to optimize user experience.

Another perspective is linked to the way player experience could be examined. Methods to measure player experience in the present study were essentially subjective and may not reveal all aspects of user experience in games. The literature showed that user experience, and more specifically player experience, can be measured by a combination of objective and subjective methods (see Caroux et al., 2015a for a review). Further studies could use more objective methods, such as physiological measures, to investigate effects of HUD design choices on other aspects of user experience such as emotional aspects.

4.4. Practical implications

Even if the results observed in the present study should be completed with further studies, some recommendations to optimize player experience when designing HUDs can be proposed. They are based on results obtained in the present research about FPS and RTS games, but they could be generalized to games that share similar characteristics, especially in terms of visual interface design.

Recommendation 1 - Displaying a permanent HUD within the visual interface of a virtual environment such as a video game may improve the understanding of this environment by the user.

Recommendation 2 - The characteristics of composition and spatial organization of this HUD should be designed with particular attention.

Recommendation 3 - Regarding spatial organization, the majority of elements of HUD should be displayed in a line at the bottom of the visual interface.

Recommendation 4 - When displaying elements of HUD in a line at the bottom of the visual interface is not possible, specific ergonomic principles of visual interface design proposed initially to improve user performance (e.g. proximity-compatibility principle), may be applied to optimize user experience.

5. Conclusion

The two experiments highlighted several points useful in designing HUDs in virtual environments such as video games. First of all, they showed the real utility of displaying a permanent HUD within visual interfaces in video games for user experience. An experimental study was necessary to observe and understand how and to what extent players use and experience HUDs according to their expertise and the game genre, in addition to the first studies published about this topic (e.g., Jørgensen, 2012). The present experiments also showed that HUD design choices, in terms of composition and spatial organization have influence on player experience. Furthermore, these choices of HUD design influence player experience in different ways according to player expertise and game genre. For games with HUDs that are perceived as very useful (e.g., in RTS games), the higher player expertise is, the more player experience is influenced. Finally, further experiments should be made to complete these findings and to extend them to other types of video game and virtual environment displays.

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Table 1. Number of participants within each experimental group in Experiment 1

Expertise	FPS game	RTS game
Less than 1h / week	5	4
More than 1h / week	3	3

Note. Expertise was based on the number of hours per week of gameplay on average in the six last months in a specific genre.

Table 2. Mean number, proportion, and mean duration (in ms) of eye fixations made by participants in each area of screen in each condition (game genre x player expertise) of Experiment 1.

Element of game interface	FPS game						RTS game					
	Novice players			Expert players			Novice players			Expert players		
	Number of Fixations	%	Mean Duration	Number of Fixations	%	Mean Duration	Number of Fixations	%	Mean Duration	Number of Fixations	%	Mean Duration
Whole screen	2263 (946)	100.0	151 (22)	1501 (1796)	100.0	126 (35)	3023 (231)	100.0	181 (20)	1929 (521)	100.0	138 (25)
Whole HUD	107 (53)	4.7	139 (19)	106	7.1	114 (22)	701 (364)	23.2	184 (24)	465 (285)	24.1	143 (40)
<i>FPS AOIs</i>												
Compass	70 (35)	3.1	138 (21)	57 (85)	3.8	129 (21)	-	-	-	-	-	-
Guns	4 (5)	0.2	137 (44)	7 (11)	0.5	99 (18)	-	-	-	-	-	-
Ammunition	8 (6)	0.3	157 (41)	7 (10)	0.5	125 (7)	-	-	-	-	-	-
Messages 1	13 (18)	0.6	127 (15)	7 (6)	0.5	110 (8)	-	-	-	-	-	-
Messages 2	11 (13)	0.5	150 (19)	25 (28)	1.7	121 (39)	-	-	-	-	-	-
Missions	1 (2)	0.1	125 (31)	3 (4)	0.2	103 (4)	-	-	-	-	-	-
<i>RTS AOIs</i>												
Map	-	-	-	-	-	-	262 (199)	8.7	200 (40)	231 (208)	12.0	152 (52)
Units	-	-	-	-	-	-	207 (115)	6.9	170 (24)	180 (98)	9.3	137 (37)
Action Buttons	-	-	-	-	-	-	169 (69)	5.6	186 (38)	35 (54)	1.8	231 (122)
Missions	-	-	-	-	-	-	18 (25)	0.6	125 (19)	2 (3)	0.1	78 (25)
Resources	-	-	-	-	-	-	1 (1)	0.1	80 (0)	12 (11)	0.6	105 (14)
Messages	-	-	-	-	-	-	4 (3)	0.1	157 (32)	2 (1)	0.1	127 (46)
Tips buttons	-	-	-	-	-	-	15 (23)	0.5	144 (38)	1 (1)	0.1	80 (0)
Action buttons Help	-	-	-	-	-	-	26 (30)	0.9	171 (24)	3 (2)	0.1	152 (100)

Note. Standard deviations are shown in parentheses.

Table 3. Mean ratios of number of fixations per element of information actually displayed in each non-permanent element of HUD in each condition (game genre x player expertise) of Experiment 1.

AOI	FPS game		RTS game	
	Novice	Expert	Novice	Expert
<i>FPS AOIs</i>				
Messages 1	1.61 (2.21)	0.38 (0.35)	-	-
Messages 2	1.86 (1.80)	0.64 (0.67)	-	-
Missions	0.09 (0.14)	0.09 (0.13)	-	-
<i>RTS AOIs</i>				
Messages	-	-	0.16 (0.11)	0.06 (0.06)
Tips buttons	-	-	4.83 (7.76)	0.11 (0.19)
Action buttons Help	-	-	2.38 (2.44)	0.09 (0.06)

Note. Standard deviations are shown in parentheses.

Table 4. Number of the participants within each expertise group according to game genre in Experiment 2

Expertise	FPS game	RTS game
Less than 1h / week	10	14
1h to 5h / week	16	17
More than 5h / week	22	17

Note. Expertise was based on the number of hours per week of gameplay on average in the six last months in a specific genre.

Table 5. Results of ANOVAs performed in Experiment 2.

ANOVA	df	F-ratio	p-value	η^2_p	Significant effects or interactions
FPS / HUD composition					
HUD composition statement rating					
HUD composition	3, 135	8.23	< .001	.16	full > others
Player expertise	2, 45	1.98	.16	-	-
HUD composition x Player expertise	6, 135	1.09	.37	-	-
Global feeling statement rating					
HUD composition	3, 135	6.45	< .001	.13	full > others
Player expertise	2, 45	2.04	.14	-	-
HUD composition x Player expertise	6, 135	0.94	.47	-	-
RTS / HUD composition					
HUD composition statement rating					
HUD composition	3, 135	50.99	< .001	.53	full > others; w/o main <i>or</i> w/o secondary > empty
Player expertise	2, 45	1.83	.17	-	-
HUD composition x Player expertise	6, 135	1.94	.08	-	-
Global feeling statement rating					
HUD composition	3, 135	49.03	< .001	.52	full > others; w/o main <i>or</i> w/o secondary > empty
Player expertise	2, 45	0.35	.71	-	-
HUD composition x Player expertise	6, 135	2.45	< .05	.10	the higher player expertise is, the larger the differences between HUDs are
FPS / HUD spatial organization					
HUD spatial organization statement rating					
HUD spatial organization	4, 180	24.80	< .001	.36	original > others; main on top > secondary on top <i>or</i> secondary on right <i>or</i> main on right; secondary on top <i>or</i> secondary on right > main on right
Player expertise	2, 45	0.47	.63	-	-
HUD spatial organization x Player expertise	8, 180	1.37	.21	-	-
Global feeling statement rating					

HUD spatial organization	4, 180	22.87	< .001	.34	original > others; main on top > secondary on top <i>or</i> secondary on right <i>or</i> main on right; secondary on top <i>or</i> secondary on right > main on right
Player expertise	2, 45	0.26	.77	-	-
HUD spatial organization x Player expertise	8, 180	1.23	.29	-	-
RTS / HUD spatial organization					
<i>HUD spatial organization statement rating</i>					
HUD spatial organization	4, 180	42.20	< .001	.48	original > others; main on right <i>or</i> secondary on right > main on top <i>or</i> secondary on top
Player expertise	2, 45	0.23	.79	-	-
HUD spatial organization x Player expertise	8, 180	1.25	.28	-	-
<i>Global feeling statement rating</i>					
HUD spatial organization	4, 180	42.04	< .001	.48	original > others; main on right <i>or</i> secondary on right > main on top <i>or</i> secondary on top
Player expertise	2, 45	0.33	.72	-	-
HUD spatial organization x Player expertise	8, 180	2.15	< .05	.09	the higher player expertise is, the larger the differences between HUDs are

Note. full = full HUD; w/o main = HUD without main element; w/o secondary = HUD without secondary element; empty = empty HUD; original = original HUD; main on top = HUD with the main element at the top side of screen; secondary on top = HUD with the secondary element at the top side of screen; main on right = HUD with the main element on the right side of screen; secondary on right = HUD with the secondary element on the right side of screen. Partial η^2 are displayed only when the main effects or interactions were significant.

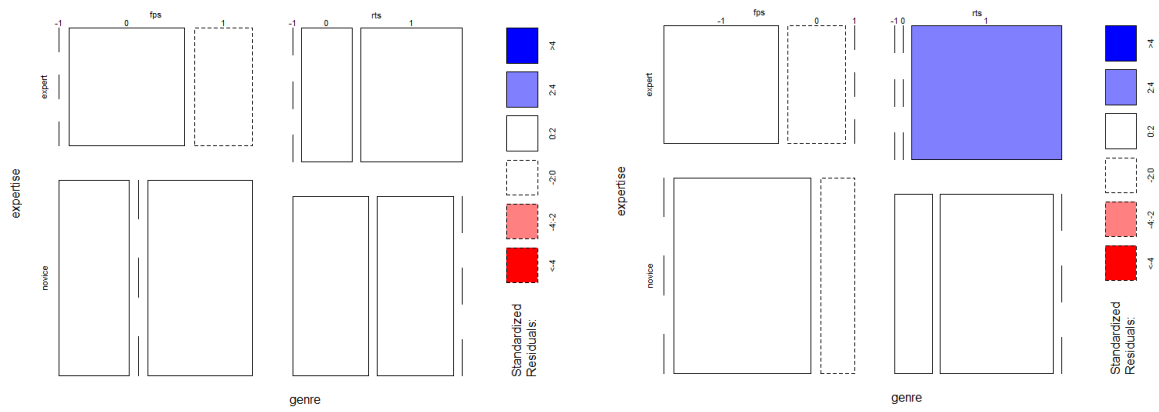


FPS game



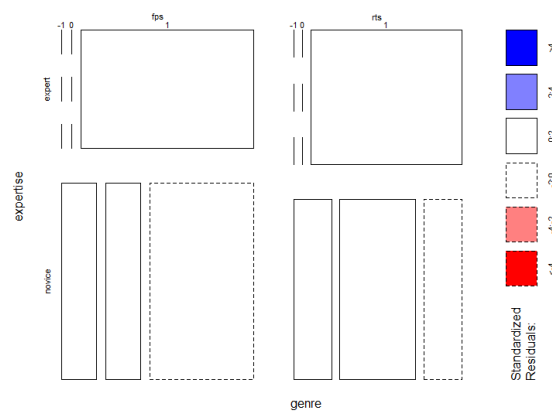
RTS game

Figure 1. Screenshots of video games used in Experiment 1. AOIs used for eye movement analysis are displayed. Red AOIs concern elements of HUD displayed permanently on screen during the game. Green AOIs concern elements of HUD displayed occasionally on screen during the game.



(a) HUD composition

(b) HUD spatial organization



(c) HUD consistency

Figure 2. Distribution of scores of valence for answers given by participants in each condition (game genre x player expertise) in Experiment 1. The three topics of interviews that are displayed (i.e. composition, spatial organization, and consistency) are those for which there are significant effects and/or interactions.

HUD
condition

FPS game

RTS game

Full



Without
main
element



Without
secondary
element



Empty



Figure 3. Different conditions of HUD composition in Experiment 2. For screenshots of the FPS game, red and green frames indicate the location of, respectively, the main element and the secondary element on the screen. These frames were not shown on the actual displays.

HUD
condition

FPS game

RTS game

Original



Main
element
on top



Secondary
element
on top



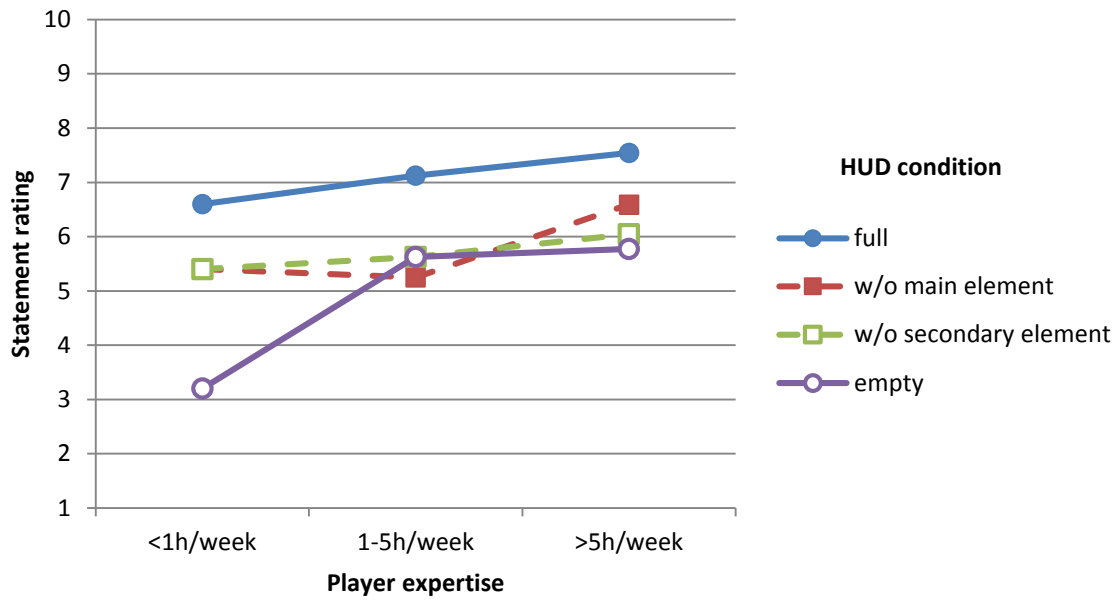
Main
element
on right



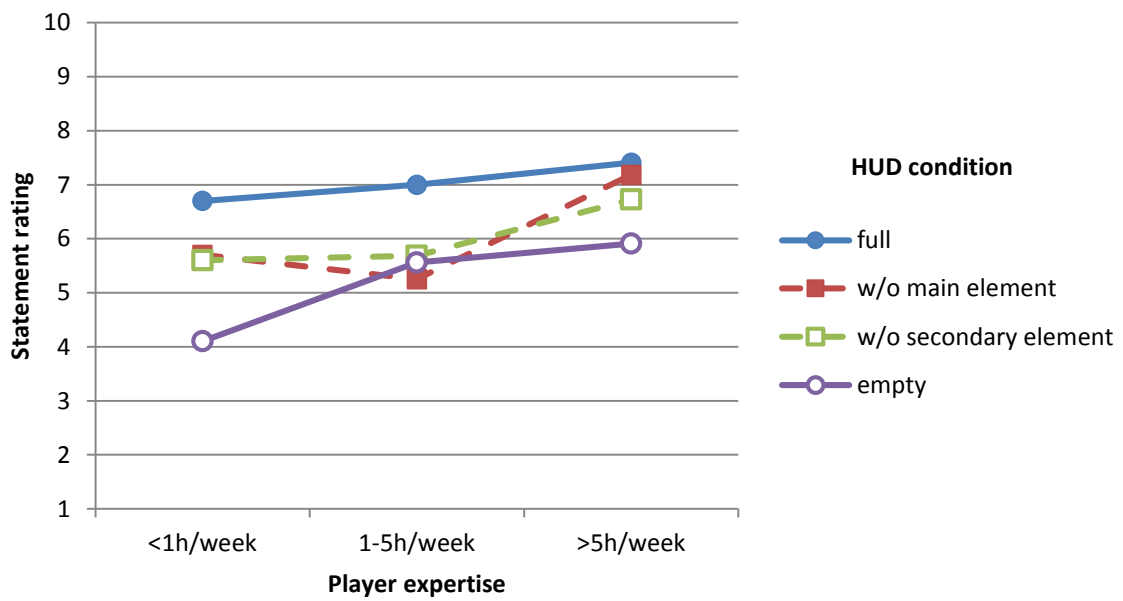
Secondary
element
on right



Figure 4. Different conditions of HUD spatial organization in Experiment 2. For screenshots of the FPS game, red and green frames indicate the location of, respectively, the main element and the secondary element on the screen. These frames were not shown on the actual displays.

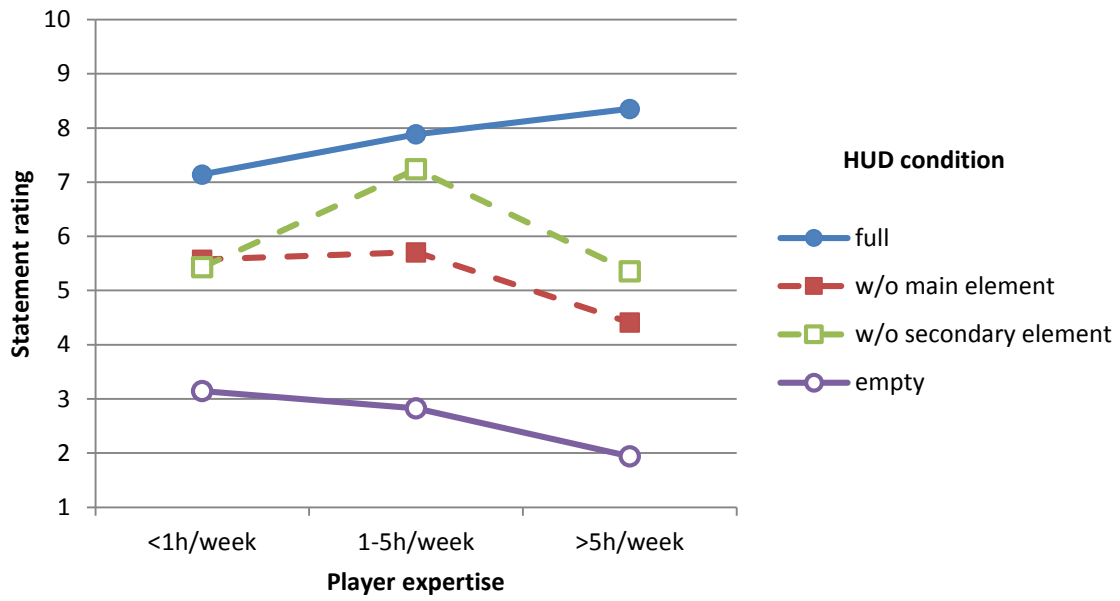


(a) Composition statement rating

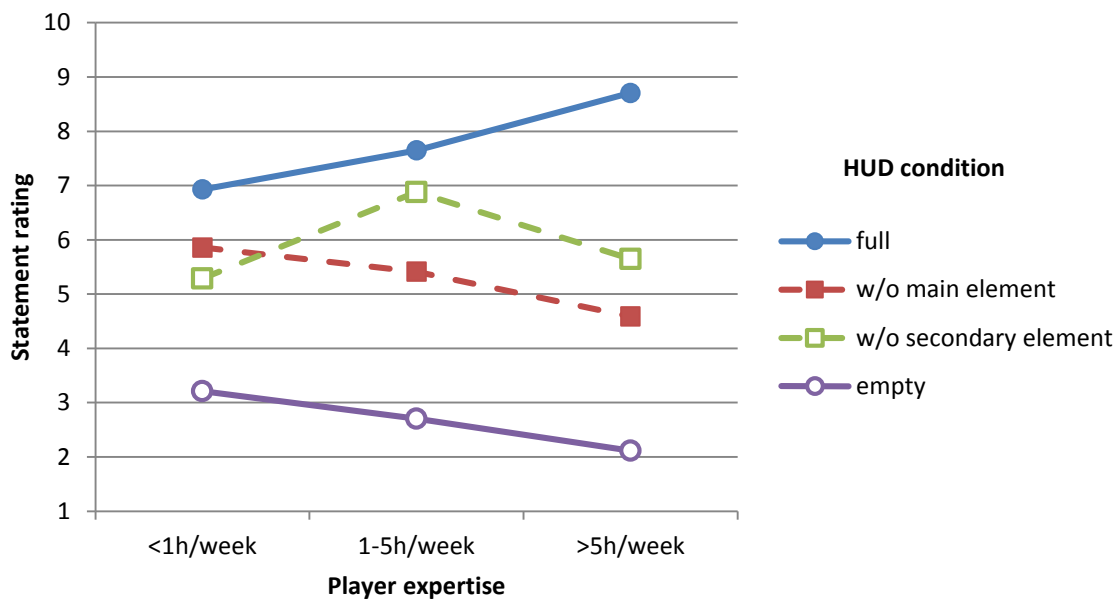


(b) Global feeling statement rating

Figure 5. Statement ratings according to HUD composition in the FPS game and player expertise in Experiment 2.

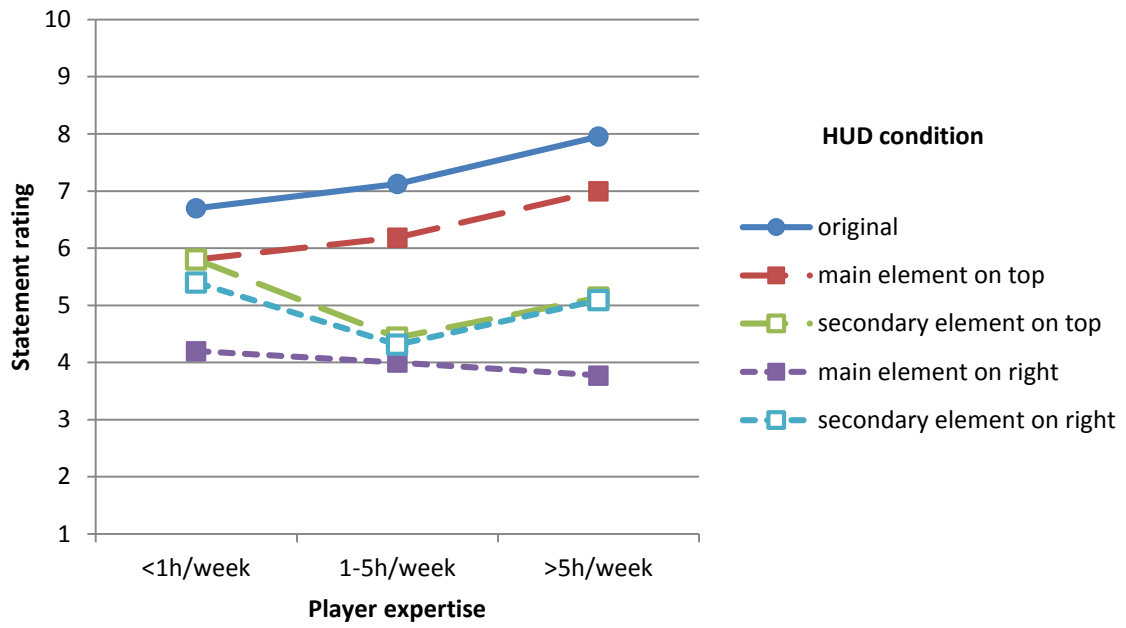


(a) Composition statement rating

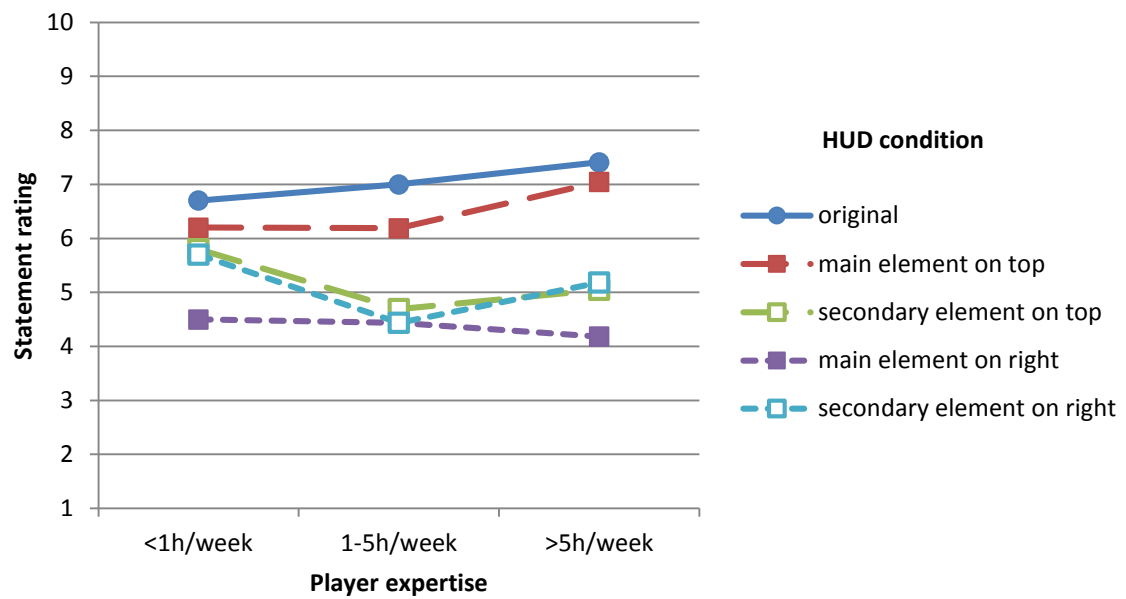


(b) Global feeling statement rating

Figure 6. Statement ratings according to HUD composition in the RTS game and player expertise in Experiment 2.

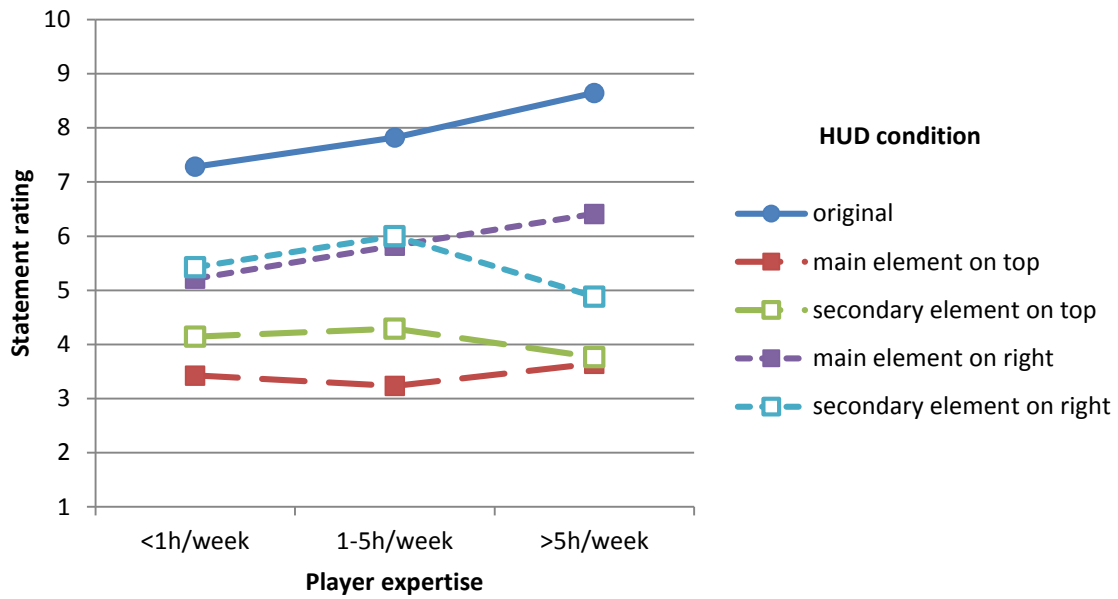


(a) Spatial organization statement rating

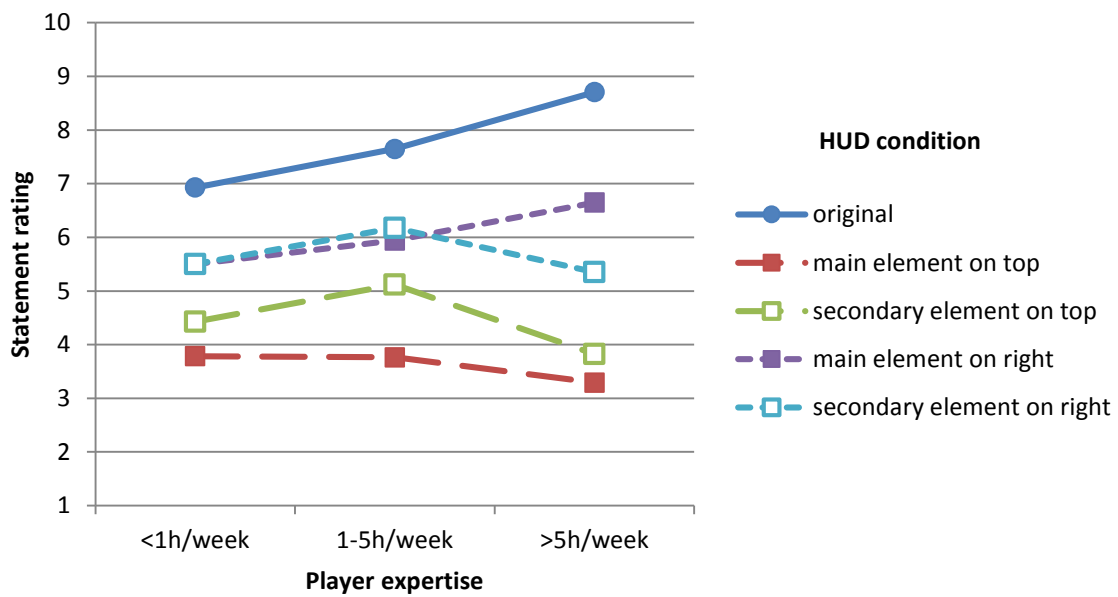


(b) Global feeling statement rating

Figure 7. Statement ratings according to HUD spatial organization in the FPS game and player expertise in Experiment 2.



(a) Spatial organization statement rating



(b) Global feeling statement rating

Figure 8. Statement ratings according to HUD spatial organization in the RTS game and player expertise in Experiment 2.