Evidence for top-down control of eye movements during visual decision making

Mackenzie G. Glaholt — Department of Psychology, University of Toronto Mississauga, Canada

Mei-Chun Wu — Department of Electronic Commerce Management, Nanhua University, Taiwan

Eyal M. Reingold — Department of Psychology, University of Toronto Mississauga, Canada

Participants' eye movements were monitored while they viewed displays containing 6 exemplars from one of several categories of everyday items (belts, sunglasses, shirts, shoes), with a column of 3 items presented on the left and another column of 3 items presented on the right side of the display. Participants were either required to choose which of the two sets of 3 items was the most expensive (2-AFC) or which of the 6 items was the most expensive (6-AFC). Importantly, the stimulus display, and the relevant stimulus dimension, were held constant across conditions. Consistent with the hypothesis of top-down control of eye movements during visual decision making, we documented greater selectivity in the processing of stimulus information in the 6-AFC than the 2-AFC decision. In addition, strong spatial biases in looking behavior were demonstrated, but these biases were largely insensitive to the instructional manipulation, and did not substantially influence participants' choices.

Keywords: eye movements, visual attention, decision making

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Introduction

Visual decision making tasks in which observers select an item from an array of alternatives resemble everyday consumer choice decisions, such as purchasing an item from an online store or browsing for items on store shelves. Recently there has been a growing interest in the patterns of eye movements that occur during these tasks. In particular, several studies have identified decision-related biases in looking behavior, where gaze is found to be biased towards the item that is eventually chosen. This gaze bias effect has been shown to be remarkably robust, and has been demonstrated across a variety of decision tasks and stimulus materials (Glaholt & Reingold, 2009a, 2009b; Glaholt, Wu, & Reingold, 2009; Pieters & Warlop, 1999; Schotter, Berry, McKenzie, & Rayner, accepted for publication; Shimojo, Simion, Shimojo, & Scheier, 2003; Simion & Shimojo, 2006, 2007; for a review see Glaholt & Reingold, in press). In addition to the prior focus of comparing looking behavior toward the chosen versus non-chosen items, the main goal of the present investigation was to explore decision-related influences on gaze behavior by employing a subtle instructional manipulation. Specifically, eye movement patterns were compared across two different decision task instructions while holding the stimulus display, and the relevant stimulus dimension, constant across tasks. We reasoned that differences in gaze biases across instruction conditions would provide evidence that such biases are tied to the decision process and reflect, at least in part, top-down influences on eye movement control. In addition, given that it has been previously established that attention is not deployed uniformly over the spatial locations in a display, another goal of the present study was to explore the extent to which the spatial location of an item in an array influences the likelihood of that item being chosen. The present interest in top-down control of eye movements in visual decision making tasks is informed by an extensive investigation of this issue in the domain of scene perception, and consequently we begin by briefly summarizing this literature. Next, we summarize several empirical studies documenting patterns of spatial selectivity in eye movements across a variety of tasks, and consider how such biases might impact decision outcome in visual decision making tasks. Finally, we provide an overview of the present methodology.

The focus of the present study on top-down control of eye movements in visual decision tasks builds upon a related investigation of this issue in the context of scene perception. Specifically, recent research in this field has resulted in a substantial body of evidence that eye movements during scene viewing cannot be solely accounted for by low-level image features (e.g., contrast,

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luminance, edge density). Instead, cognitive factors, such as the top-down goals, and scene knowledge (see Henderson & Ferreira, 2004), play an essential role in shaping the pattern of eye movements that take place during scene processing (for recent reviews see Ballard & Hayhoe, 2009; Henderson, Brockmole, Castelhano, & Mack, 2007). In a classic demonstration of the effect of task instructions on eye movements, Yarbus (1967) found that the observers' pattern of eye movements changed dramatically when they made different judgments while viewing a painting of a natural scene (e.g., estimate the age of the characters in the painting, remember the clothes worn by the characters, surmise what the characters were doing). Yarbus suggested that observers selectively sample different information in different tasks, depending on the relevance of that information to their current behavioral goal (for a recent discussion and replication of Yarbus' findings, see DeAngelus & Pelz, 2009). Thus, according to Yarbus, the influence of the instructional manipulation was due to a difference across conditions in the stimulus dimensions, features, or segments that were relevant to the viewer (see Pieters & Wedel, 2007 for a related finding in the domain of visual marketing). In contrast, in the present investigation we were interested in the effect of instructional manipulations even when the relevant stimulus dimension remains constant between conditions. Specifically, we hypothesize that even if stimulus relevance remains constant across instructional manipulations, top-down influences might still alter the manner and depth with which the stimulus information is processed. In other words, apart from biasing the relevance of different aspects of the stimulus, top-down influence might also affect the degree to which information is encoded, elaborated, integrated, or contrasted across the different areas of the display.

One idea that is consistent with this hypothesis, which was proposed in the context of visual decision making, is that as the number of decision alternatives increases, decision makers tend to become more selective in their encoding of decision information (Payne, 1976; for a review see Payne, Bettman, & Johnson, 1993). When the number of alternatives is small, the decision maker is more likely to encode each of the alternatives in depth, and compare them along many of their attributes. In contrast, in multi-alternative decisions which define a larger decision space, deep encoding of the alternatives may not always be possible given the limited information processing capacity of the decision maker. As a result, the decision maker might engage in a 'screening' process where weak alternatives are subject to shallow processing and may be excluded from further processing while promising alternatives are processed to a greater extent (Beach, 1993; Russo & Leclerc, 1994; Senter & Wedell, 1999; Wedell & Senter, 1997). Thus, for given decision task, a manipulation that increases the number of decision alternatives would be expected to increase the degree of selectivity with which decision makers process the decision information.

In a previous study (Glaholt & Reingold, 2009a), we found evidence that supports this hypothesis. In this study (Glaholt & Reingold, 2009a), we monitored eye movements while participants made two-alternative forced choice (2-AFC) and eight-alternative forced choice (8-AFC) decisions. By analyzing participants' eye movements, we documented biases in looking behavior towards the item that was eventually chosen. Specifically, we found longer total gaze duration, and more dwells with longer mean duration on the chosen item than on non-chosen items (where a dwell is a run of one or more consecutive fixations on a decision alternative). Interestingly, we found that this choice-related gaze selectivity was greater in 8-AFC compared to 2-AFC decisions. However, it is important to note that in our previous study, the 2-AFC and 8-AFC decision tasks involved very different stimulus displays (see Figure 1 in Glaholt & Reingold, 2009a). Hence it is possible that the differences we observed between eye movement patterns in the 8-AFC and the 2-AFC tasks were partly due to differences in stimulus displays. Thus, in order to provide convincing evidence that top-down influences can change the manner and depth with which stimulus information is processed, in the present study we compared the pattern of gaze selectivity across decision tasks that differed in the number of decision alternatives, but that were equated in terms of the stimulus display and the relevant stimulus dimension.

Equating stimulus displays across conditions is especially important to consider in the context of visual decision making given that is well established that both visual attention and eye movements are not distributed uniformly over visual displays. For example, several findings have pointed to a rudimentary bias in the eye movement system toward the upper visual field (Durgin, Doyle, & Egan, 2008; Heywood & Churcher, 1980; Honda & Findlay, 1992; Pomplun, Reingold, & Shen, 2001; Previc, 1996; Williams & Reingold, 2001), and to a lesser extent toward the right visual field (Efron & Yund, 1996; Hutton & Palet, 1986). The possibility that attention and eye movements might be distributed unevenly over the locations in the display relates to a common assumption in visual marketing which holds that items that are placed in certain prominent locations will receive more attention from prospective buyers, and as a result will be more likely to be chosen or purchased (for a discussion, see Pieters & Warlop, 1999). In a classic example of the effect of stimulus location on choice, Nisbett and Wilson (1977) presented decision makers with a horizontal array of five identical stockings and asked them to choose the stocking that was of the highest quality. Participants were found to be strongly biased towards choosing stockings on the right side of the display, which indicates that biases associated with the spatial layout can impact decision outcome even when stimulus materials were held constant over locations. Consequently, an additional goal for the present study was to examine whether any gaze biases over the spatial locations in the stimulus array might in turn influence the decision outcome.

In the present study we employed a subtle manipulation of task instructions in order to illustrate the influence of top-down control over eye movements in visual decision making tasks. Participants viewed a set of six images of items drawn from a single category of everyday items that might be purchased in a store (belts, sunglasses, shirts, shoes; see Figure 1). They either made a two-alternative forced choice (2-AFC) *set selection* decision requiring them to choose the more expensive of two sets of three items or a six-alternative forced-choice (6-AFC) *item selection* decision requiring them to choose the most expensive single item out of the set of six. This manipulation of task instructions was expected to induce differences in the degree of choice-related selectivity in gaze behavior. Specifically, due to the increased number of decision alternatives, the 6-AFC item selection task was expected to elicit greater choice-related differentiation in the processing of stimuli in the decision array than the 2-AFC set selection task. Importantly, these two decision tasks were closely equated in several ways. First, the stimulus displays and response modes[1] were identical across decision tasks. Second, under the present manipulation both decision tasks required the participant to consider the same dimension of stimulus information (the price, or perceived value, of the items in the display). Given that the two instructions conditions (item vs. set) were closely equated in these ways, differences in gaze bias across these conditions would provide strong evidence for top-down control of eye movements. In addition, the present design permits testing for the presence of any gaze bias towards different locations in the stimulus array, and to assess whether any such biases influence decision outcome.

Figure 1. Example of a stimulus display used in both the 2-AFC set selection and the 6-AFC item selection tasks.

Method

Participants

All participants were undergraduate students at the University of Toronto at Mississauga, and each received $10 for their participation. Separate groups of twenty-four participants took part in the 2-AFC set selection task and the 6-AFC item selection task.

Apparatus

The eye-tracker 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. The participant's monitor was set to a resolution of 1600 × 1200 and a refresh rate of 85 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

Stimuli were constructed using an image database containing 144 exemplars from each of 4 categories of everyday object (belts, sunglasses, shirts, shoes) for a total of 576 images. Several online shopping websites were used to extract these images. Each image displayed a product on white background and all images subtended 7.2° × 7.2° degrees of visual angle (360 × 360 pixels). For each of the 4 product categories, the 144 images were divided into 24 sets of 6 items, each of which appeared in a single trial, for a total of 96 experimental trials. An additional 6 images from each category were used to create 4 practice trials that familiarized the participant with the procedure. The stimulus displays in the set selection and item selection tasks were identical. In each trial the display consisted of two columns of three cells (each cell subtending 400 × 400 pixels or 8° × 8° degrees with a 1-pixel black border) with one of the columns on the left side of the screen and one on the right side of the screen (see Figure 1). The distance between the centers of each column of images was 18.7° degrees of visual angle (600 pixels).

Procedure

In both the 2-AFC set selection task and the 6-AFC item selection task, the participant initiated the trial by fixating at the center of the screen and pressing a button on a button box. The stimulus display was then presented on the screen (see Figure 1). In the set selection task, participants decided whether the set of three items on the left side of the screen or the set of three items on the right side of the screen was more expensive (choose a set). Having reached a decision, the participant selected either the left set or the right set by pressing the left or right button on the button box, respectively. In contrast, in the item selection task, participants were required to choose the single most expensive item out of all six items in the display (choose an item). Having reached a decision, the participant first indicated which side of the screen the most expensive item appeared on (by pressing the left or right button on the button box), and then further identified which of the items in that set of three was their choice (by pressing the top, middle, or bottom button on the button box). Following the participant's final response, the screen was blanked for 500 ms and the participant was prompted to initiate the next trial.

Results

We present the results of this experiment in two sections. First, we examined the pattern of choice-related gaze selectivity in the 2-AFC and 6-AFC tasks, in order to detect top-down influences on eye movement control. In the second section, we examined the distribution of gaze over the spatial locations in the stimulus display, and tested the hypothesis that any such biases might impact upon decision outcome. Throughout our analyses of the eye movement data, we included fixations that occurred from the onset of the stimulus display and until the participant made a response. For each trial we identified a series of dwells, where a dwell is a consecutive run of one or more fixations on a single stimulus area (defined as the area of the square containing one of the six display items; see Figure 1). For each of the six stimulus areas in the display, we computed the total duration (i.e., the summed duration of all dwells),[2] the number of dwells, and the mean dwell duration.

Total duration summed over all stimulus areas was longer in the 6-AFC item selection task than in the 2-AFC set selection task (6-AFC = 5.4 seconds; 2-AFC = 4.1 seconds; $F(1,46) = 4.73$, $MSE = 7.05 \times 10^5$, $p < 0.05$). This was due to longer mean dwell duration ($F(1,46) = 24.56$, $MSE = 4.86 \times 10^4$, $p < 0.001$) but not more dwells ($F < 1$) in the 6-AFC item selection task (total number of dwells: 2-AFC = 10.8; 6-AFC = 10.5). We characterized the degree of choice-related selectivity in each task in two ways. First, we contrasted gaze behavior on the chosen side of the display (or the side containing the chosen item in the item selection task) and the other side of the display. Second, we examined the degree of differentiation between stimulus items for each side of the display (chosen and other) by comparing the item with the maximum total duration (max item) and the item with the minimum total duration (min item). In each case we computed the total duration, the number of dwells, and mean dwell duration. Each of these variables was analyzed in a 2 × 2 × 2 mixed ANOVA crossing Side (Chosen vs. Other) and Item (Max vs. Min) as within-participant variables, and Decision Task (2-AFC set selection task vs. 6-AFC item selection task) as a between-participants variable. For the purpose of this analysis, trials in which less than two of the items were viewed on either side of the display were excluded (<1%).

As can be seen in Figure 2, gaze was biased towards the chosen side of the display under both task instructions. However, the bias was much larger in the 6-AFC item selection task than in the 2-AFC set selection task, in total duration ($F(1,46) = 45.77$, $MSE = 3.60 \times 10^4$, $p < 0.001$), number of dwells ($F(1,46) = 26.49$, $MSE = 0.02$, $p < 0.001$), and mean dwell duration ($F(1,46) = 62.32$, $MSE = 2.27 \times 10^3$, $p < 0.001$). Note that for the 6-AFC item selection task, the chosen side of the display contains items that were not chosen, which should tend to reduce the difference between the chosen and other sides and thereby underestimate the degree of selectivity in this task. Nevertheless, this analysis still demonstrated a greater selectivity in processing the two sides of the display in the 6-AFC task.

A more precise indication of greater differentiation in the 6-AFC item selection task than in the 2-AFC set selection task may be seen in the difference between the max and min items across tasks in either the chosen side or the other side of the display.[3] For the chosen side, the difference between the max and min items was larger for the 6-AFC item selection task than the 2-AFC set selection task, in total duration ($F(1,46) = 57.36$, $MSE = 2.3 \times 10^4$, $p < 0.001$), number of dwells ($F(1,46) = 23.28$, MSE = 0.03, $p < 0.001$), and mean dwell duration ($F(1,46) = 77.92$, $MSE = 5.16 \times 10^3$, $p < 0.001$). Interestingly, even for the side that was not chosen (or for the 6-AFC, did not contain the chosen item), there was greater differentiation between the max and min items for the 6-AFC item selection task than for the 2-AFC set selection task in terms total duration ($F(1,46) = 6.41$, $MSE = 3.27 \times 10^4$, $p < 0.05$), and mean dwell duration ($F(1,46) = 16.14$, $MSE = 2.57 \times 10^3$, $p < 0.001$), but not in number of dwells ($F < 1$). The pattern of max–min differences across tasks were stronger for the chosen side than for the other side, resulting in significant three-way interactions for total duration ($F(1,46) = 57.36$, $MSE = 2.25 \times 10^4$, $p < 0.001$), number of dwells ($F(1,46) = 53.10$, $MSE = 0.01$, $p < 0.001$), and mean dwell duration ($F(1,46) = 60.17$, $MSE = 1.54 \times 10^3$, $p < 0.001$). Taken together, the present findings provide strong evidence that the 6-AFC item selection instructions produce a greater degree of differentiation in processing of stimulus items than the 2-AFC set selection instructions.

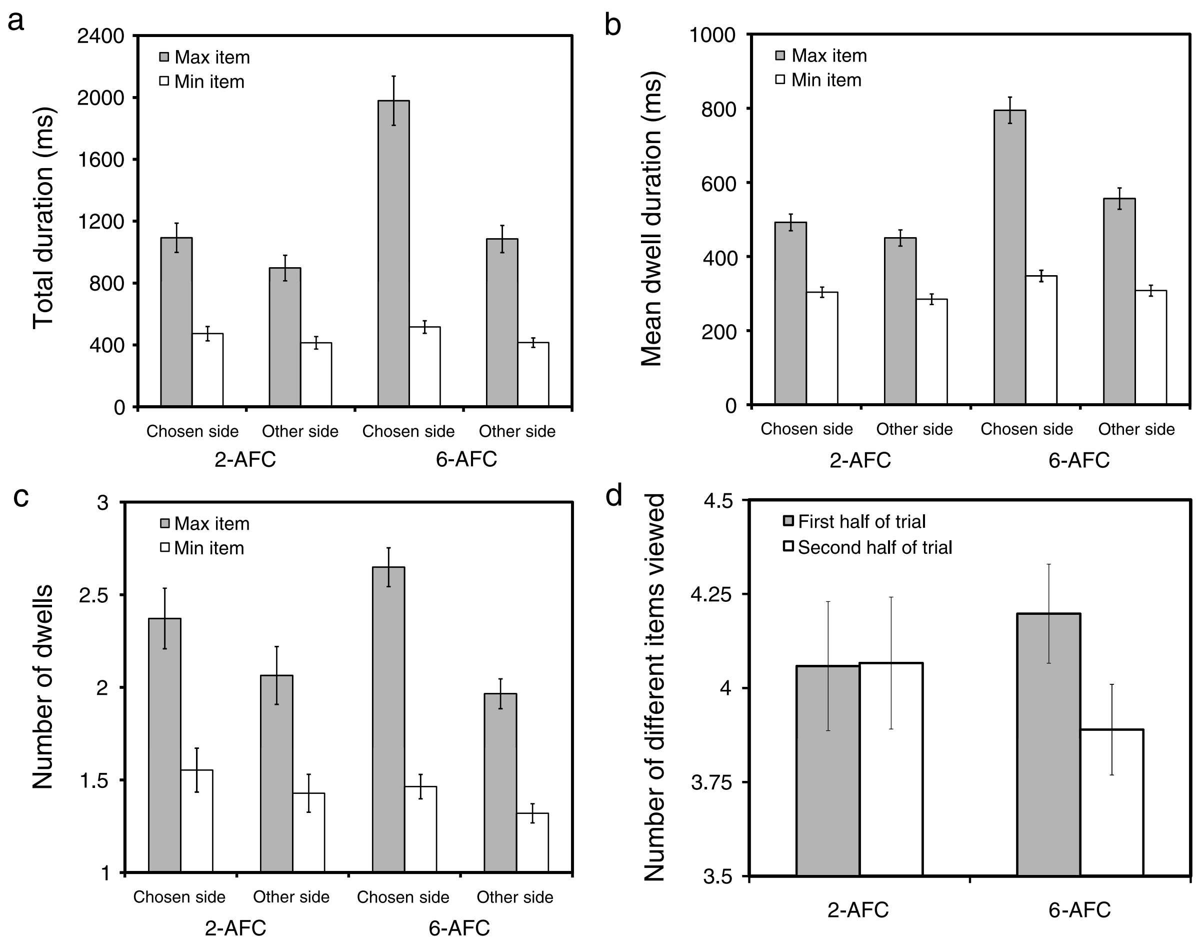

Figure 2. Measures of choice-related biases in looking behavior. Contrasting Max and Min items, on the chosen and other side of the display, for the 2-AFC set selection and the 6-AFC item selection tasks: Total Duration (panel a), Mean Dwell Duration (panel b), and Number of Dwells (panel c). Number of different stimulus areas viewed in the first half of the trial, and the second half of the trial, for the 2-AFC set selection task and the 6-AFC item selection task (panel d).

One way that participants might become more selective is by employing a 'screening' heuristic, where relevant stimulus items are considered in greater depth, and less relevant stimulus items are subject to shallow processing, or even excluded from further processing. We conducted a follow-up analysis in order to provide further support for this interpretation. Specifically, the application of a screening heuristic predicts that fewer stimulus items would be actively considered in the later part of the decision period compared to the beginning. In order to evaluate this, for each decision task, we computed the number of different stimulus areas that were viewed in the first half compared to the second half of the trial.[4] As can be seen in Figure 2 (panel d), for the 6-AFC task there was a significant reduction in the number of different stimulus areas viewed in the second half of the trial compared to the first half ($t(23) = 9.23$, $p < 0.001$). In contrast, for the 2-AFC task there was no difference in the number of different areas viewed in the first and second halves of the trial (number of areas viewed in second half was numerically larger, $t(23) = 0.29$, n.s.). This pattern of findings was reflected in a significant two-way interaction between Decision Task and Trial Half ($F(1,46) = 52.32$, $MSE = 0.01$, $p < 0.001$). This result is consistent with the hypothesis that in the 6-AFC item selection task participants employ a screening process that narrows the active set of items over the course of the trial.

Next we examined the spatial distribution of gaze over the stimulus display. Each of these measures was analyzed in a 2 ×3 × 2 mixed ANOVA that crossed Horizontal Position (left vs. right) and Vertical Position (top, middle, bottom) as within-participant variables, and Decision Task (2-AFC set selection vs. 6-AFC item selection) as a between-participants variable. As can be seen in Figure 3, there were strong spatial biases in looking behavior over the stimulus display. Total duration was biased across the vertical positions in the display ($F(2,92) = 61.56$, $MSE = 1.40 \times 10^4$, $p < 0.001$), with greater total duration on the middle locations than on the top locations, and greater total duration on the top locations than the bottom locations (all t's > 2.48, all p's < 0.05). In addition, there was a tendency for total duration to be biased towards the

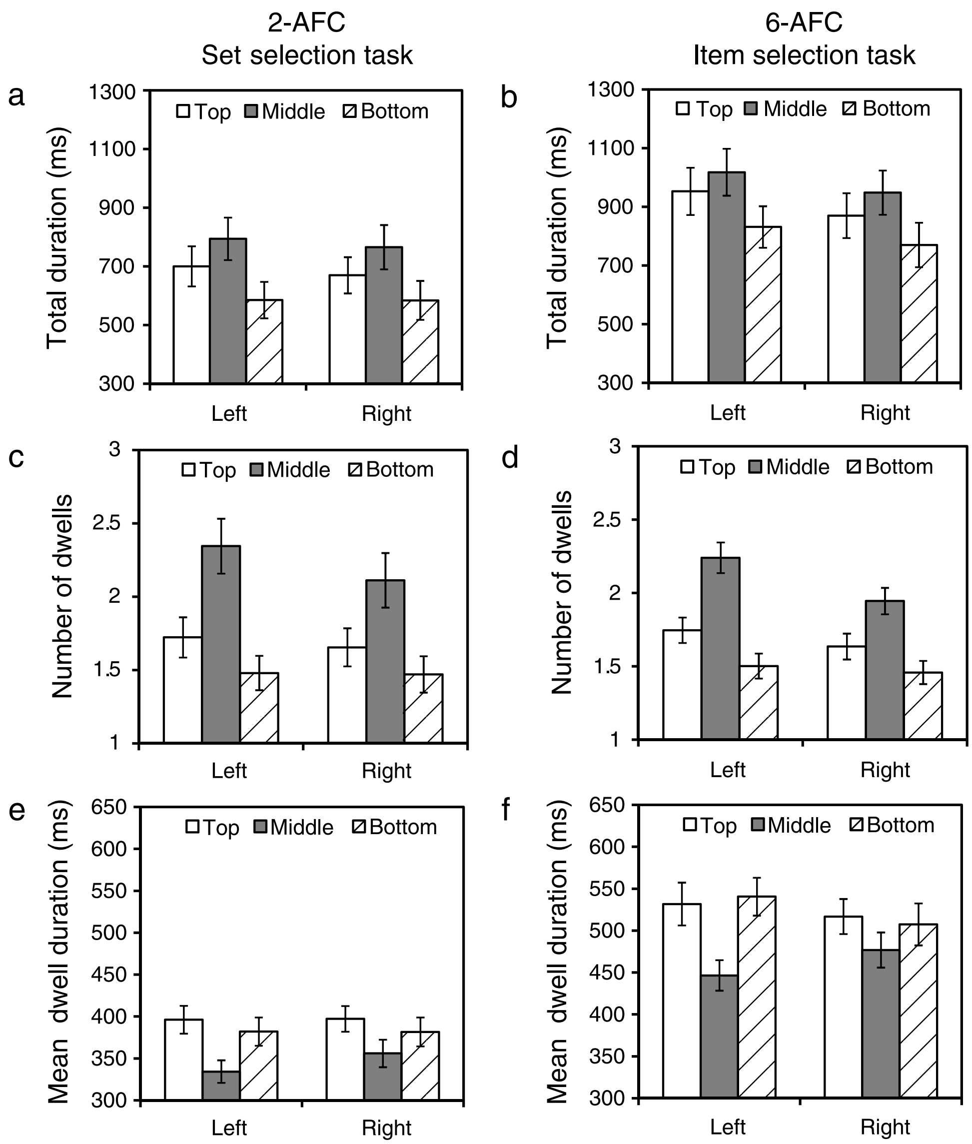

Figure 3. Measures of looking behavior as a function of Vertical Position (top, middle, bottom) and Horizontal Position (left, right) in the stimulus display, for each Decision Task (2-AFC set selection vs. 6-AFC item selection). Total Duration (panels a and b), Number of dwells (panels c and d) and Mean Dwell Duration (panels e and f).

items on the left side of the display ($F(1,46) = 18.31$, $MSE = 8.20 \times 10^3$, $p < 0.001$). As shown in Figure 3 (panels c and d) these biases in total duration were largely driven by differences in the number of dwells directed to different areas of the display. There was a significant effect of Vertical Position ($F(2,92) = 174.26$, $MSE = 0.07$, $p < 0.001$), with a greater number of dwells in the middle locations than on the top locations, and a greater number of dwells in the top locations than in the bottom locations. There were also more dwells directed to locations on the left side of the display than on the right ($F(1,46) = 38.95$, $MSE = 0.03$, $p < 0.001$), and the effect of Vertical Position was greater on the left side of the display than on the right ($F(2,92) = 25.53$, $MSE = 0.01$, $p < 0.001$). The pattern of spatial biases was somewhat different for mean dwell duration (Figure 3, panels e and f). There was a significant effect of Vertical Position ($F(2,92) = 64.18$, $MSE = 1.43 \times 10^3$, $p < 0.001$), but this was actually due to shorter dwells in the middle locations than in the top or bottom locations. The reduction in mean dwell duration for the middle location was more pronounced on the left side of the display than on the right ($F(2,92) = 12.43$, $MSE = 9.68 \times 10^2$, $p < 0.001$).

On inspection of Figure 3 it is apparent that the pattern of spatial biases was extremely similar across tasks. There was only one significant interaction involving task, where the magnitude of the bias in total duration toward the left side of the display was slightly larger for the 6-AFC item selection task ($F(1,46) = 5.76$, $MSE = 8.20 \times 10^3$, $p < 0.05$). Based on this insensitivity to differences in the task instructions, it is likely that the spatial biases observed here reflect a visual scanning strategy related to the spatial layout of the display. Interestingly, there was only a marginally significant effect of location on choice in the 2-AFC set selection task (probability of choosing left set = 0.48, probability of choosing right set = 0.52; $t(23) = 2.02$, $p = 0.06$). In the 6-AFC item selection task there was no influence of location on choice (top left = 0.17; middle left = 0.18, bottom left = 0.16; top right = 0.17; middle right = 0.17; bottom right = 0.15; all t's < 1.52, all p's > 0.14). Thus despite the presence of strong spatial biases in the allocation of attention to different stimulus locations, stimulus location had no substantial influence the outcome of the decision in either task.

Discussion

Since the early study by Yarbus (1967), there have been many demonstrations of the influence of top-down control over eye movements during natural scene viewing (for reviews see Ballard & Hayhoe, 2009; Henderson et al., 2007). In the present study we examined the influence of top-down factors on eye movement control in the context of visual decision making tasks. By employing a subtle manipulation of task instructions, we provided a novel demonstration of the way in which top-down influences can affect eye movement patterns. In particular, we hypothesized that even when the stimuli that are presented to the decision maker, and the dimension of stimulus information that is relevant to the decision task, remain constant across instructional manipulations, top down influences might still alter the manner and depth with which the stimulus information is processed. To address this question, we contrasted two tasks where participants chose which of two sets of three items were more expensive (2-AFC set selection task) or which one of six items was the most expensive (6-AFC item selection task). Based on prior research in decision making (Payne et al., 1993), and prior research on eye movements in visual decision making tasks (Glaholt & Reingold, 2009a), this manipulation was expected to influence the degree of selectivity with which participants process the stimulus information presented to them.

By analyzing participants' eye movements during these two decision tasks, we found strong evidence supporting our hypothesis. Replicating prior research in visual decision making tasks (Glaholt & Reingold, 2009a, 2009b, in press; Glaholt et al., 2009; Pieters & Warlop, 1999; Schotter et al., accepted for publication; Shimojo et al., 2003; Simion & Shimojo, 2006, 2007), in both decision tasks we observed robust biases in looking behavior toward the decision alternative that was eventually chosen. However, consistent with our hypothesis, we observed strong evidence that gaze selectivity was greater in the 6-AFC task compared to the 2-AFC task. In particular, the 6-AFC item selection task exhibited a greater degree of differentiation between the chosen side of the display and the other side of the display, in terms of total duration, number of dwells, and mean dwell duration. The 6-AFC task also showed greater differentiation between individual stimulus items within each side of the display. Furthermore, to portray differences in gaze selectivity between these tasks over the course of the decision period, we compared the number of different stimulus items viewed during the first half and second half of the trial. This revealed that for the 6-AFC item selection task, but not the 2-AFC set selection task, in the second half of the trial there was a reduction in the number of different items viewed. These differences in gaze selectivity between the 2-AFC set selection and 6-AFC item selection tasks clearly indicate that top-down influences can alter than manner and depth with which stimulus information is processed during visual decision making tasks.

The increase in gaze selectivity in the 6-AFC item selection task compared to the 2-AFC set selection task is likely to be related to differences in the processing requirements of the two tasks. For example, the 2-AFC set selection task might require the decision maker to integrate the value of three items in each of two sets (i.e., how expensive the items are as a group) and then compare those two sets, while the 6-AFC item selection task might require the decision maker to differentiate and compare the values of six individual stimulus items. While further research is required to specify the processing requirements of these set and item selection tasks, we speculate that due to the increase in the number of decision alternatives, the 6-AFC item selection task might impose greater cognitive demands on decision makers than the 2-AFC set selection task. Prior research in decision making (Payne et al., 1993) has argued that when faced with a complex decision task that exceeds available processing resources (e.g., a decision with many alternatives), decision makers employ heuristic strategies in order to make the decision more manageable. For example, participants might employ a screening process where relevant information is processed in greater depth and less relevant information is processed to a more limited extent or excluded from further processing. Consistent with this idea, in a prior study (Glaholt & Reingold, 2009a) we manipulated the number of decision alternatives (8-AFC vs. 2-AFC) and found evidence for an increase in gaze selectivity in decisions with more alternatives. However, in this prior study, and to our knowledge in all prior manipulations of the number of decision alternatives variable, differences in the number of alternatives were confounded by differences in the stimulus displays presented to the decision maker (e.g., more alternatives entails more stimulus items displayed). Conversely, in the present study, motivated by our interest in studying top-down influences on eye movements, we contrasted decisions that featured identical stimulus displays, but that differed in terms of the number of alternatives. However, in order to achieve this, we employed two tasks instructions (set vs. item selection) that are likely to have introduced differences across instructional conditions over and above the number of decision alternatives. Nevertheless, consistent with our prior findings (Glaholt & Reingold, 2009a), we found that participants exhibited a greater degree of gaze selectivity under the 6-AFC item selection instructions than the 2-AFC set selection instructions. Furthermore, supporting the presence of a screening process in the 6-AFC item selection task, participants sampled a smaller set of stimulus items in the second half of the trial compared to the first, a pattern that was not present in the 2-AFC set selection task. Hence while we acknowledge that the present manipulation of task instructions is likely to have introduced other differences in processing requirements in addition to the number of decision alternatives, we argue that when taken together with our prior findings (Glaholt & Reingold, 2009a), the present finding of increased gaze selectivity in the 6-AFC item selection task relative to the 2-AFC set selection task supports the general claim that the number of decision alternatives is a key factor influencing the degree of gaze selectivity observed in visual decision making tasks.

The second goal of the present investigation was to test for biases in looking behavior associated with the spatial layout of the display, and to assess whether any such biases might influence decision outcome. Our analysis of the distribution of gaze across the stimulus display confirmed the presence of strong spatial biases in both decision tasks. Consistent with prior findings (Durgin et al., 2008; Heywood & Churcher, 1980; Honda & Findlay, 1992; Pomplun et al., 2001; Previc, 1996; Williams & Reingold, 2001), we found evidence for greater allocation of spatial attention to top locations relative to bottom locations in the display. In contrast to prior findings, we found a strong gaze bias towards the middle locations relative to the top and bottom locations, and we also observed a slight bias towards the left side of the display. While the cause of these biases is difficult to determine, we speculate that they might reflect an oculomotor strategy related to the spatial layout of the display. For example, the bias towards the middle locations was characterized by shorter but more frequent dwells. We speculate the middle location may receive additional dwells that occur when the participant's gaze transits from the top to the bottom of the display (and vice versa). Most importantly, in contrast to the common assumption in marketing which holds that items receiving more attention should have an advantage, these biases did not have a substantial influence on choice.[5] Furthermore, the pattern of bias in the distribution of eye movements over the spatial locations in the display was extremely similar under the 2-AFC set selection and 6-AFC item selection instructions. For this reason they are likely to reflect a visual scanning strategy that is driven by the layout of the stimulus display, but that does not interact with the specific requirements of the decision task. This demonstrates that attention can be biased towards a stimulus due to characteristics of the display, but that this need not necessarily interfere, or interact, with the top-down effort to selectively process stimuli according to their relevance to the decision task. Further research is needed to understand the relationship between these two sources of gaze bias, and to identify conditions under which they might interact.

More generally, taken together with prior demonstrations and proposals, the present study demonstrates the usefulness of eye movement measurements for the study of visual decision making (for a review see Glaholt & Reingold, in press). In the present study, eye movement recordings allowed us to examine several theoretical issues in the context of visual decision making, such as the influence of top-down factors on eye movement control, and the presence and impact of biases in the distribution of spatial attention over the locations in the stimulus display. In addition, the present methodology illustrates that in the context of visual decision making tasks it is possible to manipulate task requirements while controlling for factors such as low-level stimulus characteristics and the relevant stimulus features and dimensions. Consequently, visual decision making tasks might offer a unique platform for the broader research program concerning factors that influence eye movement control during the performance of complex cognitive tasks.

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Corresponding authors: Mackenzie G. Glaholt/Eyal M. Reingold.
Email: mackenzie.glaholt@gmail.com/reingold@psych.utoronto.ca.
Address: University of Toronto at Mississauga, Department of Psychology, 3359 Mississauga Road N. RM 2037B, Mississauga, Ontario, Canada L5L 1C6.

Footnotes

[1]The speeded response that terminated the trial was identical in both tasks. In the 6-AFC task, there was an additional non-speeded response that identified the item (i.e., top, middle, or bottom) within the side that was selected by the first response.

[2]In order to control for the possible effect of the overall difference in total duration between the 2-AFC and 6-AFC tasks, for each analysis of total duration we also conducted an analysis based on the proportion of total duration. The results of the analyses based on proportion

of total duration were extremely similar to the results based on total duration.

[3]For the 6-AFC task, the chosen item had the maximum total duration in 75% of trials, and for the 2-AFC task, the chosen side had the maximum total duration (i.e., greater than the non-chosen side) in 69% of trials.

[4]To divide the trial into two halves, the dwell sequence was split in the middle creating two sections with an equal number of dwells in each; for trials with an odd number of dwells, the middle dwell was excluded from the analysis.

[5]The only evidence of an influence of biases in the spatial distribution of eye movements on choice was a trend towards participants choosing the right side in the 2-AFC set selection task. This is consistent with the finding of Nisbett and Wilson (1977) of a bias towards choosing items on the right side of the display.

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