Eye-pointer Coordination in a Decision-making Task Under Uncertainty

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Abstract: Eye-tracking (ET) systems, which capture eye movements, are often used to measure human behavior while interacting with a user interface. Given the high costs and challenges of acquiring, installing and ensuring good calibration of ET systems, the use of pointer (or mouse) tracking is gaining interest as a viable alternative in research on human-computer interaction. In this study, we measured and evaluated temporal and spatial relationships between eye and pointer movements in a standardized task that allowed us to examine the relationship between eye and pointer movements while participants made decisions under conditions of high and low uncertainty. We collected data from N=81 participants and applied a range of metrics to a total of 5205 decision trials. The overall findings show that the convergence between eye and pointer movements is consistently high. Importantly, there are differences in levels of convergence depending on the temporal, spatial and combined temporo-spatial metrics used. There are also differences in eye-pointer convergence depending on the relative level of decision uncertainty in the task. In conclusion, the present findings favour the use of pointer tracking to analyse human-computer interaction in more complex tasks.

1 INTRODUCTION

The individual style of interaction with a computer can give insights into user experience, usability and design of the user interface, and also about the users' interests, preferences or personality (e.g., (Olson and Olson, 2003; Dillon and Watson, 1996; Pocius, 1991)). The latter finding reflect the increasing interest in understanding the influence of the user behaviour in human-computer interaction (HCI) (Djamasbi et al., 2008; Payne et al., 1988).

The eye-tracker (ET) technique is the usual approach for tracking human behavior since the mid-1970s (Rayner, 1998). ET is thought to permit insight into individuals' cognitive states (Just and Carpenter, 1976; Olk and Kappas, 2011). A major drawback of ET is the expensive equipment, challenges of calibration, and data loss. In addition, participants need to be physically present for ET studies, which can lead to smaller sample sizes (Chen et al., 2001; Rodden and Fu, 2007).

More recently, several interesting approaches for pointer tracking analysis have been developed. In contrast to eye-tracking systems, pointer-tracking data can be acquired easily and without extra equipment. Taking into account that the results of both systems are similar, using x and y coordinates across the screen, pointer-tracking is gaining interest as a viable alternative to ET.

In the present study, we measured eye and pointer movement, computed a range of metrics and evaluated temporal and spatial relationships between eye and pointer movements in a standardized decision making task. This task, the Iowa Gambling Task (IGT) (Bechara et al., 1994), allowed us to examine these relationships while participants made decisions under conditions of high and low uncertainty.

The IGT was originally devised as a well-controlled laboratory simulation of real-life decision-making under conditions of uncertainty. At the beginning of the task, the participant is unfamiliar with the probabilities of the negative and positive outcomes of the different decision alternatives that are presented to the participant. In the first phase of the task, the de-

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cision maker must search, explore and learn the possible contingencies of monetary gains and loss in order to maximize the overall monetary outcome of the task. In this sense the participant explores the task contingencies and engages in decision making under conditions of high uncertainty (cf. (White and Roth, 2009; Marchionini, 2006)). After gathering information and acquiring an understanding of the task's reward and loss contingencies, participants learn to maximize the overall monetary outcome and in effect make decisions under conditions of higher certainty. We use these phases of the task to differentiate and analyse information search and decision making behavior under conditions of less compared with more certainty. We examined whether there is a difference in the temporal and spatial relationship between eye gaze and pointer movements in the more uncertain compared with the less uncertain phases of the task.

2 BACKGROUND

An issue associated with the eye-tracking equipment is loss of calibration that can lead to missing missing data or deviation between the recorded and actual eyed position. According to the context and task, it is possible to correct this data. Hornof and Halverson (2002) reported an approach that depends on required fixation locations to re-calibrate the eye tracker. In their experiment, it was required to click on a specific target and, assuming that the participant looks at the target during the click, to determine if the distance between the eye-tracking data and the click was higher than a certain threshold, the eye tracker would be automatically recalibrated after the click. An alternative technique consists of two linear regressions (one for horizontal dimension - x-axis - and another for vertical dimension - y-axis) between the known data points and the corresponding raw data (Blignaut et al., 2014).

In HCI, most authors attempt to find a relationship between the eye movements and pointer movements during web browsing using a computer mouse (Chen et al., 2001; Cooke, 2006; Rodden and Fu, 2007; Rodden et al., 2008; Bieg et al., 2010; Huang et al., 2011; Liebling and Dumais, 2014; Milisavljevic et al., 2018), while others build predictive models of the eye gaze based on mouse movements (Guo et al., 2013; Huang et al., 2011; Navalpakkam et al., 2013).

A strong correlation between pointer position and gaze position was found by Chen et al. (2001) in different styles of websites. The authors conclude that when the mouse is moving to a meaningful region, the eye gaze is very correlated with the pointer movement. Cooke did in 2006 a similar approach, concluding that people move more the pointer while searching information (Cooke, 2006).

Restricting the analysis, Rodden and Fu (2007) considered the time spent in specific regions by pointer and eye, finding proportions ranging from 25.8% and 59.9%. Later, in 2008, Rodden et al. (2008) identified three patterns that seem to indicate active mouse usage: following the eye vertically, following the eye horizontally, and marking a particular result.

Whilst determining the influence of visual search for a target in pointer-eye coordination, Bieg et al. (2010) observed two behaviours: usually, the eye reaches a targeted region before the mouse cursor does, and if the participant knows the target location, pointer movements begin without eye guidance. The study of Liebling and Dumais (2014) also took into account past experience on the interface in use, concluding that the pointer and eye movements are not coordinated during one-third of the time depending on the type of target and familiarity with the task.

Some studies also followed a different approach and, instead of comparing directly the eye and pointer cursor, set up mouse features to predict gaze. A study that improved the eye-pointer correlation using a variety of cursor behaviours and time-related pointer features, also concludes that the future position of the pointer has a strong correlation with the current eye position (Huang et al., 2012). Navalpakkam et al. (2013) predicted eye gaze with 67% accuracy using mouse features and found a strong correlation between eye and pointer in areas of user main interest. Believing that the relation between eye and pointer movements is dependent on the task performed, Milisavljevic et al. (2018) predicted the regions where the pointer and eye are for different tasks with an accuracy of 70%.

The acquisition of eye-tracking data in the context of the IGT has been mainly done to analyse pupil dilation as a measure of cognitive effort and arousal during the decision process (Fiedler and Glöckner, 2012; Franco-Watkins and Johnson, 2011), as a marker for uncertainty (Lavín et al., 2014) or as an anticipation of disadvantage and advantageous decks (Simonovic et al., 2017). Zommara et al. (2018) explored the existence of a gaze bias towards the chosen deck and conclude that this happens with or without using a mouse.

In contrast, pointer-tracking is increasingly being used in psychological research, such as social cognition, decision-making and learning (for a review, see (Freeman et al., 2011)). Some studies correlated the mouse response dynamics with the subjects' preferences (e.g. (Koop and Johnson, 2013; Chen and Fischbacher, 2016)). For example, Koop and Johnson (2013) used the IGT and pointer-tracking and, using metrics from mouse paths, showed that they could reveal participants' preferences for different decision alternatives.

3 STUDY SETUP

3.1 Data Acquisition

To capture eye movements, we used a SMI Red250 eye tracker running IView software. The eye gaze data file includes the person ID, the trial number, the x and y position (in pixels) to where the right and left eyes are looking, among other information.

The IGT was developed in Presentation software, from Neurobehavioral Systems ® and the pointer-tracking data was being recorded to an independent file in the local disk that is saved after the end of the game. This file contains the person ID, the trial number, the x and y pointer's position (in pixels) and time.

3.2 Participants

81 volunteers - 59 female and 22 male - participated in this study, with ages between 16 and 34 years old. Participants were students and recruited by mailing list. All participants were native or fluent speakers of Standard German, consistently right-handed (Annett, 1970). All were healthy, with normal, or corrected-to-normal, vision, no record of neurological or psychiatric illness and no current medication use. None reported gambling problems. Written informed consent was obtained before participation according to the guidelines of the Declaration of Helsinki. Each volunteer received 20 Swiss Francs for participation. All participants were tested individually in a small, sound-attenuated, dimly lit experimental room.

3.3 Task

The IGT (Bechara, 2007) is a widely explored task that simulates the daily decision-making under conditions of uncertainty. It is a card game with four decks that differs in the amount of money that could be won or lost. The game starts by giving the player a fictitious amount of money that should be increased as much as possible. It covers 100 trials, which is unknown to the player, and in each one of them, the participant needs to choose one card out of four (by clicking on it with the cursor). After each choice, it is revealed the money won or lost. At a certain moment of the IGT, the player should understand that there are two advantageous decks (Buelow and Suhr, 2009).

3.4 Procedure

Participants attended a single testing session in a quiet and comfortable laboratory room, lasting approximately 60 min. The experiment was conducted in three phases: First, informed consent and demographic data were collected. Second, pointer data and eye-tracking data were acquired during the IGT. Finally, subjects answered a questionnaire that is not reported in the present study.

In Figure 1 is represented how the IGT was structured. As is conventionally done, a learning profile during the IGT can be discerned from an examination of the card selections in blocks of 20 cards across the 100 card choices (block 1, cards 1-20; block 2, cards 21-40 ... block 5, cards 81-100). In each trial, the participant is instructed to focus on the question mark. After a brief moment, a set of four cards is shown and the question mark is replaced by the cursor, that is only available from this moment. The distribution of the decks on the screen was adjusted to acquire the eye and pointer-tracking data, with two decks at the top and two decks at the bottom. The participant is told to choose a card from one of the decks by pressing the mouse button on the corresponding deck (choice phase). After choosing a card, a red rectangle appeared around the deck chosen and the cursor disappears. Only after 1.5 seconds the win and punishment are shown as feedback. Participants are told that the goal of the game is to maximize their winnings and that they are free to switch from any deck to another at any time. The participants began with a loan of 2000 CHF. Participants had no knowledge of the distribution of probability and magnitude of gains and losses over the decks or how many trials they must play.

4 PRE-PROCESSING

As already referred, a problem that arises in every study involving eye-tracking data is due to equipment losses of calibration. Given that we aim to compare the pointer data and eye-tracking data, we considered the trials of all subjects and just removed the pointer-tracking data correspondent to the lost data of the eye-tracking. The average percentage of lost data for all subjects was 23.83% and the values range from 0.15% to 99.99%. Besides, 10.7% of the trials had no data recorded. Using the remaining data, there was still some eye-tracking data out-of-calibration.

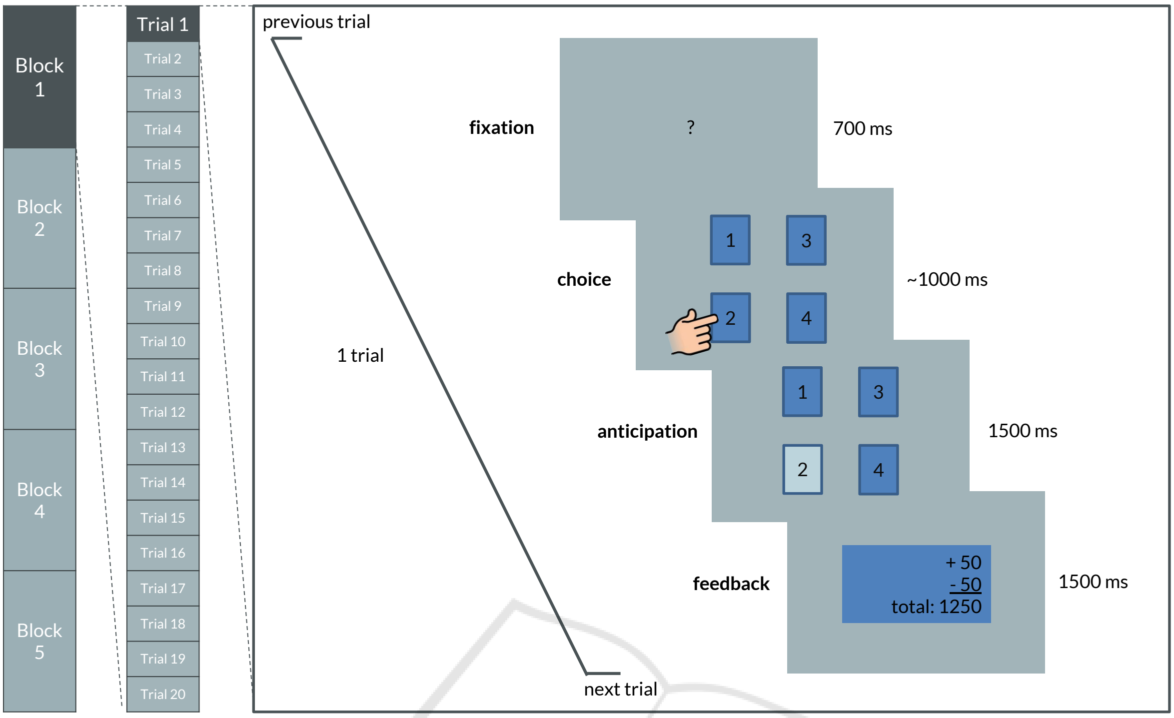

Figure 1: IGT schematic representation of the sequential phases of each trial and respective duration. The total game was divided into 5 different blocks, each one with 20 trials. A trial was composed by four phases, the fixation, the choice while the subject is deciding the deck he/she want to select, the anticipation phase to present the deck selected and, finally, the feedback with the monetary win, loss and the current money.

The method applied in this work to correct the eye-tracking data is an adaptation of the one presented by Hornof and Halverson (2002).

In our experiment, this problem was essentially solved with two linear regressions (one for X coordinates and another for Y coordinates) between the known data and the corresponding raw data in two parts:

1. Adjustment of the eye-tracking data by translating the whole set of coordinates according to the difference between a known fixation position and its given position. The IGT was programmed to have a question mark in the centre of the screen, and then the cursor replace the mark. This forces the player to look initially to the middle of the screen and therefore, having the initial position of the eye-tracking for each player able us to translate the x and y axes. This procedure requires the correct acquisition of the initial fixation of the eye, otherwise, the calibration can not be done and the respective trial should not be considered. 9.5% of the initial trials have no fixation at the beginning and, consequently, they were not considered.

2. Adjustment of the eye-tracking data by scaling a known distance. It was assumed that when the participant clicks in a target, he tends to look at it. The distance between the pointer and eye coordinates during the click (the choice of the deck) was accessed for each trial. The ratio between the pointer and eye coordinates in the moment of the click was computed and multiplied to the eye-tracking data (this method was based on (Hornof and Halverson, 2002)). This step is only applied if, after the first step, the distance between eye and pointer at the click time was higher than 80 pixels. This procedure requires the correct acquisition of the final fixation of the eye, otherwise no conclusion can be made and this trial should not be considered. 5% of the trials resulted from the first calibration have no fixation during the time of clicking and, consequently, were not considered. More than 60% of the trials had not the final fixation near the click area, so these trials were calibrated. Figures 2 and 3 are an example of a trial that, to be correctly compared to mouse movements, have to be calibrated.

Even with the application of the two-phased linear regression, some trials still have not suitable eye gaze data. To remove this data, the ratio between the amount of data outside the region of interest (the cen-

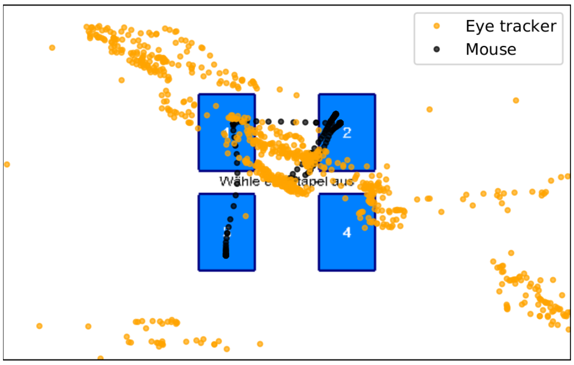

Figure 2: Example of a trial before calibration.

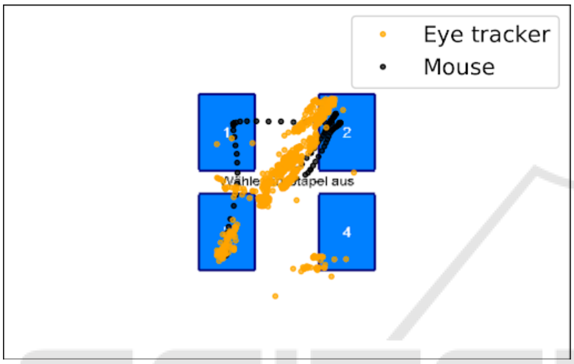

Figure 3: Example of a trial after calibration.

tral square where the decks are) and the total data - outside ratio - was computed. 11.2% of trials were discarded with this procedure, considering a threshold higher than 20% of outside ratio.

A difference between this method to correct eye-tracking data and the approaches presented in other studies (for example, (Chen et al., 2001)) is this elimination of the trials that, after the correction, are still uncalibrated. If this procedure had been done in the data without calibration 89.1% of the trials would be eliminated. This process of calibration reduced our dataset from 8100 trials to 5205.

5 COMPARISON METRICS AND RESULTS

To compare the eye gaze and cursor movements during a decision-making task, some measures were computed to take into consideration the spatial and temporal domain. With this purpose, it was considered a few regions inside the IGT - each deck constituted a region and the last region was constituted by the space outside the decks. Two of the metrics calculated, spatial coordination and temporal coordination, were adapted from Chen et al. (2001) and Rodden and Fu (2007). Another variable was introduced, temporal-spatial coordination, to assess the amount of time that the eye gaze and the cursor were visiting the same region.

5.1 Spatial Coordination (SC)

Independent of time, this feature only evaluate if, during a trial, the participant had a consistent interest in the regions manifested both by pointer and eye movements. This feature is the ratio between the number of regions that were visited by both eye gaze and cursor and the total number of regions visited by eye or pointer, according to which of the two visited more regions.

The considered regions were "Deck 1", "Deck 2", "Deck 3" and "Deck 4". Region "Outside the decks" was not considered since it is a region visited by both eye gaze and cursor in almost all trials, and, therefore, the ratio would increase significantly due to a region which is nearly compulsory to visit. For example, to go from a deck to another, it is required to visit the region "Outside the decks", as well as at the beginning of each trial, where the participants were instructed to focus on the middle of the screen.

In terms of possibilities, if the eye gaze and cursor visited the exactly same decks, this ratio has its maximum value of 1. A more specific example, if in a certain trial the eye gaze visited "Deck 1" and "Deck 4" and the pointer visited only the "Deck 4", the value of this relation would be 0.5.

The mean value of all trials for each participant was determined. The values range from 0.00 to 1.00 and the mean value and its standard deviation are 0.78 ± 0.29. In our study, it was only considered, for the eye gaze, the regions visited for more than 60 ms, which corresponds the minimum fixation duration according to SMI (2010).

5.2 Temporal Coordination (TC)

In contrast with the previous feature described, the one extracted from temporal coordination takes into account the time spent in each region by the eye gaze and by the cursor. For each trial, it is calculated the total duration spent by the pointer and eye gaze in each region, to then find the correlation between these two measurements (Rodden and Fu, 2007). This correlation was calculated for each region and this feature is the result of its mean. Here, in addition to the decks' area, also the area outside the decks is important to be considered as a region. The correlation was measured by the Pearson correlation coefficient, which measures the linear relationship between the two datasets. It varies between -1 and +1, with the extremes implying the strongest linear relationships (negative and positive, respectively) and 0 indicating no correlation (Sedgwick, 2012).

The times' correlation coefficient ranges from 0.59 to 0.84, with a mean value and a standard deviation of 0.66 ± 0.09.

5.3 Temporal-Spatial Coordination (TSC)

This variable covers the spatial information and the temporal information, quantifying the ratio between the time where the eye gaze and the cursor were in the same region and the trial time. Similar to temporal coordination, this feature also considered the five regions mentioned above. The mean value of all trials was calculated and the values range from 0.00 to 1.00 with a mean value and a standard deviation of 0.65 ± 0.19.

5.4 High and Low Uncertainty Conditions

When the participants know in advance the deck that will be selected, they make a fast decision. Therefore eye and mouse move directly from the centre of the screen to the chosen deck. In this condition, both movements should highly correlate. In contrast, when the participants explore the options and waver between different decks, those movements may not be correlated. To differentiate these two conditions, the less uncertain condition is established when the eye gaze and the cursor only visit one region, and the more uncertain condition is verified in the other trials, in which the eye gaze and/or cursor examine more than one deck. In our data set, 62% of the trials represent the low uncertainty condition.

The three metrics previously presented were assessed for these two conditions and the results are presented in Tables 1 and 2. As expected, the results show a higher correlation between the eye and pointer movements in non-exploratory condition. Nevertheless, although spatial coordination shows a decrease of 48% from non-exploratory to exploratory trails, the decline is inferior for temporal coordination (22%) and temporal-spatial coordination (16%). This means that the time spent by the eye gaze and cursor in the same regions is comparable in both conditions, but the visited regions diverge in the exploratory condition. This suggests that the common regions visited by both pointer and eye gaze are the ones where the participant spends the most of the time, and there are regions that the eye gaze rapidly visits, and the cursor does not visit at all.

Table 1: Relation between eye and pointer movements for non-exploratory condition.

	Mean	STD	Min	Max
SC	0.97	0.17	0.00	1.00
TC	0.81	0.05	0.76	0.90
TSC	0.71	0.17	0.01	0.99

Table 2: Relation between eye and pointer movements for exploratory condition.

	Mean	STD	Min	Max
SC	0.49	0.16	0.00	1.00
TC	0.59	0.11	0.48	1.00
TSC	0.55	0.18	0.00	0.97

6 CONCLUSIONS

The presented study compared eye and mouse movements during a decision task to understand whether pointer-tracking could serve as a useful alternative to eye-tracking for assessing user behavior.

To ensure correct analysis and comparison of eye and pointer data, it was necessary to resolve calibration issues and eye drift in the eye gaze data. The design of the IGT in this study allowed us to determine the initial and final eye fixation in each trial and therefore, to spatially correct the recorded eye positions within each decision trail. By applying this procedure, we were able to use 65% instead of just 11% of the eye data in further analyses.

Our three approaches for evaluating the coordination between eye and pointer movements are consistently high. Spatial coordination has a higher mean correlation, which is in line with previous studies that reported a stronger correlation of eye and mouse movements in areas of interest and not necessarily moving at the same time (Huang et al., 2011; Navalpakkam et al., 2013; Bieg et al., 2010). Still, the temporal coordination is higher than the correlations reported in previous studies (Rodden and Fu, 2007).

Regarding the relationship between eye and cursor trajectories in conditions of higher and lower uncertainty, the developed work demonstrated that there is a high correlation when uncertainty is low. Nevertheless, when a person hesitates between different decision alternatives this correlation decreases and, contrary to what was expected, the results of the temporal coordination is higher than spatial coordination. This could mean that in uncertain trials the pointer movement in the area of interest is relatively consistent with gaze.

The temporal-spatial coordination, as a combination of coordination metrics, gives a clear picture of the convergence between eye and mouse movements. The level of correlation is somewhat lower in less uncertain conditions. Nevertheless, the findings support the idea that pointer tracking may be useful as an alternative to eye-tracking.

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