Towards intelligent user interfaces: Anticipating actions in computer games

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ABSTRACT

The study demonstrates how the on-line processing of eye movements in First Person Shooter (FPS) games helps to predict player decisions regarding subsequent actions. Based on action-control theory, we identify distinct cognitive orientations in pre- and post-decisional phases. Cognitive orientations differ with regard to the width of attention or "receptiveness": In the pre-decisional phase players process as much information as possible and then focus on implementing intended actions in the post-decisional phase. Participants viewed animated sequences of FPS games and decided which game character to rescue and how to implement their action. Oculomotor data shows a clear distinction between the width of attention in pre- and post-decisional phases, supporting the Rubicon model of action phases. Attention rapidly narrows when the goal intention is formed. We identify a lag of 800-900 ms between goal formation ("cognitive Rubicon") and motor response. Game engines may use this lag to anticipatively respond to actions that players have not executed yet. User interfaces with a gaze-dependent, gaze-controlled anticipation module should thus enhance game character behaviours and make them much "smarter".

Categories and Subject Descriptors

H.1.2 [**Models and principles**]: User/machine systems—*Human information processing*

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Keywords

HCI, user interface, FPS games, decision-making, anticipation, mindset, attention, eye movements, gaze control.

1. INTRODUCTION

When humans interact with each other, they often predict what their interaction partner is about to do at the next instant. In fact, the anticipation of future actions seems to be accomplished rather effortlessly. Furthermore, predictions are usually highly accurate (e.g., [1], [12]).

The capability to foresee what is happening next or what the interaction partner intends to do presents advantages with regard to influencing the course of interaction. Depending on the situation, predictions may be used to the mutual benefit of the interactors. Alternatively, predictions can allow one of the interactors to gain an advantage over the other. In the latter case, the interaction situation is normally a concurrent one. Here, adaptations to one's behaviour or preparatory measures to defend anticipated actions of an opponent can be initiated before the opponent actually executes that action. This saves valuable processing time and can reduce response latency.

In human-machine interaction design, anticipative capabilities would present a highly desirable, novel quality of user interfaces. The game engine of a First Person Shooter (FPS) game, for example, that already knows what players are going to do before they actually touch the game controller, could respond more "intelligently". It could, for example, strengthen the defense of a particular computer game bot that is likely to come under threat. The bot is thereby better prepared when the envisioned attack becomes real.

The question now arises which cues are valid and (more or less) easily available that allow for inferring interaction partners' intentions and possible future actions. It is a reliable finding from human-human interaction studies that establishing mutual eye contact between interactors as well as observing the interaction partner's eye gaze conveys essential information with regard to the successful accomplishment of an either collaborative or concurrent task (for an overview, see [13]).

Eye contact may signal, for example, interest, facilitate obtaining information about the interaction partner (e.g., [16]), regulate turn taking or indicate comprehension difficulties in conversation (e.g., [20]). From observing the interaction partner's eye gaze, one can rather accurately tell where the partner's center of attention is located (e.g., [3], [21], [19]). Human-machine interfaces that monitor the user's eye gaze may thus be able to generate cues as to what the user intends from analysing the spatio-temporal distribution of attention.

The present study demonstrates how the on-line processing of eye movements in FPS games helps to predict players' decisions regarding subsequent actions, for example , where to turn to next in the game. Our approach is clearly different from using eye gaze or particular oculomotor parameters to directly control players' perspective, navigate (own) game characters or execute specific game character actions (e.g., [11], [10]). Taking into account concepts of action-control theory, the following sections will introduce the basics of decision-making from a cognitive psychology perspective. We will motivate why decision-making is a particularly suitable task for the investigation and illustrate that visual attention indicates different processing stages and contains valid parameters – as measured in eye-movement recordings – for a reliable decision prediction.

1.1 Shielding-interruption Dilemma

When playing computer games such as First Person Shooters, often situations arise where a player's behaviour can best be described by "Thinking paralyses acting, acting paralyses thinking!".

"Thinking paralyses acting, ...": On the one hand, players who, for example, want to rush to the rescue of one of their game characters, are "paralysed" by thinking for too long about which character is in most need of support. Thus, by the time they make up their mind, it may be too late to take any action. The character that would have needed support is in a desperate, hopeless situation already. Or, worse even, more than one game character have moved outside the "reach" of the player in the meantime.

"... acting paralyses thinking!": On the other hand, when making a decision too early, players subsequently concentrate on the implementation of that fixed intention only. In that case, players may ignore possibly better alternatives as the game proceeds. For the example given here this means that, at a later stage of the scene, another character comes under immediate threat and should be supported instead of the character initially chosen – who might be "safe" again by this time.

In cognitive psychology, the phenomenon sketched above is commonly referred to as the "shielding-interruption dilemma" of volitional action control [7]. The shielding-interruption dilemma characterises many decision-making processes in everyday life.

For decision-making processes in FPS games, the shielding-interruption dilemma consists in the demand for players to narrow their "scope" for information retrieval at some stage of the decision-making process. Only this focusing allows them to shield their intention against concurrent intentions and to be able to implement the intended action. However, due to the rapid sequences of actions in FPS games, game situations change quickly. Players should therefore also process new information, which they must achieve by widening their scope for information retrieval again. This should enable them to reformulate their intentions, at least to some extent, in order to make optimal decisions and thus take the best action. The quality of the decision and action can then be objectively evaluated, for the present example, by the number of saved game characters.

1.2 Rubicon Model of Action Phases

We choose to analyse the decision-making process in FPS games by referring to the Rubicon model of action phases [8][4]. The Rubicon model is a cognitive-actional theory that decomposes human actions into four consecutive action phases: *pre-decisional, post-decisional, actional* and *post-actional phases* (see Figure 1).

In order to understand what characterises the different action phases of the Rubicon model, let us reconsider the "rush to the rescue" example mentioned above. According to the Rubicon model, in the *pre-decisional* phase, an FPS game player will scan the current situation of his/her characters in the game. Assuming that game characters populate various locations in the scene, the player will normally use the entire width of the scene, scan the left, the centre and the right hand side and deliberate which character needs assistance most – for example, because an enemy is approaching. When the player decides on one of the alternatives, he/she crosses the "Rubicon" and formulates the goal intention, for example, rescue the centre character.

In the subsequent, *post-decisional* phase, the player plans the implementation of the intended action and waits for the optimal time for action execution. The player then executes the action (here, move towards the centre character) in the *actional* phase. Finally, the player evaluates the completed action in the *post-actional* phase where he/she reflects on the success of the previously executed action.

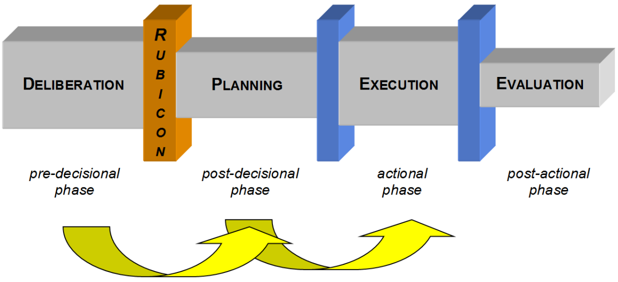

Figure 1: The Rubicon model of action phases [8][4].

1.3 Concept of Cognitive Mindsets

The four action phases of the Rubicon model are associated with specific "cognitive mindsets" that affect the ability to perceive and to process information. We will coin the term "receptiveness" to describe this ability.

For the given FPS game setting, we will concentrate on the first two action phases of the Rubicon model, that is the pre- and post-decisional ones. For these phases, the "concept of mindsets" [6] distinguishes between *deliberative* and *implemental* mindsets.

The pre-decisional phase is associated with a *deliberative mindset*. The deliberative mindset enables players to process as much information as possible from a wide field of view. Taking all feasible options into consideration allows players to determine the optimal goal intention for the subsequent action phase.

The post-decisional phase then demands an *implemental mindset*, leading to a narrowing of the (visual) field for information retrieval [5]. With a view to the shielding processes, attention is thus focused on implemental, planning aspects of the actions. Players plan in detail, for example, how to rescue the previously chosen game character.

Furthermore, in accordance with volition theories [15] that state volitional shielding processes should increase *abruptly* immediately after intention formation, the concept of mindsets theoretically postulates a *rapid* decrease of deliberative activities after crossing the Rubicon [4]. Identifying a discontinuous course of the shielding function could allow us to determine the so-called *"cognitive Rubicon"*.

According to [2], however, we must not expect to find pre- and post-decisional activities and associated mindsets being completely disjunctive. This means that activities that are normally associated with the post-decisional phase or implemental mindsets such as more detailed action planning, can also be found in the pre-decisional phase. In turn, pre-decisional activities usually found during deliberative mindset, may also be observed in the post-decisional phase. We must therefore expect a certain amount of wide-range visual scanning after the Rubicon decision is made. To date, empirical testing of the concept of mindsets has only sparsely investigated the course of the volitional shielding function, for example, in [9] or [14].

This led us to investigate whether we can identify distinct cognitive orientations in the pre- and post-decisional phases of the decision-making process in FPS games. The cognitive orientations should differ with regard to the *width of the receptiveness*, assuming information being processed from a wide field (of view) in the deliberative mindset phase and from a narrow field in the implemental mindset phase. By analysing the course of the width of receptiveness during the decision-making process, we can test the hypothesis whether volitional shielding does indeed increase abruptly. If this is the case, we should be able to exactly determine the time of the cognitive Rubicon. The difference of this cognitive Rubicon time to the time when players communicate their actions to the game engine via game controllers (e.g., mouse button press) is of particular interest for game programming. As the cognitive Rubicon is certainly crossed earlier than the response button is pressed, programmers can use this lag to implement human-computer interfaces with anticipatory capabilities that reliably predict players' actions.

In summary, the present studies aims at answering the following research questions in the context of designing an intelligent user interface for FPS games that features a gaze-dependent anticipation module for game character control by the game engine: Does the width of receptiveness differ between the deliberative and the implemental mindset phases of the decision-making process in FPS games? Which course does the width of receptiveness take during decision-making processes in FPS games? When do we cross the cognitive Rubicon in FPS games?

2. METHOD

2.1 Participants

16 adults participated in the experiment, aged between 19 and 35 years. All participants had normal or corrected-to-normal vision, full colour vision and no other visual impairments. The participants had medium experience in playing FPS games (approximately 1 hour per week), however, they were naive to the experimental task.

2.2 Stimuli

Participants viewed short animated video sequences of an FPS game from an egocentric perspective (see Figure 2). Video sequence durations varied between 6.5 and 9 seconds with a mean duration of 7.2 seconds (standard deviation $\sigma = 0.75$). The video sequences were generated using *GarageGames Torque 3D*[1] game creation platform. Each participant viewed 26 video sequences.

Video sequences showed opponent game characters (yellow) pursuing the player's characters (red) in either 2 vs. 2 (number of opponents vs. number of player's characters), 3 vs. 2 or 4 vs. 2 situations.

Opponents and player characters formed two small "groups" of characters. During the video sequence presentation, the distances of characters within each group varied with opponents approaching player characters or player characters being able to widen the distance to opponents. The two character groups remained within the left or right half of the display screen and did not cross sides or intermingle. Players could not control the characters' movements.

As players in the experiment had to decide which of their game characters needed help most and how to help (for details, see Section 2.3), all video sequences had to be unambiguous with regard to which "who"- and "how"-decisions were correct. Video sequences were thus created so that at a particular time during the presentation of each sequence (on average, within 4 to 6 seconds into the scene), only one of two possible choices for the who-decision became obvious. Similarly, during the remaining part of the scene, only one of two possible choices for the how-decision was clearly visible as being the correct one.

The selection of video sequences that were to be used in

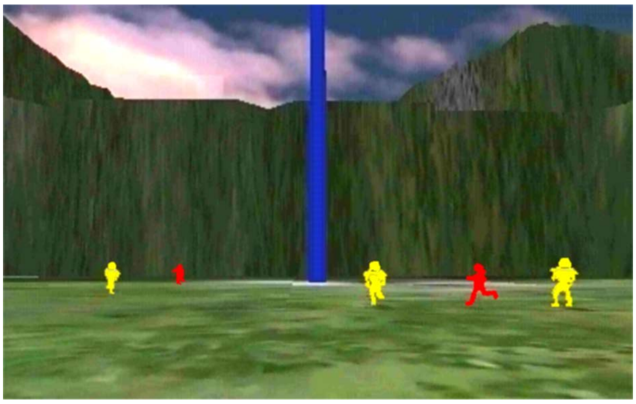

Figure 2: Still image from a video sequence stimulus of the FPS game.

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[1] http://www.garagegames.com/products/torque-3d

the experiment, the choice of which decisions were the correct ones and the determination of the optimal time for the who-decision (“optimal” meaning the earliest possible time that allows for correctly assessing the situation) were done by highly proficient FPS players (“experts”) who rated scenes in a pre-experiment. None of the participants of the pre-experiment took part in the experiment reported here.

2.3 Procedure

At the beginning of the experiment, participants (players) received written instructions explaining their task. This was followed by an eye-tracker calibration procedure, a single practice trial and 26 experimental trials. In each trial, before the stimulus video sequence was shown, a short recalibration of the eye tracker was performed. Immediately before the video presentation started, a fixation cross was displayed at the centre of a blank screen for 500 ms.

While the video sequences were shown, players had to decide which of their characters was under most threat from the opponent game characters and was thus in most need of support/needed to be rescued. The who-decision question for players was formulated as follows: “Is your character on the left or on the right more in need of help?”. After this who-decision that marks the “Rubicon decision”, participants decided how to implement their action by choosing a weapon that would immobilise the persecutor without harming the player’s character. The how-decision question for players was formulated as follows: “Do you use a pistol or rocket to help your character?”.

Depending on the proximity of opponent and player characters, either the pistol or the rocket was the correct choice. The pistol and the rocket could both immobilise the opponent players, however, if applied incorrectly, also the player’s characters. While the pistol better reaches nearby targets than far away ones and works very precisely, the rocket can reach targets in the distance and has a less localised impact, i.e. spreads wider. The pistol would therefore be the correct choice of weapon when the players’ and opponent characters were nearby and/or close to each other. The rocket would be the correct choice of weapon when the players’ and opponent characters were far away and/or further apart. All sequences were unambiguous with regard to which who- and how-decisions were correct (also see previous section 2.2).

Players communicated the who-decision by pressing a response key (right or left, respectively) on a computer keyboard as soon as they made up their mind during the video sequence presentation. All video sequences were shown to full length. At the end of each video sequence, players orally communicated their how-decision.

Eye movements were recorded during the presentation of the video sequences. All relevant experimental and trial information, video start and end events as well as response button presses were synchronised with the eye-movement recordings, time-stamped and stored as triggers in the eye-tracker data output files. Participants were instructed to accomplish the task as accurately as possible.

2.4 Data Analysis

In order to analyse the cognitive level of receptiveness and its width during decision-making in FPS games, we analysed the participants’ eye movements. [22], [9] and [14] already applied this method successfully to monitor visual attention in decision processes. Saccade amplitudes and the ratio of “deliberative saccades” measure the width of the field of view and therefore serve as valid parameters to assess the width of attention and the width of receptiveness. We define deliberative saccades as those saccades that are longer than 4.5 degrees and reach across the centre of the display screen. This ensures that only saccades between (not within) character groups are correctly classified as being deliberative.

2.5 Experimental Design

We computed statistical analyses for the dependent variables saccade amplitude SL (horizontal component), the ratio of deliberative saccades RDS (vs. non-deliberative saccades) and fixation durations FD, comparing means between pre- and post-decisional action phases (independent variable). Statistical data analyses for within-subjects effects (repeated measures) were computed using SPSS 14.0. The α-level for all statistical tests was set to 0.05. Apart from ANOVA F and p values, we also computed effect sizes η^2.

2.6 Apparatus

We used an SR Research EyeLink II eye tracker to record participants’ eye movements at a sampling rate of 500 Hz. Before the start of the experiment, a multi-point calibration procedure was performed. Before each trial, a single-point drift-correction procedure was performed to ensure accurate data recordings throughout the whole experiment. Stimuli were shown on a 17-inch CRT screen, subtending a visual angle of 32.1 degrees horizontally and 24.4 degrees vertically. The screen resolution was set to 640 x 480 pixels at a refresh rate of 85 Hz. Participants were seated approximately 60 cm from the screen. Figure 3 visualises the experimental setting.

Figure 3: Experimental setting with the SR Research EyeLink II eye-tracking system in the laboratory.

3. RESULTS AND DISCUSSION

The qualitative analysis of a sample gaze trajectory provides a good starting point before the quantitative analysis of the eye-movement parameters in the subsequent paragraphs. Figure 4 illustrates a typical gaze trajectory recorded during the decision-making process.

Following the horizontal component of the eye gaze (black curve) over the temporal course of the decision-making pro-

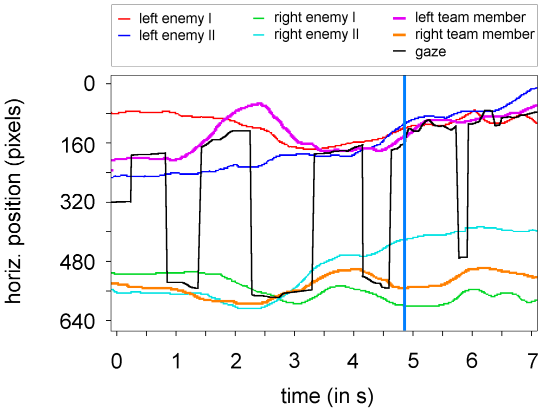

Figure 4: Character movements (horizontal component) and gaze trajectory during the decision-making process.

cess, we clearly note that attention shifts frequently between the two character groups as characters move about the scene (coloured curves) before the manual response (who-decision, blue vertical line at around 4.8 s). Individual characters, mainly the player's characters ("team member"), are visually pursued for short time intervals before attention shifts to the character group on the other side of the display. Few saccades occur between characters within one group.

The visual pattern drastically changes in the post-decisional phase after the response button press (Rubicon decision). Individual characters within the left group are visually traced almost exclusively, frequent short saccades occur between characters within this group. Only one deliberative saccade is made to the other group.

We regard these qualitative observations as first hints towards the existence of two distinct visual processing strategies that rather abruptly change around the time of the Rubicon decision. Whereas there is some indication that the pre-decisional phase is indeed characterised by deliberation between the options across the display, the gaze pattern in the post-decisional phase hints at localised action planning. These observations will now be validated by the quantitative analysis of the eye-movement parameters.

In the pre-decisional phase before the who-decision, the ratio of deliberative saccades RDS reaches 60% (of all saccades) on average. This is much higher than after the response button press, i.e. in the post-decisional phase of the decision-making process, when RDS drops to 35%. This means that before the button press almost 2 out of 3 saccades are longer than 4.5 degrees and shift attention between the two groups of characters on the display screen. The statistical comparison of means confirms that RDSs are significantly different between the two phases ($F(1;15) = 136.776; p < 0.001$). The effect size η^2 amounts to 0.901. We must, however, not ignore the fact that neither phase is exclusively characterised by deliberation nor planning activities. In the deliberation phase before the response button press, we find around 40% implemental, planning saccades while in the implemental phase after the response button press still approximately 1 in 3 saccades is deliberative.

The average saccade amplitude SL in the pre-decisional phase measures 7.3 degrees. In the post-decisional phase when players decided on the weapon to use for implementing their action, SL is notably lower and only measures 3.4 degrees. This leads to a highly significant narrowing of the width of receptiveness after crossing the Rubicon ($F(1;15) = 51.522; p < 0.001$). The effect size η^2 amounts to 0.915. Figure 5 sketches the mean amplitude of a deliberative saccade (red bar) and that of a non-deliberative, planning saccade (yellow bar).

When comparing fixation durations FD between the pre- and post-decisional phases, we find that FD reaches 289 ms on average per fixation in the pre-decisional phase. Subsequently, FD rises to 311 ms on average in the post-decisional phase. The ANOVA demonstrates that the difference in fixation durations between the two decision phases is significant ($F(1;15) = 13.539; p = 0.002$). The effect size η^2 measures 0.474.

Trial-by-trial analysis demonstrates that in all individual sequences these significant differences in RDS, SL and FD exist between pre- and post-decisional phases. From significant changes in RDS and SL in particular, we can clearly distinguish between the width of attention in pre- and post-decisional phases – a wide and narrow field of view, respectively. As the width of receptiveness narrows when the Rubicon is crossed, we can conclude that the concept of cognitive mindsets can be applied successfully to decision-making in FPS games. This conclusion is supported by the finding that a clear distinction between phases in visible in FD. Relatively short fixation durations before the Rubicon decision coincide with results from natural scene viewing and visual search reported in, e.g., [17]. Here, the initial scene scanning can be understood as guided by similar processes as in the present experiment's deliberative mindset phase. Information from a wider field of view is processed in order to gain a coarse overview of the scene and to obtain selected relevant hints – where short FDs suffice – that guide attention to task-relevant objects that are subsequently inspected in more detail – requiring longer FDs.

We will use Figure 6 for a descriptive analysis of the temporal course of the width of receptiveness during the decision-making process. The illustration shows the width of attention by charting the ratio of deliberative saccades as a function of time. Data is averaged over all 416 decisions processes and the time is shifted relative to the response

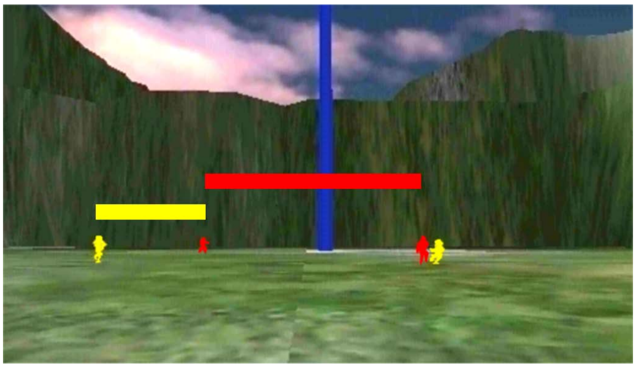

Figure 5: Illustration of mean deliberative saccade amplitude (7.3 degrees) across display centre (red bar) and non-deliberative saccade amplitude (3.4 degrees) within character group (yellow bar).

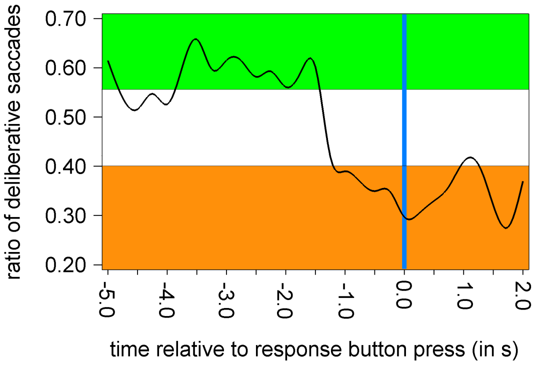

Figure 6: Time course of ratio of deliberative saccades RDS. Response button press at time t=0.

button press at time $t = 0$, highlighted by the blue vertical line. The green area marks where RDS is above 55%, i.e. when players process information from a wide field of view and show deliberative activity. In the orange area, RDS is below 40%, indicating a rather narrow, focussed field of view and thus planning activity. The course of the function shows a significant decrease in RDS within a very short time interval which can be regarded as strong support for the abrupt increase of volitional shielding processes: Until about 1.5 s before the response button press, the width of receptiveness is rather wide and two of three saccades are deliberative ones. Immediately after, the width of receptiveness "collapses" and drops steeply within 1.5 s to slightly less than 30% around the time of the response button press. The increase of RDS at about 1 s after the button press in not unexpected [18] and marks "verification" saccades that players often execute to verify their decision.

In order to determine the time of the cognitive Rubicon, we compute when the maximum effect size for the difference between pre- and post-decisional width of receptiveness is reached. In other words: When does the difference in RDS between pre- and post-decisional phases become maximal? So far, we divided pre- and post-decisional phases by the time of the response button press, resulting in an effect size of $\eta^2 = 0.901$ for RDS (s. above). To maximise η^2, we shift backwards the "dividing line" between pre- and post-decisional phases in 50 ms steps and compute analyses of variance for RDS for these data sets. As Figure 7 illustrates, the effect size η^2 reaches a maximum of 0.950 at approximately 800 ms (red vertical line) before the "original" dividing line, i.e. the time of the response button press. This means that the magnitude of "switching" between deliberative and implemental cognitive mindsets clearly increases when we allow around 800 ms for the time from the – apparently unconsciously – cognitive decision to the motor response.

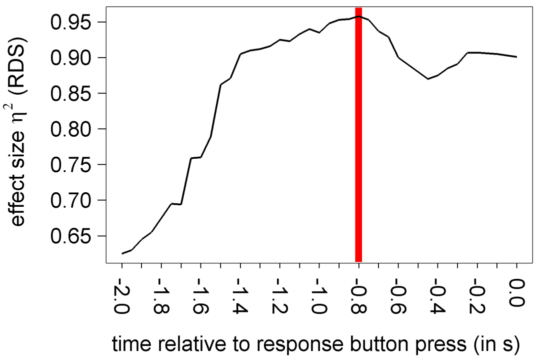

Figure 7: RDS effect size for adjusted cognitive Rubicon times. Response button press at time t=0.

In analogy to Figure 6, Figure 8 shows the temporal course of the width of receptiveness during the decision-making process by charting the saccade amplitude SL as a function of time. Again, data is averaged over all 416 decisions processes and the time is shifted relative to the response button press at time $t = 0$, highlighted by the blue vertical line. The green area marks where SL is above 7.0 degrees, i.e. when players process information from a wide field of view and show deliberative activity. In the orange area, SL is below 4.0 degrees, indicating a rather narrow, focused field of view and thus planning activity. The function of SL shows an almost identical course as RDS with a significant decrease in saccade amplitude within a similarly short time interval, again before the response button press. This yields further support for the abrupt increase of volitional shielding processes. The increase of SL at the end of a trial underlines the verification saccade hypothesis.

In order to validate the cognitive Rubicon time that we computed on the basis of RDS, we apply the above-mentioned effect-size maximisation method to SL data. Again, shifting backwards the dividing line between pre- and post-decisional phases in 50 ms steps and computing analyses of variance for SL for these data sets, results in a maximum effect η^2 for SL of 0.925 at approximately 900 ms before the response button press (see Figure 9, the red line indicates the cognitive Rubicon time). This time is rather similar to the 800 ms computed on the basis of RDS data. There thus seems to be a rather convincing consistency in the magnitude of the cognitive Rubicon time, independent of the underlying dependent variable. We can thus reliably establish the cogniti-

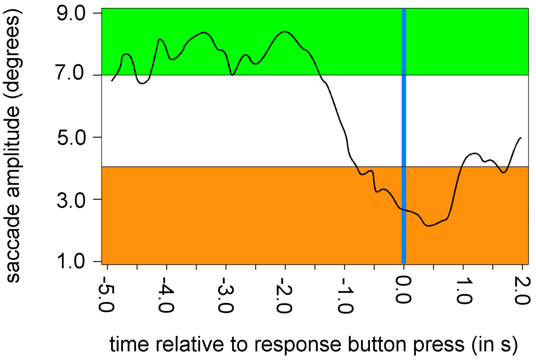

Figure 8: Time course of saccade amplitudes SL. Response button press at time t=0.

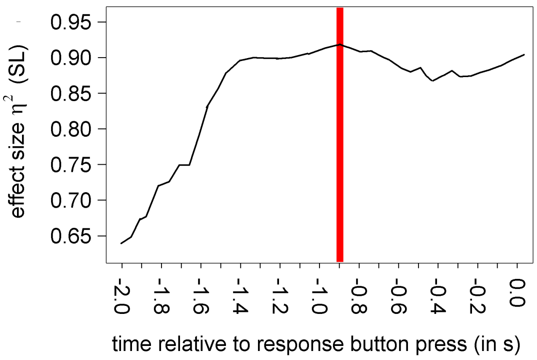

Figure 9: SL effect size for adjusted cognitive Rubicon times. Response button press at time t=0.

ve Rubicon time at between 800 to 900 ms before the motor decision.

4. CONCLUSION

The present study has successfully demonstrated that the theoretical postulates from volitional theories as formulated in the concept of mindsets can be empirically confirmed for decision-making processes in FPS games. This has considerable implications for the development of intelligent human-computer interfaces that can anticipate actions in computer games – and possibly beyond.

We could identify distinct cognitive orientations in the pre- and post-decisional phases of the decision-making process in FPS games. The cognitive orientations clearly differ with regard to the width of the receptiveness: Information is being processed from a wide visual field in the deliberative mindset phase and from a narrow field in the implemental mindset phase. Deliberative and implemental mindsets apparently characterise decision-making in FPS games and thus support the Rubicon theory of action phases.

Furthermore, by analysing the course of the width of visual attention during the decision-making process, we can confirm that the width of receptiveness narrows considerable within a short time interval rather than being a slow moving process. This confirms the hypothesis that volitional shielding does indeed increase abruptly after players cross the (cognitive) Rubicon during decision-making in FPS games. We must not forget, however, that the shielding-interruption dilemma exists in each action phase as pre- and post-decisional activities are not completely disjunctive.

Finally, the abrupt switch between deliberation and planning allows us to rather accurately determine the time of the cognitive Rubicon. As the goal intention apparently forms between 800 to 900 ms before the motor response when the focus of visual attention rapidly narrows, this presents a considerable lag between the cognitive Rubicon and the manual response.

The existence of a lag of this magnitude opens the door for significant improvements to a wide range of applications with gaze-controlled human-machine interfaces. The present eye-movement study has demonstrated that monitoring oculomotor parameters provides reliable and stable cues as to when which decisions are cognitively (or “internally”) made - well before a decision is communicated manually. This gives programmers of game engines a good chance to account for players’ coming actions and thus to implement human-computer interfaces with anticipatory capabilities. This is a novel feature in FPS games. By providing a human-computer interface that feeds current user behaviour into the game engine, we can create game characters whose behaviours are more “intelligent” and adaptive or responsive to the user. User interfaces with a gaze-dependent, gaze-controlled anticipation module should thus enhance game character behaviours and make them much smarter. With eye-tracking devices becoming more widely available at lower prices, the technical pre-requisites should be provided for the use of such gaze-controlled interfaces in the nearer future.

We will evaluate how the current findings can be transferred to active game play situations in further studies. The present setting ensures optimal experimental control and thus provides ideal conditions for a reliable statistical analysis. To test the ecological validity, however, using interaction scenarios, rather than pre-recorded video sequences with no interaction component, will more closely resemble the “real” gaming situation. We will also validate the generalisation capabilities of our findings by investigating other game situations in FPS games as well as other computer games.

Of course, machines anticipating user actions present a highly desirable quality in many other human-computer interaction scenarios as well. Applications that take advantage of such interfaces need not be restricted to games and entertainment. We could easily think of transferring this novel quality of human-computer interaction to safety-critical applications. It could, for example, be used in driver-assistant systems in vehicles. Drivers’ visual attention patterns in critical situations, where often decisions have to be made between different escape route options, could be evaluated online. This should yield reliable predictions about the driver’s route choice. Combined with input from computer-vision based traffic scene analysis, route choice could then be checked for safety and, if deemed unsafe, recommendations could be issued to the driver about possible dangers or better choices – or the system might autonomously initiate appropriate safety measures.

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