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The time course of gaze bias in visual decision tasks

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In three experiments, we used eyetracking to investigate the time course of biases in looking behaviour during visual decision making. Our study replicated and extended prior research by Shimojo, Simion, Shimojo, and Scheier (2003), and Simion and Shimojo (2006). Three groups of participants performed forced-choice decisions in a two-alternative free-viewing condition (Experiment 1a), a two-alternative gaze-contingent window condition (Experiment 1b), and an eight-alternative free-viewing condition (Experiment 1c). Participants viewed photographic art images and were instructed to select the one that they preferred (preference task), or the one that they judged to be photographed most recently (recency task). Across experiments and tasks, we demonstrated robust bias towards the chosen item in either gaze duration, gaze frequency or both. The present gaze bias effect was less task specific than those reported previously. Importantly, in the eight-alternative condition we demonstrated a very early gaze bias effect, which rules out a postdecision response-related explanation.

Keywords: Eye movements; Preference; Gaze bias; Decision making.

In their interactions with the visual environment, observers produce high velocity eye movements referred to as saccades. Saccades are required in order to align the high-acuity foveal region of the visual system (the central two degrees of vision) with objects of interest in the visual field. The periods between saccades during which the eye is relatively still are referred to as fixations. Visual input is obtained during fixations and is largely suppressed during saccades (see Rayner, 1998, for a review). There is ample evidence that eye movements are preceded by an attentional shift to the saccadic target, and

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consequently the spatial distribution of eye fixations is a good indirect measure of the distribution of visual attention (e.g., Deubel & Schneider, 1996; Henderson, 1993; Hoffman, 1998; Hoffman & Subramaniam, 1995; Kowler, Anderson, Dosher, & Blaser, 1995; Rafal, Calabresi, Brennan, & Sciolto, 1989; Rayner, McConkie, & Ehrlich, 1978; Remington, 1980; Rizzolatti, Riggio, Dascola, & Umiltà, 1987; Rizzolatti, Riggio, & Sheliga, 1994; Schneider & Deubel, 1995; Shepherd, Findlay, & Hockey, 1986). Furthermore, the link between the eye movement and attentional systems is supported by neurophysiological data (e.g., Goldberg & Wurtz, 1972; Kustov & Robinson, 1996; Mohler & Wurtz, 1976; Wurtz & Mohler, 1976) and work with neuropsychological populations such as neglect patients (e.g., Johnston & Diller, 1986; Walker & Young, 1996). Due to the tight coupling between attention and eye movements, measures of gaze duration and location have proven to be invaluable in both cognitive and applied research. However, surprisingly few studies have investigated the relationship between eye movements and preference.

Shimojo, Simion, and colleagues (Shimojo, Simion, Shimojo, & Scheier, 2003; Simion & Shimojo, 2006, 2007) introduced a novel research paradigm examining eye movements during two-alternative forced-choice (2-AFC) preference decisions. Shimojo et al. (2003) showed participants pairs of faces and had them select the face that they found more attractive by pressing one of two corresponding keys. Participants' eye movements were monitored. The authors employed an analysis of eye-movement data (referred to as a "gaze likelihood analysis"), which plots, for each time point in a period prior to the response, the likelihood that observers' gaze was directed towards the stimulus that was eventually chosen. They found that during the last second before the response there was a progressively increasing bias in the observers' gaze towards the chosen stimulus.

To explain this effect, Shimojo et al. (2003) proposed a model of preference decisions where both gaze and intrinsic preference contribute to the decision. This model specifies two component processes related to looking behaviour that interact to produce preference decisions. The first process is preferential looking, where one tends to look longer at the stimulus that one likes (Birch, Shimojo, & Held, 1985; Fantz, 1964). The second process is the mere exposure effect, where merely looking at a stimulus increases preference for that stimulus (Kunst-Wilson & Zajonc, 1980; Moreland & Zajong, 1977, 1982; Zajonc, 1968). Shimojo et al. (2003) suggest that these two processes can combine to create a positive feedback loop (dubbed a gaze cascade) that progressively increases the activation of one of the decision options until it exceeds the threshold for response.

Shimojo et al. (2003) considered and rejected an alternative explanation that may complicate the interpretation of the gaze bias effect. Specifically, gaze bias might reflect at least in part, a postdecision interval occurring prior to response in which participants continue fixating the chosen stimulus. During such a delay, participants may be engaging in a variety of processes such as memorization of, or programming of, the response. Regardless of the cause, here we use the term "response-related explanation" to refer to the argument that the gaze bias documented by Shimojo, Simion, and colleagues is at least in part due to participants' tendency to continue fixating on the chosen stimulus after the decision but prior to the recording of the response.

Shimojo, Simion, and colleagues (Shimojo et al., 2003; Simion & Shimojo, 2006, 2007) advanced several arguments against a response-related explanation. Specifically, they argued that if gaze bias is due to response-related phenomena, it should not be specific to preference decisions and should occur when other forced-choice decision tasks are used. In addition, they argued that a critical goal for their research would involve demonstrating an early gaze bias that occurs long before the response and, consequently, is less likely to be contaminated by response-related processes. To see if the gaze bias was manifest in other tasks, Shimojo et al. (2003) had separate groups of observers view the same pairs of faces under different decision instructions (e.g., choosing the face that was more round). Gaze likelihood analysis revealed a much more pronounced gaze bias in the preference task than in other tasks, a finding that Shimojo et al. suggested is not consistent with a generic response-related explanation (see also Simion & Shimojo, 2006, for a similar task difference).

Looking for evidence of an early gaze bias, Simion and Shimojo (2006) employed a gaze-contingent window paradigm in which participants made preference decisions while viewing pairs of faces through a small circular window that was continually centred on their point of gaze. Face information was available inside the window and was masked outside the window. This viewing mode substantially lengthened trial duration, and importantly a gaze bias was observed as early as seven seconds prior to the response. Simion and Shimojo argued that such an early gaze bias cannot be solely due to response-related processes.

Simion and Shimojo (2007) provided additional evidence against the response-related explanation of the gaze bias effect. On each trial, a pair of faces was displayed for a random duration and participants were asked to choose the more attractive face. After the disappearance of the faces, participants were asked to indicate their choice if they did not do so while the faces were presented (decision), or to confirm their choice if they provided a response earlier (decision confirmation). Examining the gaze bias associated with responses occurring after the disappearance of the display, Simion and Shimojo demonstrated a much stronger gaze bias effect when such responses constituted a decision rather than a decision confirmation. Based on these findings, the authors argued that the gaze bias reflects, at least in part, decision processes rather than postdecision response-related processes.

The main goal of the present research was to further explore the time course of the gaze bias effect. In particular, we attempted to provide unequivocal evidence of a gaze bias independent of response-related phenomena. Experiment 1a was designed to replicate the study by Shimojo et al. (2003). In order to examine the generality of their effect, our 2-AFC preference decision task employed a different stimulus set (black & white photographic art) and a different control task (recency task: Participants were required to choose the photograph that they thought was taken more recently). In order to lengthen trial durations, in Experiment 1b we used a gaze-contingent window paradigm similar to Simion and Shimojo (2006), and in Experiment 1c we introduced an eight-alternative forced-choice (8-AFC) version of the preference and control tasks. In addition to the gaze likelihood analysis, the 8-AFC condition permitted more comprehensive analyses of the time course of gaze behaviour.

METHOD

Participants

All participants were undergraduate students at the University of Toronto at Mississauga, and each received $10 for their participation. Separate groups of 12 participants took part in Experiments 1a, 1b, and 1c.

Apparatus

The eyetracker employed in this research was SR Research Ltd. EyeLink 1000 system. Following calibration, gaze-position error was less than 0.5°. Stimulus displays were presented on a 19-inch Viewsonic monitor. In Experiments 1a and 1b, the participant's monitor was set to a resolution of 1024×768 and a refresh rate of 120 Hz, and in Experiment 1c it was set to a resolution of 1600×1200 and a refresh rate of 75 Hz. Participants were seated 60 cm from the display and a chinrest with a head support was used to minimize head movement.

Materials and design

Four hundred greyscale images were obtained from an archival database of photographic art that was sold in art auctions (Live Auctioneers website). The photographs varied widely in style and subject matter (e.g., portraits, landscapes, social interactions, objects, architecture, etc.; see Figure 1 for an

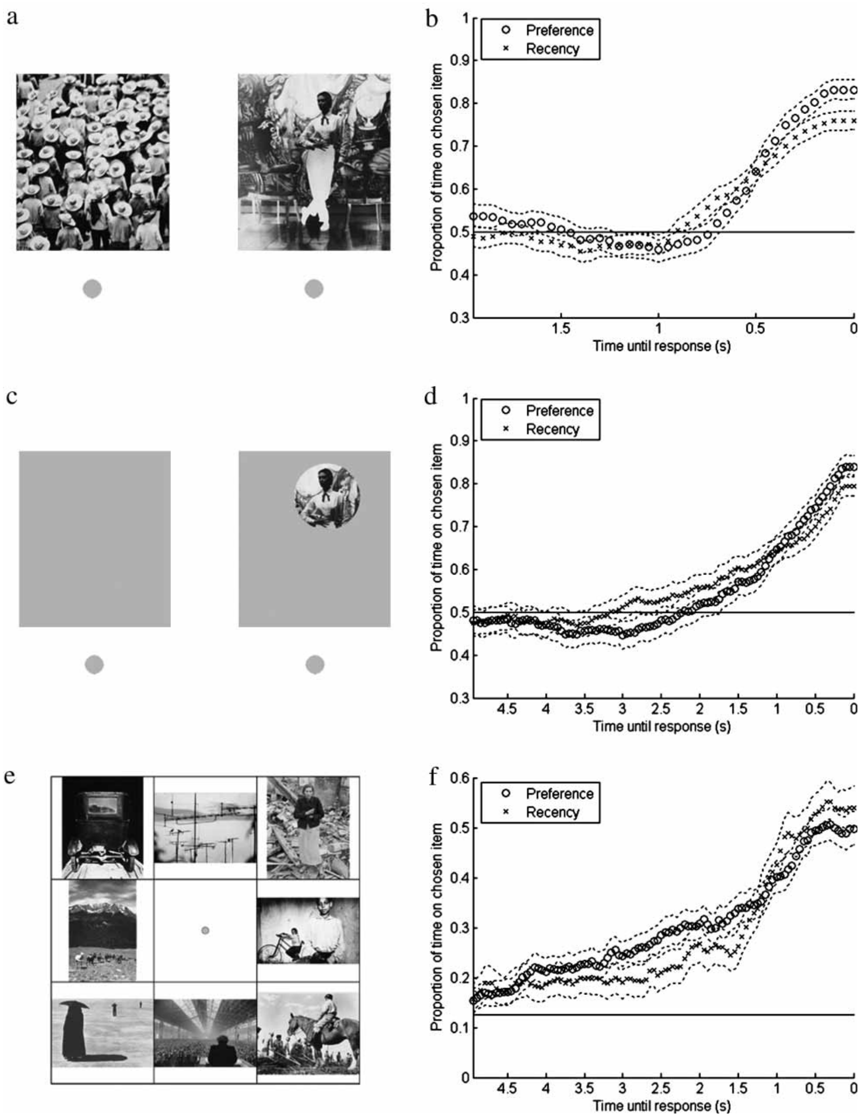

Figure 1. Stimulus displays for Experiments 1a (panel b), 1b (panel c), and 1c (panel e), and gaze likelihood plots for Experiments 1a (panels b), 1b (panel d), and 1c (panel f). Gaze likelihood curves plot the proportion of time spent on the chosen item, for each 50 ms time bin in the interval prior to the response. Dotted lines represent 95% confidence intervals about each time bin derived from bootstrapping.

illustration). In all experiments, each participant performed two tasks: Preference and recency, and the order of tasks was counterbalanced across participants. In the preference task the participant was instructed to select the image that he/she liked the most. In the recency task the participant had to select the image that he/she judged to be photographed most recently (i.e., was the most modern in content and/or style). Across images, there was a small but significant correlation between the number of times an image was selected as the preferred image, and the number of times it was selected as the most recent (Pearson's $r = .20$, $p < .01$). Consequently, it appears that the preference and recency decisions have very little variance in common (4%). For Experiments 1a and 1b, 200 2-AFC image pairs were created such that pairs were closely matched in size. Images were scaled such that their longest dimension (height or width) occupied 12.5° of visual angle (400 pixels) (see Figure 1a). Half of the pairs appeared in the preference task and half appeared in the recency task. Within each task, there were four initial practice trials followed by 96 experimental trials. In Experiment 1b, four practice trials and 50 experimental trials (a subset of the stimuli used in Experiment 1a) were used in each task. The displays were identical to Experiment 1a, with the exception that a 4.7° gaze-contingent circular window (150 pixels in diameter) was continuously centred on the point of gaze (average delay between physical eye movements and display update was 6.67 ms). Images were unchanged inside the gaze contingent window but were replaced with uniform grey field outside (see Figure 1c). In Experiment 1c, 384 images were used to create the 8-AFC stimulus arrays (192 in each task). Twenty-four trials were created by randomly dividing the 192 images into sets of 8. This was carried out four times so that each stimulus appeared with a random set of seven other stimuli, four times over the 96 trials in each task. Each task began with four practice trials composed of images that were not used elsewhere. The eight stimuli for each trial were presented in a 3×3 array, where each cell measured $8° \times 8°$ degrees of visual angle (400×400 pixels) (see Figure 1e).

Procedure

The trial sequence in Experiment 1a began with a side-by-side presentation of a pair of images (a one pixel wide black frame surrounded each image). The distance between image centres was 15.6° degrees of visual angle (500 pixels) (see Figure 1a). A grey dot was located below each image. To respond, the participant fixated the dot below the chosen image. Having fixated the dot for 400 ms, the dot turned green and a chime sounded to indicate that the selection was recorded. The images then remained onscreen for another 400 ms, and were then replaced with grey rectangles of the same size. The next trial started following a 400 ms interval.

The trial sequence in Experiment 1b was identical to Experiment 1a with the exception of the gaze-contingent viewing mode (see Figure 1c).

Participants were instructed that they had to deliberately explore the images and that when they made a decision they were to fixate the grey dot below the chosen image (grey dots were always visible). Given that the trials were longer and more effortful, they were self-paced (initiated by pressing the spacebar).

In Experiment 1c, the trial sequence began with the presentation of eight images arranged in a 3×3 grid (gridlines were shown as one pixel wide black lines) (see Figure 1e). When the participant had reached a decision, they looked at a grey circle located at the centre of the screen and pressed a button on a button box. This caused the circle to turn green, which signalled the participant to then fixate the item they had chosen in order to select it. After having gazed at their choice for 500 ms, a chime sounded and the trial ended. The 3×3 grid remained onscreen between trials, and participants advanced to the next trial by fixating the central (empty) grid square and pressing a button on a button box.

RESULTS

Prior to analysing gaze bias, we contrasted global measures of performance across the three experiments. To compute global performance measures, we defined a dwell as one or more consecutive fixations on a single image (a dwell ended when participants shifted their gaze to another image). For each trial we recorded the number of dwells, average dwell duration, and the total duration (i.e., summed duration across all dwells). Table 1 presents the averages for each of these global performance measures by task and experiment. For each variable, a 2×3 mixed ANOVA, which crossed task (preference, recency) and experiment (1a, 1b, 1c), was performed.

For all three experiments, the recency task produced longer decision times, $F(1, 33) = 14.58$, $MSE = 8.50 \times 10^6$, $p < .001$, more dwells, $F(1, 33) = 16.65$, $MSE = 1.31$, $p < .001$, and longer dwells, $F(1, 33) = 4.55$, $MSE = 3.80 \times 10^5$,

TABLE 1
Means and standard errors (in parentheses) for total duration, number of dwells, and mean dwell duration, by task and experiment

Condition (experiment)	*Total duration (ms)*		*Number of dwells*		*Mean dwell duration (ms)*	
	Preference	*Recency*	*Preference*	*Recency*	*Preference*	*Recency*
2-AFC (1a)	3038 (573)	3961 (714)	3.61 (0.27)	3.91 (0.28)	792 (83)	957 (96)
2-AFC gaze contingent (1b)	8481 (939)	13244 (1988)	2.68 (0.09)	3.33 (0.17)	3144 (274)	3822 (355)
8-AFC (1c)	5064 (562)	7250 (762)	10.5 (0.64)	12.9 (0.63)	468 (28)	556 (46)

$p < .05$. In addition, experiments varied substantially in terms of total duration, $F(2, 33) = 19.56$, $MSE = 1.71 \times 10^7$, $p < .001$, number of dwells, $F(2, 33) = 207.86$, $MSE = 2.68$, $p < .001$, and average dwell duration, $F(2, 33) = 126.05$, $MSE = 5.00 \times 10^5$, $p < .001$. Specifically, the free-viewing 2-AFC condition in Experiment 1a produced comparable decision times to the ones reported by Shimojo et al. (2003) (average of 3–4 s). As expected, the gaze-contingent condition in Experiment 1b and the 8-AFC condition in Experiment 1c produced substantially longer decision times than those obtained in Experiment 1a, both $F\text{s} > 9.20$, $p\text{s} < .01$. However, the manner in which decision times were lengthened differed dramatically across these two conditions. Compared to the free-viewing 2-AFC condition, the gaze-contingent condition elicited fewer dwells, $F(1, 22) = 6.92$, $MSE = 1.00$, $p < .05$, and much longer dwells, $F(1, 22) = 110.94$, $MSE = 7.36 \times 10^5$, $p < .001$, whereas the 8-AFC condition produced more dwells, $F(1, 22) = 194.39$, $MSE = 3.89$, $p < .001$, and shorter dwells, $F(1, 22) = 15.45$, $MSE = 1.02 \times 10^5$, $p < .01$.

We used several convergent analysis methods in order to study the gaze bias effect. Following Shimojo et al. (2003), we performed a gaze likelihood analysis. This analysis plots the proportion of time that participants' gaze was directed at the chosen item over the period of time just prior to the decision. The analysis window spanned 2 s for Experiment 1a, and 5 s for Experiments 1b and 1c. The gaze likelihood curves averaged across participants are shown in Figure 1. In addition, we obtained 95% confidence intervals using a bootstrap resampling procedure (Efron & Tibshirani, 1994).

Consistent with the findings of Shimojo et al. (2003) and Simion and Shimojo (2006), a substantial gaze bias was documented in all three experiments. In the free-viewing 2-AFC paradigm (Experiment 1a) the bias was evident at 700 ms before the response in the preference task and at 800 ms prior to response in the recency task. In the gaze-contingent 2-AFC paradigm (Experiment 1b), the bias towards the chosen item deviated from chance at about 2 s prior to the response in the preference task and at about 3 s prior to the response in the recency task. The duration of these effects is shorter than the 7 s effect reported by Simion and Shimojo (2006). It is likely that differences between studies in either the size of the gaze-contingent window or the nature of stimulus materials used might account for the differences in the duration of the gaze bias. In the 8-AFC paradigm (Experiment 1c), a gaze bias was present throughout the 5 s window in both tasks. However, unlike prior findings by Shimojo, Simion, and colleagues the differences in the gaze likelihood curves between the preference task and the control task were fairly subtle. In Experiment 1a and 1b, preference produced slightly steeper curves and higher final values than recency; the reverse was true for Experiment 1c.

However, the interpretation of the gaze bias observed in the gaze likelihood curves is complex, as it may reflect either longer dwells on the chosen item, more frequent dwells on the chosen item, or a mixture of both. Accordingly, for the 2-AFC conditions (Experiments 1a and 1b) for each item type (i.e., chosen vs. other), we computed total duration, average dwell time, and number of dwells. As can be clearly seen in Table 2, for each task in each experiment, there was a significant overall tendency to look longer at the chosen item (i.e., a gaze bias in total dwell time), all Fs > 12.39, $MSE = 1.17 \times 10^5$, ps $< .01$. It is also clear that this overall gaze bias was not due to longer dwells on the chosen item: No chosen versus other difference in Experiment 1a), $F(1, 11) < 1$; significant difference in the wrong direction in Experiment 1b, $F(1, 11) = 40.56$, $MSE = 7.33 \times 10^4$, ps $< .01$. It is unclear why in the gaze-contingent viewing condition dwell durations on the chosen items were on average shorter than dwell durations on nonchosen items. The gaze-contingent condition involves laborious and inefficient extraction of task-related information and consequently the termination of a given dwell (i.e., dwell duration) might vary in part depending on the speed with which decision-related diagnostic information is accumulated. If this is the case, the present finding might indicate that the gaze-contingent viewing mode produces a tendency to choose items from which task-related information is more easily obtained.

Rather than being due to differences in mean dwell duration, the overall gaze bias appears to be exclusively driven by a greater number of dwells on the chosen item, both $F(1, 11) > 45.74$, $MSE = 0.02$, ps $< .001$. In addition, it is important to note that in both experiments, the last dwell was directed at the chosen item in a very high proportion of trials: Chance = .50; Experiment 1a: Preference = .81, recency = .77; Experiment 1b: Preference = .84, recency = .79; all ts > 6.13, all ps $< .001$. Thus, it appears that in the 2-AFC conditions the bias seen in the gaze likelihood curves towards the end of the trial is strongly influenced by the bias in the placement of the last dwell.

Compared to the 2-AFC conditions, the 8-AFC condition in Experiment 1c produced a much larger number of dwells overall (see Table 1), and a substantial decrease in the proportion of trials in which the last dwell was directed at the chosen item: Chance = .125; preference: .48; recency: .48; both ts > 11.44, ps $< .001$. These two factors permitted a much more detailed examination of the time course of biases in dwell duration and dwell frequency in the 8-AFC condition. Accordingly, we introduced a dwell sequence analysis that compared dwell time and dwell frequency by item type (chosen vs. other), at each of eight dwell positions prior to the response. We also computed dwell time and frequency by item type for the first dwell in the trial.

TABLE 2

Total duration, number of dwells, and mean dwell duration on the chosen item and the other item, per trial, for each task in the 2-AFC conditions (Experiments 1a and 1b)

	Preference						*Recency*					
	Total duration (ms)		*Number of dwells*		*Mean dwell duration (ms)*		*Total duration (ms)*		*Number of dwells*		*Mean dwell duration (ms)*	
Condition (experiment)	*Chosen*	*Other*	*Chosen*	*Other*	*Chosen*	*Other*	*Chosen*	*Other*	*Chosen*	*Other*	*Chosen*	*Other*
Free-viewing	1663	1376	1.99	1.66	799	785	2092	1869	2.08	1.84	953	962
2-AFC (1a)	(310)	(267)	(0.15)	(0.13)	(81)	(90)	(378)	(339)	(0.15)	(0.13)	(94)	(101)
Gaze-contingent	4412	4069	1.51	1.18	2908	3450	6798	6446	1.79	1.56	3633	4060
2-AFC (1b)	(437)	(405)	(0.06)	(0.04)	(248)	(310)	(1058)	(932)	(0.10)	(0.09)	(341)	(377)

Standard errors are shown in parentheses.

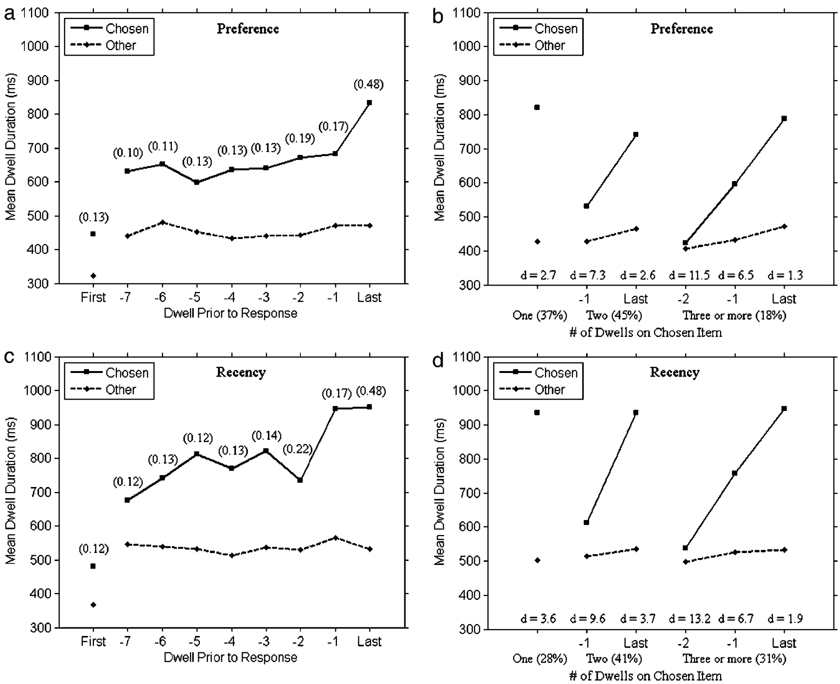

Figure 2. Dwell sequence analysis in Experiment 1c: (1) Dwell duration for the chosen and other items for each of the last eight dwells prior to response, and for the first dwell (preference in panel a, recency in panel c). Above each sequence position, in parentheses, is the proportion of trials in which the chosen item occupied that serial position. (2) Dwell duration analysis for trials with one, two, or three or more visits to the chosen item (preference in panel b, recency in panel d). The percentage of trials falling into each category is printed in parentheses. To create a baseline, chosen items were matched with other items at the same serial position. For each chosen–other pair, the average distance from response is printed below (d = distance in dwells).

As shown in Figure 2, the dwell sequence analysis reveals a striking difference in the duration of dwells on the chosen item compared to other items, at every point along the dwell sequence. To explore this we conducted a $2 \times 2 \times 8$ repeated measures ANOVA which crossed task (preference, recency), item type (chosen, other), and dwell position (last eight positions). Dwells were longer in recency decisions than in preference decisions, $F(1, 11) = 8.43$, $MSE = 1.69 \times 10^5$, $p < .05$. More importantly, the chosen item had greater dwell duration than other items at each sequence position, all $ts > 2.89$, $ps < .05$, and that difference increased toward the end of the trial producing a significant interaction between item type and position, $F(7, 77) = 5.16$, $MSE = 1.38 \times 10^4$, $p < .001$. For both tasks, this difference in dwell duration was already present in the first dwell in the trial, $F(1, 11) = 32.74$, $MSE = 5.12 \times 10^3$, $p < .001$.

Unlike the difference in dwell duration that is present at each position, the frequency of dwells on the chosen item (see Figure 2) deviated from chance (.125) only for the last few dwells in the sequence: Preference: Last three dwell positions, all $t\text{s} > 2.97$, $p\text{s} < .05$; recency: Last four positions, all $t\text{s} > 2.33$, all $p\text{s} < .05$). Thus, in marked contrast to the 2-AFC conditions, in the 8-AFC condition dwell duration appears to be a much more sensitive indicator of gaze bias than dwell frequency.

To further explore the difference in dwell duration between the chosen and other items, we divided the trials based on the number of dwells on the chosen item. Given that on average there were approximately two dwells per trial on the chosen item (preference = 1.86, recency = 2.18), we divided the trials into three groups, with one, two, and three or more dwells on the chosen item (for trials with more than three dwells the last three dwells were analysed). For each dwell on the chosen item we computed its position in the dwell sequence counting back from the response. We contrasted each dwell duration on the chosen item with the average duration of all dwells in the same dwell sequence position that were directed at nonchosen items. Figure 2 displays mean dwell duration by item type (chosen, other) for trials with one, two, or three or more visits to the chosen item. As shown in the figure, for both the preference and recency tasks, trials with one or two dwells on the chosen item demonstrated consistent gaze bias, all $t\text{s} > 3.43$, $p\text{s} < .01$. In contrast, for trials with three or more dwells on the chosen item, gaze bias was only evident in the last two dwells on the chosen item, all $t\text{s} > 2.62$, both $p\text{s} < .05$. In addition, for trials with two or three dwells, the difference in dwell duration between the chosen and other items increases significantly across visits to the chosen item, both $F\text{s} > 21.28$, $p\text{s} < .001$. Finally, the duration of the last dwell (or only dwell) on the chosen item did not vary significantly as a function of trial type ($F < 1$), possibly indicating that the final dwell on the chosen item reflects the operation of obligatory decision processes.

DISCUSSION

The present experiments replicated the gaze bias effect in preference decisions reported by Shimojo, Simion, and colleagues (Shimojo et al., 2003; Simion & Shimojo, 2006, 2007) and provided convergent evidence that this effect represents a very robust phenomenon. Specifically, preference decisions in our free-viewing 2-AFC condition in Experiment 1a produced a pattern of findings that closely matched Shimojo et al. (2003), and in preference decisions in the gaze-contingent condition in Experiment 1b, findings were obtained that strongly resembled those reported by Simion and Shimojo (2006). In addition, in Experiment 1c we extended these prior findings by demonstrating a dramatic gaze bias effect for preference decisions in multielement arrays (i.e., 8-AFC condition).

However, one of the important assumptions underlying the gaze cascade model proposed by Shimojo et al. (2003) concerns the task specificity of the gaze bias effect. Shimojo et al. and Simion and Shimojo (2006) examined preference decisions with face stimuli and employed a control task in which participants were asked to judge the roundness of the face. Similarly, in the present experiments, we compared the preference and recency tasks. In contrast to Shimojo, Simion, and colleagues (Shimojo et al., 2003; Simion & Shimojo, 2006), who documented a qualitative difference between preference decisions and the control task, across our three experiments the recency and preference tasks produced very similar findings. Future research is required to investigate whether, as argued by Shimojo, Simion, and colleagues, gaze bias has a unique role in preference decisions. Our findings suggest that the gaze bias effect might be a more general phenomenon characteristic of a variety of visual decisions. One possible difference between the recency task employed in the present study and the roundness task used by Shimojo, Simion, and colleagues concerns the greater extent of semantic encoding required by the former and the relatively shallow processing required by the latter. Clearly more research is required to investigate the relevance of such task differences to the gaze bias effect.

Regardless of the issue of task specificity, the primary goal for the present investigation, and an important goal for prior research by Shimojo, Simion, and colleagues (Shimojo et al., 2003; Simion & Shimojo, 2006, 2007), was the attempt to document a conclusive demonstration of a gaze bias effect that cannot be accounted for by postdecision response-related explanations. Similar to Simion and Shimojo (2006), we employed manipulations that lengthened the duration of preference decisions, and we looked for an early gaze bias effect that is sufficiently removed from the response and therefore less likely to be influenced by response-related processes. Specifically, Experiment 1b was patterned after the gaze-contingent window paradigm introduced by Simion and Shimojo (2006) and led to substantially lengthened preference decisions times. Surprisingly, although preference decision times were almost three times longer in the gaze-contingent condition than in the free-viewing 2-AFC condition in Experiment 1a, the former condition produced fewer dwells than the latter condition. Further analysis of the 2-AFC conditions (Experiments 1a and 1b) revealed that while more time was spent on the chosen item overall, individual dwells on the chosen item were not longer than dwells on the other item. Rather, the gaze bias effect was driven primarily by an increase in the frequency of visits to the chosen item and a marked tendency for the final dwell to be directed at the chosen item. Taken together, the small number of dwells produced (3–4 dwells), the absence of a gaze bias in individual dwell duration, and the strong bias in the placement of the final dwell make it difficult to rule out response-related explanations of the gaze bias effects that were demonstrated in the 2-AFC tasks.

It is in this context that the 8-AFC task introduced in Experiment 1c provides a unique contribution. Compared to the 2-AFC conditions, the findings from the 8-AFC condition revealed qualitative differences in the pattern of gaze behaviour. Specifically, the 8-AFC task produced many more dwells, shorter dwells, and a pattern of increasing bias in individual dwell durations from the very first dwell and throughout the trial. In addition, the gaze bias in dwell duration was evident regardless of the number of visits to the chosen item in the trial. Furthermore, in marked contrast to the 2-AFC conditions, in the 8-AFC condition dwell duration appears to be a much more sensitive indicator of gaze bias than dwell frequency. This is because, in the 8-AFC condition, although the bias in dwell duration is evident from the very first dwell, the dwell frequency bias occurs only in the last few dwells in the trial. Most importantly, the early gaze bias in dwell duration documented in the 8-AFC task cannot be accounted for by response-related explanations.

There are several possible differences that may explain these differences in gaze behaviour between the 2-AFC and 8-AFC conditions. The 2-AFC tasks might involve greater reliance on a comparison between the memory representation of the nonfixated alternative with the fixated one. In the case of multielement arrays, the options being considered may be too numerous to adequately represent in visual working memory, and often nonadjacent, making peripheral processing less efficient. Thus, multielement arrays might encourage a strategy that relies on rapid and repeated visual inspections of alternatives resulting in shorter and more numerous dwells. If this interpretation is correct then multielement arrays may increase the coupling between the item being inspected and the item being processed, possibly resulting in dwell duration being a more sensitive indicator of selective processing of items. Although this speculation is consistent with the findings we reported, further research is required to investigate these issues.

On the whole, we would argue that the present experiments clearly demonstrated the potential usefulness of multielement arrays for the study of visual decision making. Most importantly, we provided conclusive evidence for an early gaze bias effect that cannot be accounted for by response-related factors. A particularly dramatic illustration of this early bias was obtained by considering the very first dwell in the trial. Specifically, dwell durations were substantially longer when the first dwell was directed at the item that was later chosen as compared to the duration of first dwells on other items. It is important to note that participants did not demonstrate an increased tendency to direct the first dwell to the chosen item, indicating that initial parafoveal or peripheral processing of the stimulus array was ineffective in determining task relevance. Instead, this early bias might indicate that from the very first dwell the task relevance of the fixated item is evaluated, and this evaluation partially determines the first dwell duration. In addition, the magnitude of this differentiation increased in the last few dwells prior to response. However, unlike the differentiation early in the trial, towards the end of the trial selectivity towards the chosen item was expressed not only by an increase in dwell duration, but also by an increase in the likelihood of fixating the chosen item. These results might suggest that early in the trial gaze bias constituted an influence on the "when" (latency), and not the "where" (destination), of eye movements (see Findlay & Walker, 1999, and Rayner, 1998, for reviews of the independence of these two aspects in eye movements control). In contrast, near the end of the trial both aspects of eye movements were biased. Finally, although our findings of gaze bias in the multielement array conform to the accelerated differentiation pattern predicted by the gaze cascade theory (Shimojo et al., 2003; Simion & Shimojo, 2006, 2007), our failure to find the task specificity predicted by this theory led us to hypothesize that gaze bias might be a more general phenomenon characteristic of a variety of visual decisions.

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