A gaze bias with coarse spatial indexing during a gambling task

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Abstract

Researchers have used eye-tracking methods to infer cognitive processes during decision making in choice tasks involving visual materials. Gaze likelihood analysis has shown a cascading effect, suggestive of a causal role for the gaze in preference formation during evaluative decision making. According to the gaze bias hypothesis, the gaze serves to build commitment gradually towards a choice. Here, we applied gaze likelihood analysis in a two-choice version of the well-known Iowa Gambling Task. This task requires active learning of the value of different choice options. As such, it does not involve visual preference formation, but choice optimization through learning. In Experiment 1 we asked subjects to choose between two decks with different payoff structures, and to give their responses using mouse clicks. Two groups of subjects were exposed to stable versus varying outcome contingencies. The analysis revealed a pronounced gaze bias towards the chosen stimuli in both groups of subjects, plateauing at more than 400 ms before the choice. The early plateauing suggested that the gaze effect partially reflected eye-hand coordination. In Experiment 2 we asked subjects to give responses using a key press. The results again showed a clear gaze bias towards the chosen deck, this time without any influence from eye-hand coordination. In both experiments, there was a clear gaze bias towards the choice even though the gaze fixations did not narrowly focus on the spatial positions of choice options. Taken together, the data suggested a role for gaze in coarse spatial indexing during non-perceptual decision making.

Keywords Iowa Gambling Task · Decision-making · Gaze bias · Preference formation

Introduction

Effects of gaze bias and preference formation have been widely demonstrated in relation to orienting behavior in evaluative decision-making. It has already been known for decades that humans are able to develop a preference towards unfamiliar objects over time simply by looking at the items; mere repeated exposure enhances the preference formation for an object (Zajonc 1968). Natural to the concept of liking, we spend more time looking at

preferable objects than at non-preferable objects. Shimojo et al. (2003) showed that this tendency extends to looking at objects we choose rather than those we do not choose in the course of a decision-making process between two options presented simultaneously. In their studies, gaze likelihood analysis was applied, examining the proportion of the observer's gaze directed at the stimulus that eventually will be chosen. Pairs of faces were presented on a display, and subjects were asked to choose which one was more attractive, less attractive, or rounder, by pressing a key. The likelihood of gazing at the eventually-chosen stimulus progressively increased from chance level to a significant inspection bias, until the response was given; a phenomenon the authors called a “gaze-cascade effect.” Their findings suggested that the gaze cascade is a model that can accommodate data that appear to show a gaze bias towards the chosen option. Several studies have built on this work to investigate gaze bias towards the chosen option during visual decision-making in forced-choice decisions in preferential and non-preferential tasks (Simion and Shimojo 2006, 2007; Glaholt and Reingold 2009a, b; Schotter et al. 2010; Morii and Sakagami 2015).

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Researchers have indicated that the gaze bias appears to be a general visual characteristic pronounced during decision-making.

Most of the studies have focused on tasks where the critical information of the stimuli depends on the visual features of the image, as when subjects are asked to indicate their preferred image from pairs of faces, pairs of abstract figures generated by Fourier descriptors, or graphic arts images. In such choice situations, there is no uncertainty about the information. Moreover, all the relevant information is accessible through visual perception alone. Indeed, it has been suggested that the stimulus type is crucial in generating a gaze bias (Park et al. 2010; Liao et al. 2011). The role for gaze as predictive of future choice might be inherently related to visual perception, when the gaze is used to access visual features for evaluative purposes. Studies have shown that fixation patterns are influenced by the context of the visual scene and by the saliency of the stimulus representations, thus revealing top-down as well as bottom-up influences (Henderson 2003). Alternatively, the role of gaze in preference formation might reflect an orienting process, whereby the gaze enables a spatial approach to a particular stimulus, indexing its spatial position rather than accessing its visual features. Several studies revealed the important role of navigation cells in the brain and how spatio-frequency features are affected by the information acquired through visual attention (Yan et al. 2016; Seif and Daliri 2015). To examine the possibility of a role of the gaze in orienting during preference formation, we investigated the gaze likelihood in a decision-making task in which the stimulus complexity is not explicitly determined by its visual features, but can only be grasped through active learning on the basis of the history of choice outcomes. For this purpose, we adapted the Iowa Gambling Task (IGT; Bechara et al. 1994), a well-known paradigm that is frequently used to assess decision-making deficits under uncertainty (Toplak et al. 2010; Cui et al. 2013). For present purposes, we changed the IGT to a two-choice version.

In this gambling task, subjects can optimize their intake through probabilistic learning. In each trial, the subjects should select a card from one of four decks; some decks are more advantageous than others, and subjects are asked to maximize their outcome across 100 trials (Bechara et al. 1994, 1997). Each deck is associated with its own probability distribution; through learning, subjects shift from decision-making under ambiguity in early trials to decision-making under risk in later trials (Brand et al. 2007). In the original IGT, decks were counter-intuitively arranged so that higher payoff decks resulted in long-term loss, whereas lower payoff decks yielded long-term gain. In the present study, we used only two decks (named A and C in accordance with the original IGT) to create a forced-choice

task with two alternatives, presented right and left, for comparison with previous studies that have shown cascading effects through gaze likelihood analysis.

Thus, we aimed to investigate whether the gaze can be predictive of choice in IGT. Additionally, we examined whether changes in the IGT schedule have any impact on choice behavior and gaze bias. Subjects were divided into two groups; one group (“Stable group”) encountered fixed rules, as the payoff of the decks did not change across trials; the other group (“Variable group”) experienced changes in the payoff of the decks during the task.

Experiment 1

Materials and methods

Subjects

The subjects were 28 students from Kyushu University, with a mean age of 22.75 ± 2.15 years. The subjects were divided into two groups (both $n = 14$) in which they were exposed to a different context; either stable (i.e., contingency of stimulus and outcome is fixed) or variable (i.e., contingency of stimulus and outcome changes). All subjects were right-handed and had normal or corrected-to-normal vision. They were individually tested over a 1-h session, and were paid 1000 Japanese yen as compensation for their participation in this study. The subjects did not receive an additional bonus related to their performance in the IGT. All had no gambling experience, and reported to be healthy with no history of neurological disease. Written informed consent according to APA ethical principles was obtained before the experiment. All subjects were naïve to the purpose of the experiment.

Apparatus and stimuli

Subjects’ eye movements were recorded during the sessions using the Eye Tribe eye-tracking system at 60 Hz sampling rate; a system with sufficient reliability for present purposes (Dalmaijer 2014; Ooms et al. 2015). Before the start of a session, subjects were asked to follow the dot on a display to complete a 12-point calibration. The display screen was placed at a distance of approximately 60 cm. After the calibration, the gaze coordinates were calculated through Eye Tribe with an average accuracy of less than $.5^\circ$ visual angle on a 24-inch display. During the experiment, the subject’s chin and forehead were stabilized using a chin rest to minimize head movements. Decks were presented on a display with 1920×1080 pixels; the visual angles of each object subtended approximately $3.8^\circ \times 3.8^\circ$ (110×110 pixels). All events and recordings were

controlled through code written in Psychopy (version 1.84.2), for reference see (Peirce 2007, 2009).

Experimental task

In this computerized adapted version of IGT, only two decks, A and C, were presented simultaneously on a display, each with a different payoff scheme (Fig. 1). The task lasted for 45 min, and consisted of one session. Deck A in this experiment was color-coded red; deck C was color-coded green (Overman et al. 2004; Koop and Johnson 2011). The color variable does not affect performance (Overman et al. 2011; Overman and Pierce 2013). In the current study the color of the decks was counterbalanced across subjects and groups to avoid a confound from the saliency of color. We designed our experiment using a similar reward-and-punishment scheme as in the original IGT; both decks led to frequent unpredictable losses and constant gains. The difference between the two decks lies in the presented payoff structure. The red deck A produces constant high immediate gains; however, in the long term, due to large unpredictable losses, this deck results in a negative payoff. The green deck C yields constant low immediate gains, but results in a positive long-term payoff thanks to lower unpredictable losses. After selecting deck A, ‘high paying-high risk,’ during the course of ten trials, the subjects could earn 1000 points; however, they also encountered 5 unpredictable punishments, for a total of 1250 points, thus incurring a net loss of 250 points. On the other hand, after selecting deck C, ‘low paying-low risk,’ ten times the subjects could earn 500 points, and they encountered 5 unpredicted punishments of only 250 points, giving a positive net score of 250 points. Therefore, deck A was the disadvantageous deck; deck C the advantageous deck. Subjects initially started with 2000 points; they did not receive any bonus related to their performance in IGT. The total score, accumulated across trials, was displayed and updated each trial at the bottom of the computer screen.

Procedure

The subjects were instructed to maximize their profit as much as possible; they were asked in each trial to select a card from one of two decks by left-clicking on the mouse when the cursor was positioned on the deck. In this task, the subjects were not informed about the decks’ payoff structure or the number of blocks in a session; the subjects were also blind to which group they were assigned to, either the Stable or Variable group. Before the task, the subjects were informed that there were advantageous and disadvantageous cards.

A trial started with the presentation of a fixation cross at the center of the screen for 500 ms; this was followed by a display of the two decks. After each response, feedback was shown for 2000 ms, indicating the reward and the loss associated with the chosen deck. The response time was defined as the time from the onset of the decks on the display until the choice. The task was self-paced.

Subjects were asked to click only on a deck, not on other areas of the screen. If a click was detected in a different area, the trial was aborted and repeated. To control the start of the response time, the mouse cursor was fixed at the bottom center of the screen at the beginning of each trial. A session consisted of 3 blocks of 60 trials, for a total of 180 trials. One group, “Stable group,” was exposed to a stable context; $n = 14$ (i.e., the payoff structure for each deck is always fixed across blocks). The other group, “Variable group,” was exposed to a variable context; $n = 14$ (i.e., the payoff for the decks changed across blocks). Decks’ positions were fixed across trials, but counterbalanced across groups (subgroups, $n = 7$).

In the first block, both groups had the same payoff structures, deck A being disadvantageous, deck C advantageous. From the second block, the Variable group encountered a change in the context. Deck A produced the same expected value as deck C; both decks had the same payoff scheme, with long-term gain. According to the matching law (Herrnstein 1961; Revusky 1963), the subjects should alternate between two decks without significant differences in the choice rate. Finally, in the third

Fig. 1 Experimental task. A trial starts with a fixation for 500 ms, followed by the onset of the decks on the display. The red square represents deck A; the green square represents deck C. After subjects

choose a deck, feedback is presented below their choice for 2000 ms concurrently for each trial; the total score is updated at every selection. (Color figure online)

block, the Variable group experienced a reversal, deck A yielding a positive net score, but deck C yielding a negative net score.

Results

Behavioral analysis

Behavioral performance for each deck for both groups was calculated in line with previous IGT studies, calculating the mean proportion of choice (e.g., Fernie and Tunney 2006; Steingroever et al. 2013; Bull et al. 2015). Both groups showed the expected adaptive behavior. Consistent with previous studies, the Stable group gradually developed a preference for the advantageous deck C (Fig. 2a); the Variable group also showed adaptive behavior to the payoff structure, aiming to optimize the intake by changing their choices in accordance with the new contingencies (Fig. 2b). To assess the learning curve in IGT, net scores are used to indicate the improvement of performance during task trials (Bechara et al. 2000; Bechara and Damasio 2002). Therefore, in the present study net scores (the number of advantageous choices minus the number of

disadvantageous choices) are used and expressed as proportions in 60-trial blocks (Fig. 2c). For the Stable Group, a one-way within-subjects repeated measures ANOVA on net scores revealed a significant effect of Block $F(2, 26) = 17.132$, $MSE = .030$, $p = .000$, $\eta^2 = .569$. The mean net score for block 1 was .169, CI [.03, .30]; for block 2, $M = .443$, CI [.29, .60]; for block 3, $M = .540$, CI [.37, .71]. A one-way repeated measures ANOVA on net scores revealed a main effect of Block also for the Variable group, $F(2, 26) = 7.093$, $MSE = .060$, $p = .003$, $\eta^2 = .353$. The mean score for block 1 was .176, CI [.02, .33]; for block 2 (in which there was no difference in payoff between the two decks), $M = .031$, CI [−.04, .10]; for block 3, $M = .379$, CI [.20, .56].

Figure 2d shows the response times, clearly decreasing over trials for both groups. A two-way repeated measures ANOVA (Group $\times$ Block) on response times revealed a main effect of Block, $F(2, 52) = 21.776$, $MSE = .175$, $p = .000$, $\eta^2 = .456$. There was no significant difference between groups, $F(1, 26) = .123$, $MSE = 3.05$, $p = .729$, $\eta^2 = .005$; nor was there an interaction between Group and Block, $F(2, 52) = .104$, $MSE = .175$, $p = .902$,

Fig. 2 Behavioral performance in Experiment 1 for the Stable and Variable groups. **a** Mean proportion of choice by block for the Stable group (deck A, black line; deck C, black dashed line). **b** Mean proportion of choice for the Variable group. **c** Mean net scores for the Stable group (black line) and the Variable group (gray line). **d** Average response times across blocks for both groups. All error bars reflect the 95% confidence interval around the mean

$\eta p^2 = .004$. Subjects tended to take less time to decide in the later trials, as they became more familiar with the task.

Gaze likelihood analyses

Gaze likelihood analyses were conducted following the procedures by Shimojo et al. (2003). Since the current task did not require detailed visual analysis, we conducted all analyses with two sets of areas of interest: a narrow set, with areas of interest covering the exact areas of the decks, and a wide set, with areas of interest covering the entire hemifields (i.e., half of the screen) in which the decks appeared. For any data sample, if the gaze occurred outside the areas of interest, the sample was not included in the analysis. In the narrow analysis, we assigned a value of 1 if the subject's gaze was directed to the exact area of the chosen deck, and a value of 0 if the subject's gaze was directed to the exact area of the other, non-chosen deck. Any gaze data outside either deck area was treated as 'not-a-number'. In the wide analysis, we assigned a value of 1 if the subject's gaze was directed to the side (i.e., anywhere in the hemifield) of the chosen deck, and a value of 0 if the subject's gaze was directed to the side (i.e., anywhere in the hemifield) of the other, non-chosen deck. In this case, any gaze data outside the screen was treated as 'not-a-number'.

We computed gaze likelihood curves on the data for each 60-trial block separately. All samples were calculated by averaging the likelihood of inspection of the chosen target across all trials and subjects, using the last 1.5 s (90 samples) before the response. Figure 3 shows the probability of looking at the chosen deck as a function of time before the decision (i.e., a mouse click on the chosen target), for both groups in the three blocks separately, using the wide areas of interest (similar data patterns were obtained for the narrow areas of interest; see supplementary Fig. 1).

The pattern of data indicates a progressive gaze bias over time to the chosen target prior to the decision. The data with wide areas of interest were fitted using a four-parameter sigmoid curve; all conditions produced a good fit, with R^2 values consistently above 90%. For the Stable group, the R^2 was 99% in block 1, 93% in block 2, and 95% in block 3; for the Variable group, the R^2 was 98% in block 1, 99% in block 2, and 99% in block 3. To test whether there was a significant gaze bias, we combined the data from all trials (using for each trial the data samples from -1.5 s to 0 s) and conducted a one-tailed one-sample t-test against chance level (0.5). We obtained a significant gaze bias effect for both the Stable group, $t(13) = 16.729$, $p = .000$, $d = 4.471$, and the Variable group, $t(13) = 15.568$, $p = .000$, $d = 4.161$. The tests of normality revealed that the data points for both Stable and

Variable groups were normally distributed; $p = .73$ for Stable group, and $p = .18$ for Variable group.

Next, in order to investigate exactly when the subjects started shifting their gaze towards the chosen option, we sub-divided the time until decision into 15 bins of 100 ms. Bonferroni correction was used to set the alpha level. One-tailed one-sample t-tests showed a significant gaze bias already at 1500 ms before the decision for the subjects in the Stable group, $t(13) = 5.520$, $p = .000$, $d = 1.475$, and at 1300 ms for subjects in the Variable group, $t(13) = 4.038$, $p = .000$, $d = 1.079$.

Discussion

Consistent with previous IGT studies, the findings demonstrate that subjects learned to develop a preference towards the advantageous deck over trials to increase their winnings during the task. Both groups of subjects improved their winnings and took less time to decide as they progressed with the task. Importantly, the results show clear evidence of subjects developing a gaze bias to the option they ultimately choose prior to the decision time, even though the task did not require a specifically visual analysis of the targets.

However, two observations with respect to the gaze bias suggested that the data might partially reflect other factors in addition to the ad-hoc preference formation. Particularly, the gaze bias plateaued near the maximum value already more than 400 ms before the decision. This early plateauing might be due to eye-hand coordination, as subjects are required to move the mouse cursor to the target area before they can indicate their choice. Thus, it might be argued that the procedure with a mouse click effectively forces the subjects to apply a gaze bias. Furthermore, the gaze bias did not start from chance level, but already exhibited a significant bias at 1500 ms before the decision in the Stable group, suggesting that the subjects had already begun their decision process even before the targets were presented on the screen. Given that the positions of the decks were fixed across trials, the procedure in Experiment 1 allowed subjects to pre-allocate their gaze to their preferred deck before a trial started. Thus, to address these potential influences on the gaze bias, we conducted a second experiment, requiring new groups of subjects to respond by a key-press instead of a mouse-click, and randomizing the location of the decks on a trial-by-trial basis.

Experiment 2

Experiment 2 was designed as a follow-up to Experiment 1, to provide further evidence of a gaze bias during decision making in a simplified version of the IGT. With two new

Fig. 3 Gaze likelihood analysis for the Stable group (upper graphs) and the Variable group (lower graphs) in Experiment 1. Shown are plots of gaze likelihood towards the chosen deck as a function of time until the decision (from -1.5 to 0 s); the solid black lines show the

data fitting to a four-parameter sigmoid curve. **a** For the Stable group, gaze likelihood in block 1, $R^2 = 99\%$; **b** block 2, $R^2 = 93\%$; **c** block 3 $R^2 = 95\%$. For the Variable group, **d** gaze likelihood in block 1, $R^2 = 98\%$; **e** block 2, $R^2 = 99\%$; **f** block 3, $R^2 = 99\%$

groups of subjects we conducted an exact replication of Experiment 1, changing only two procedures. First, the subjects were required to respond by a key-press instead of a mouse-click. Second, the positions of the decks were randomized on a trial-by-trial basis.

Materials and methods

Subjects

The subjects were 28 students from Kyushu University, with a mean age of 22.53 ± 3.24 years; they were divided into two groups, Stable ($n = 14$) and Variable ($n = 14$). All subjects were right-handed and had normal or corrected-to normal vision. They were individually tested over a 1-h session and paid 1000 Japanese yen as compensation for their participation. All had no gambling experience and reported to be healthy. Written informed consent according to APA ethical principles was obtained before the experiment and all were naïve to the purpose of the experiment.

Apparatus, stimuli, experimental task and procedure

The experiment was conducted exactly as in Experiment 1, except for the following two changes. First, subjects were asked to indicate their choice by a button press on a keyboard. Second, the positions of the decks on the screen

were randomized. Subjects were instructed to press the left arrow to choose the left deck, and the right arrow to choose the right deck.

Results

Behavioral analysis

As in Experiment 1, both groups showed the expected adaptive behavior. The Stable group gradually developed a preference for the advantageous deck C (Fig. 4a); the Variable group also showed adaptive behavior to the task rule, aiming to optimize the intake by changing their choices in accordance with the new contingencies (Fig. 4b).

Figure 4c shows the data of mean net scores as a function of 60-trial blocks for both Stable and Variable groups. One-way repeated measures ANOVA on net scores showed no significant effect of Block for the Stable group, $F(2, 26) = 1.990$, $MSE = .035$, $p = .157$, $\eta^2 = .133$. For the Variable group, One-way repeated measures ANOVA produced a main effect of Block, $F(2, 26) = 4.281$, $MSE = .096$, $p = .025$, $\eta^2 = .248$. The mean score for block 1 was .186, CI [.09, .28]; block 2, $M = .067$, CI [$-.21$, .34]; block3, $M = .405$, CI [.25, .56]. Figure 4d shows the response time for both groups. A two-way repeated measures ANOVA (Group $\times$ Block)

Fig. 4 Behavioral performance in Experiment 2 for the Stable and Variable groups. **a** Mean proportion of choice by block for the Stable group (deck A, black line; deck C, black dashed line). **b** Mean proportion of choice for the Variable group (deck A, black line; deck C, gray dashed line). **c** Mean net scores for the Stable group (black line) and the Variable group (gray line). **d** Average response times across blocks for both groups. All error bars reflect the 95% confidence interval around the mean

revealed a main effect of Block $F(2, 52) = 17.228$, $MSE = .231$, $p = .000$, $\eta^2 = .399$. Over trials, the response time decreased for both groups. Analysis showed that there was no significant difference between groups with respect to response time, $F(1, 26) = .019$, $MSE = 6.05$, $p = .893$, $\eta^2 = .001$; there was also no interaction between Group and Block, $F(2, 52) = .237$, $MSE = .231$, $p = .790$, $\eta^2 = .009$.

Gaze likelihood analyses

Similar to Experiment 1, we computed gaze likelihood curves on the data for each 60-trial block separately. Figure 5 shows the probability of looking at the chosen deck as a function of time before the decision (i.e., a key press to indicate the choice), for both groups in the three blocks separately, using the wide areas of interest (similar data patterns were obtained for the narrow areas of interest; see supplementary Fig. 2). The data were fitted using four-parameter sigmoid curve. All graphs showed a good fit in all blocks; R^2 above 95% in all blocks for the Stable group as well as the Variable group.

One-tailed one-sample t -tests against a fixed value of 0.5 showed a significant gaze bias towards the chosen deck

across trials for both groups; $t(13) = 7.394$, $p = .000$, $d = 1.976$ for the Stable group; $t(13) = 9.533$, $p = .000$, $d = 2.548$ for the Variable group. The tests of normality revealed that the data points for both Stable and Variable groups were normally distributed; $p = .27$ for Stable group, and $p = .70$ for Variable group. The subjects started shifting their gaze towards the chosen option approximately 700 ms prior to the decision; $t(13) = 4.952$, $p = .000$, $d = 1.324$ for the Stable group; $t(13) = 5.849$, $p = .000$, $d = 1.563$ for the Variable group. Thus, unlike in Experiment 1, the pattern of gaze likelihood indicates that the subject's gaze progressively increased from chance level at the start of the trial. Furthermore, in Experiment 2 there was no evidence of the gaze likelihood plateauing near the maximum level before the decision.

Discussion

The results in Experiment 2 support and strengthen the results obtained from the previous experiment. Again, both groups of subjects adapted their choices to increase their winnings. In doing so, their gaze was predictive of choice, with clear evidence of a bias, starting from chance level and reaching maximum level around the time of the

Fig. 5 Gaze likelihood analysis for the Stable group (upper graphs) and the Variable group (lower graphs) in Experiment 2. The format is the same as in Fig. 3. **a** For the Stable group, gaze likelihood in block

1, $R^2 = 99\%$; **b** block 2, $R^2 = 98\%$; **c** block 3 $R^2 = 97\%$. For variable group, **d** gaze likelihood in block 1, $R^2 = 98\%$; **e** block 2, $R^2 = 97\%$; **f** block 3 $R^2 = 97\%$

decision. Unlike in Experiment 1, there was no plateauing of the gaze likelihood at 400 ms prior to the response. Thus, on a methodological note, we suggest that mouse-click procedures, though arguably more ecologically valid, may change the orienting processes during decision-making due to the required eye-hand coordination. More generally, an interesting question for further research will be to what extent motor factors, such as eye-hand coordination, can be dissociated from perceptual versus cognitive factors during preference formation.

As for the timing when the gaze bias starts to develop toward a decision, Liao and Shimojo (2012) reported that the subject's gaze was significantly biased to the chosen target from approximately 800 ms prior to the decision. Our results closely mirror their finding, with the subject's gaze in the present experiment significantly biased from approximately 700 ms prior to the decision, in both the Stable and Variable groups.

General discussion

In a set of two experiments, we investigated the gaze bias effect using a well-known paradigm, namely, the Iowa Gambling Task (IGT), which requires active learning from subjects in order to optimize their winnings over trials. In Experiment 1, we used a mouse-click version of the task,

with predictable locations for the two decks with different payoff structures. In Experiment 2, we used a button-press version of the task, with unpredictable locations for the two decks. In both experiments we found clear evidence that the gaze was predictive of choice long before the actual moment of the decision. Moreover, in both experiments, the gaze likelihood, gradually developing a bias for the target that will eventually be chosen. The results suggested a role for the gaze during risky choice, where the decks' payoff structure implies different levels of risk, in much the same way as during evaluative decision-making that requires a specific analysis of the visual features of different choice options.

The present study builds on previous contributions to use eye-tracking to capture the role of gaze during decision-making processes (e.g. Franco-Watkins and Johnson 2011; Krajbich and ArmelC 2010; Weaver et al. 2011). Recent studies showed that the gaze bias effect might be a general characteristic in visual decision-making; studies reported that the cascading of gaze likelihood for non-preferential tasks did not differ from that for preferential tasks (Glaholt and Reingold 2009b, 2011; Nittono and Wada 2009; Schotter et al. 2010; Morii and Sakagami 2015). Our findings indicate that the role of the gaze in preference formation is not necessarily tied to a perceptual analysis of visual features. Indeed, our data extend previous findings that gaze patterns may be informative about

Fig. 6 Distribution of gaze positions on the screen. **a** The gaze positions in Experiment 1, “Mouse click”; **b** the gaze positions in Experiment 2, “Button Press”. The gaze positions are plotted on the display of 1920×1080 pixels; data collapsed across all trials for both groups of subjects. Red framed squares represent the positions of

the decks on the screen; the red dashed line indicates the midline of the display, separating the left and right visual hemifields. The data shows the gaze distribution from the presentation of the fixation cross until the feedback of gain and loss. (Color figure online)

decision-making also in gambling tasks (Glöckner and Herbold 2011; Fiedler and Glöckner 2012). More specifically, through gaze bias analysis, following the procedures established by Shimojo et al. (2003), we find that gaze bias both reflects and influences the decision-making under uncertainty, when the visual features of the choice options merely serve as references to the history of rewards and punishments (i.e., the payoff structure for different decks), not as intrinsic characteristics that define the quality of the object (e.g., as in the case of face attractiveness, in which the visual features of the face determine its attractiveness). Thus, even when the visual features do not need to be inspected to form a qualitative representation, subjects tend to develop a gaze bias for the object they will choose.

In our data, the gaze appears to have a role in spatial indexing rather than in the perceptual analysis of visual features. This proposal is further supported by the pattern of gaze distributions (see Fig. 6). The gaze positions in both experiments tended frequently to fall outside the visual areas of the decks. Yet, using wide areas of interest around the choice options, covering entire hemifields, we were able to obtain prominent gaze bias. This pattern of results suggests that the subjects were not closely examining the visual features of the choice options. Instead, the most straightforward explanation is that the subjects used a minimalist strategy of spatial indexing, whereby the gaze serves as a deictic mechanism to facilitate the cognitive processing during decision-making (i.e., looking at the item currently being considered). Researchers have reported that fixation patterns during visual inspection differ according to the task when humans use the knowledge in a context to guide their fixations (Henderson et al. 2009; Wiener et al. 2012). In the present study, a coarse representation sufficed

for this purpose, especially during the early stages of decision-making in Experiment 1 (i.e., before guiding the mouse cursor to the choice option), and throughout the entire decision process in Experiment 2. The subjects needed merely to distinguish between left and right, a task that could be accomplished most economically with a coarse spatial resolution at the level of hemifields.

In sum, the results of the current study on gaze likelihood show the development of a gradual gaze bias toward a risky choice. Rather than having a role in the perceptual analysis of visual features, in the present paradigm the gaze may serve as a coarse spatial index to facilitate the cognitive processing during decision making.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval Written informed consent according to APA ethical principles was obtained before the experiment. APA guidelines.

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