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Preview benefit survives a three-dimensional rotation of the rigid configuration of search items

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ABSTRACT

When some distractors (old items) are presented prior to others (new items) during an inefficient visual search task, search becomes easier, as though observers were able to exclude the old items from the search. This phenomenon, called preview benefit, occurs when the locations of the old items are deprioritized relative to the locations of the new items, through a process of visual marking. It has been demonstrated that preview benefit persists when the old items move on the display, if the spatial relationships among the old items remain unchanged, suggesting that the memory template for visual marking represents the spatial configuration of the old items. One remaining question is whether the configuration is coded in two- or three-dimensional coordinates. In the present study, we examined whether preview benefit was preserved when all items were graphically rendered in three-dimensional coordinates and rigidly rotated around the vertical axis at a constant angular velocity. Preview benefit occurred in this situation, suggesting that the memory template for visual marking represents the spatial configuration in three-dimensional coordinates.

1. Introduction

Visual scenes typically have rich and detailed information. In contrast, the brain has severely limited capacity and thus, not all information can be processed at any given moment (Chun & Wolfe, 2001). To override this limitation, our visual system uses some strategies to focus on small bits of information that are likely to have behavioral significance, while ignoring other information. Traditional studies of selective attention have enquired what factors may be important in drawing attention to a subset of objects by using a visual search task, in which observers search for a target in the presence of distractors (Treisman & Gelade, 1980; Wolfe, 1994). Of particular relevance, two types of factors have been suggested: image-based *bottom-up* factors, such as feature singletons and abrupt stimulus onsets (e.g., Treisman & Gelade, 1980; Yantis & Jonides, 1984), and knowledge-based *top-down* factors, such as expectancy for the target's location and feature (e.g., Egeth, Virzi, & Garbart, 1984a, 1948b). While both factors are extensively used to navigate our visual attention toward behaviorally relevant information in visual inputs, there has been a large gap between experimental and real-life situations. In a typical experiment of visual search, stimuli are confined within a frontoparallel plane, i.e., on a computer display, with no particular depth cues. Thus, stimuli are perceptually rendered as confined within two-dimensional (2D) coordinates defined by the horizontal and vertical axes with no variabilities along the depth axis. As a result, it is not evident that current theories derived from such experiments can fully predict search performances when objects are naturally distributed in three-dimensional (3D) coordinates under typical real-life situations.

The goal of the present study was to examine search performance when visual stimuli were graphically rendered in 3D coordinates that would better reflect natural environments in the real world. More specifically, we focused on a benefit observed in visual search, called *preview benefit*, which occurs when search is made easier after previewing some distractors within a tiny period in advance, as if old items were excluded from search (Watson & Humphreys, 1997). To examine preview benefit, the search performances, as indexed by the slope of reaction time (RT) as a linear function of the number of items (set size), hereafter called *search slope*, are compared across three search conditions: the "preview," "full," and "half" conditions. Let us imagine an inefficient serial search task with visual stimuli consisting of two successive frames, so that half of all distractors appear in the first frame for previewing, and in the second frame, new items (the remaining distractors and a target) are added at previously unoccupied locations. The search performance in this preview condition is compared with those in the full and half conditions. Under the full condition, all items are presented simultaneously; under the half condition, the first frame in

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the preview condition is omitted and only the second frame is shown. When preview benefit occurs, the search performance in the preview condition will be improved relative to that in the full condition and, in a limiting case, will become equivalent to the search performance under the half condition—that is, the performance will become indistinguishable from that in the condition in which observers search for the target among only new items, as if all the previewed distractors were completely ignored.

While preview benefit has been replicated in a number of studies, debates regarding the interpretation of this effect have been continuing until the present. A dominant theory dictates that preview benefit reflects an active inhibitory bias applied to the locations of old items via a memory template representing information about the locations (e.g., Watson & Humphreys, 1997) and features (e.g., color) of the old items (e.g., Olivers & Humphreys, 2002). This active process is referred to as *visual marking*. However, several researchers argue that preview benefit can be explained either by automatic onset capture to new items (e.g., Donk & Theeuwes, 2001), or by perceptual segmentation derived from the temporal asynchrony between new and old items (e.g., Jiang, Chun, & Marks, 2002b). A critical difference between the inhibition theory and other theories is the contribution of the inhibitory process. It has been demonstrated that visual processing at locations occupied by old items are actively inhibited when preview benefit occurs; for example, a task-irrelevant probe dot that appears at one of the locations of the old rather than new items is less detectable (Watson & Humphreys, 2000; Olivers & Humphreys, 2002; Osugi & Murakami, 2014; Osugi, Kumada, & Kawahara, 2009). However, there are also several studies suggesting that both attentional capture to new stimulus onset and perceptual grouping contribute to preview benefit (e.g., Donk & Theeuwes, 2001; Jiang et al., 2002b). Therefore, it is currently argued that inhibitory marking, onset capture, and temporal grouping all contribute to preview benefit, with their rates of contribution depending on stimulus characteristics and task demands (e.g., Watson & Kunar, 2010).

When old items move, changing their spatial configuration, preview benefit disappears given that old and new items share the same color (Olivers & Humphreys, 1999; Watson, 2001), but not when their colors differ (Watson & Humphreys, 1998) or when a preview display is followed by a secondary preview after some period of time (Kunar & Humphreys, 2006). In Watson (2001) study, observers searched for a target letter T among L's, all in motion at the same angular speed along rotary trajectories about a common center of rotation. In one condition in which the configuration changed, half of distractors rotated clockwise and the other half rotated counter-clockwise. In the other condition in which the configuration remained unchanged, all stimuli coherently rotated clockwise. Preview benefit occurred only in the latter condition, in which the spatial configuration of the old items could be perceptually grouped as having a common fate, suggesting that the memory template involved in visual marking holds the spatial relationship of the old items, as if they comprised a unitary rigid object. Similarly, in a stationary display, preview benefit occurred even when old distractors suddenly changed their locations if the configuration remained unchanged (Kunar, Humphreys, Smith, & Hulleman, 2003), suggesting that the configuration cue is used to protect the memory template from transient location changes.

One remaining question is whether the configuration of old items is memorized in 2D or 3D coordinates in the memory template involved in visual marking. One possibility is that the configuration is memorized in 2D coordinates, as in "display" (x, y) coordinates, and inhibition is applied to items visually marked on such a flat and frontoparallel map. Lower stages in the hierarchy of visual processing preserve retinotopic organizations, and each visual neuron has its receptive field occupying a small region on the retina. Thus, if the configuration of old items is memorized in accordance with some form of visual representation in the lower stages of visual processing, visually marked locations will be tracked on a flat map consistent with retinotopy. This idea is consistent with a model that the saliency map, a visual representation that guides our behavior of attentional selection, is stored as a two-dimensional flat map in area V1 (Li, 2002); a brain-imaging study also argues that preview benefit may have its neural correlate in the de-activations of early visual areas, including V1 (Dent, Allen, & Humphreys, 2011).

It is also possible that visual marking operates in 3D-like, allocentric coordinates. A previous study demonstrated that preview benefit survived when old items were occluded behind moving occluders and later reappeared when new items were added to the display (Kunar, Humphreys, Smith, & Watson, 2003), suggesting that the memory template involved in visual marking memorizes the locations of old items in some form of representation in which at least depth-order from the occlusion cue has been solved. This hypothesis was supported by studies on a carry-over effect of inhibition using stimuli in a stereoscopic depth scene comprising two, nearer and farther, upright surfaces (e.g., Dent, Humphreys, He, & Braithwaite, 2014; Dent, Braithwaite, He, & Humphreys, 2012). In this experiment, old and new items were distributed on two virtual depth surfaces. All old items were presented in one of the two surfaces ("old plane") and new items were added on both the old plane and the other surface ("new plane"), that is, the target could appear on the old or new plane with equal probability. Search performance in discriminating the target letter was slower and more inefficient when the target appeared on the old plane than when it appeared on the new plane. The interpretation was that inhibition spread to the target, when the target and old distractors shared the same stereoscopically defined surface. Furthermore, several studies on the multiple-object tracking task demonstrated that the visual system can use 3D coordinates to attend to multiple regions simultaneously, if pictorial depth cues (e.g., Liu et al., 2005) or binocular disparity (e.g., Viswanathan & Mingolla, 2002) induces the perception of a coherent 3D environment. These findings suggest that the locations of objects are represented so as to be compatible with 3D, rather than 2D, coordinates before the stage of attentive tracking.

If the representation is compatible with 3D coordinates, there are still two possibilities for the way the memory template is constructed; the storable configuration of old items might be restricted within a plane, as in an alphabet letter drawn on a sheet of paper that could be slanted in 3D coordinates; alternatively, the system could handle a more 3D-like configuration, as in molecular structure, as a memory template. We named these two possible strategies "planar" and "volumetric," and examined which was actually the case.

We asked whether preview benefit occurred when items were graphically rendered in 3D coordinates and rigidly rotated around the y-axis at a constant rotation velocity. If the spatial configuration of old items were coded in the 2D "display" coordinates in the memory template, the 3D rotation would drastically deviate the actual configuration of items on the display from the stored configuration in the memory template, disrupting preview benefit. In contrast, if the spatial configuration of old items were coded in 3D coordinates in the memory template, the difference between the stored and actual configurations would be only a matter of rotational transform, and preview benefit would survive given that the system has access to spatial processing pertinent to mental rotation (Shepard & Metzler, 1971). There is yet another possibility in-between; if the memory template only stored a 2D configuration confined within a common plane, but the system knew how to mentally rotate it in 3D coordinates, then preview benefit would survive when a "planar" configuration is to be memorized, but would not when a more complicated "volumetric" configuration is to be memorized. As such, two configurations, "planar" and "volumetric" were tested. In the "planar" configuration, old items were constrained to be within a common plane and rigidly rotated around the vertical axis at a constant rotation velocity. In the "volumetric" configuration, the locations of the old items were more freely distributed in 3D coordinates and rigidly rotated around the vertical axis at a constant rotation velocity.

Two experiments were conducted. In Experiment 1, the search slopes across the "preview," "full," and "half" conditions were compared. If preview benefit were present, the slope in the "preview" condition would be smaller than that of the "full" condition. Furthermore, if the maximal preview benefit occurred, the search slope would be indistinguishable between the "preview" and "half" conditions. Such comparisons were made by using the "planar" and "volumetric" configurations to find the answer to our research question, that is, whether preview benefit survives 3D rotation of the search items. In Experiments 2 and 3, we attempted to better control the issue of accidental occlusions among search items.

2. Experiment 1

2.1. Methods

2.1.1. Participants

Twelve adults (6 females; mean age = 24.6 years) participated. The number of participants was determined on the basis of those in previous studies (e.g., Watson and Humphreys, 1997; Osugi & Murakami, 2015). Our study followed the Declaration of Helsinki guidelines and was approved by the Ethics Committee of the Graduate School of Humanities and Sociology at the University of Tokyo in Experiments 1 and 2, and by the Ethics Committee of the Faculty of Humanities and Social Sciences at Yamagata University in Experiment 3. Written informed consent was obtained from all participants. All participants had normal or corrected-to-normal visual acuity.

2.1.2. Stimuli and apparatus

All stimuli were presented on a CRT monitor (Iiyama HM204DA, 1024 × 768 pixels), which was controlled by a computer (Apple Mac Pro) with the Matlab (Mathworks Inc.) programming environment, Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997; Kleiner, Brainard, & Pelli, 2007), and the Open-GL utility toolkit. The size of the monitor was 40 × 30 cm. The viewing distance was 57 cm. The CIE xy coordinates and luminance values at the maximal intensities of the red, green, and blue phosphors, and those of the mean luminance gray were {(0.619, 0.340), 10.95 cd/m^2}, {(0.280, 0.611), 28.23 cd/m^2}, {(0.153, 0.080), 3.61 cd/m^2}, and {(0.320, 0.348), 16.38 cd/m^2}, respectively. The screen refresh rate was 60 Hz. We used the "gluPerspective" function to set up a perspective projective matrix; the field of view angle in the Y direction ("fovy") was 30 degrees and the distances from the viewer to the near and far clipping planes were 1.0 and 100.0, respectively. The viewing position at an eye point (specified by parameters "eyeX," "eyeY," and "eyeZ" of the "gluLookAt" function) in the virtual space were 7.05, 5.13, and 12.21, respectively (i.e., 15, 60, and 70 for the radial distance, azimuthal angle, and polar angle, respectively).

A fixation cube (size parameter 0.2; approximately 0.7 cm wide on the display) colored cyan (R:G:B = 0:1:1) was presented at the center of the display. The background was uniform gray (R:G:B = 0.5:0.5:0.5). The search items were red (R:G:B = 1:0:0) cubes (size parameter 0.5; approximately 1.8 cm) with zero, one, or two dots. The target was a cube with one dot at the bottom or no dot, whereas distractors were cubes with two dots (size parameter 0.25; approximately 0.9 cm) at the top and bottom. The search items were presented in a virtual 3D space that was defined by the origin "0" and X (horizontal), Y (vertical), and Z (depth) axes as in the Open-GL conventions. The angle of depression from the eye point to the origin was 20 degrees, so that the X-Z plane should look slightly slanted to the observer. We used two spatial configurations, namely the "planar" configuration for Experiment 1A and the "volumetric" configuration for Experiment 1B. In Experiment 1A, the items were distributed on the X-Z plane. They were presented at pseudo-randomly chosen locations within an invisible 5 × 5 matrix on the X-Z plane (except for the fixation-cube location, which was at the center of the matrix; Fig. 1A; each cell had a size parameter of 1.0; approximately 3.6 cm). In contrast, in Experiment 1B, the items were volumetrically distributed in 3D coordinates (Fig. 1B). More specifically, the X, Y, Z locations of the items were pseudo-randomly chosen within an invisible 5 × 5 × 5 matrix in the X-Y-Z volume (except for the fixation-cube location, which was at the center of the matrix). The target could be presented at any of these locations with equal probability.

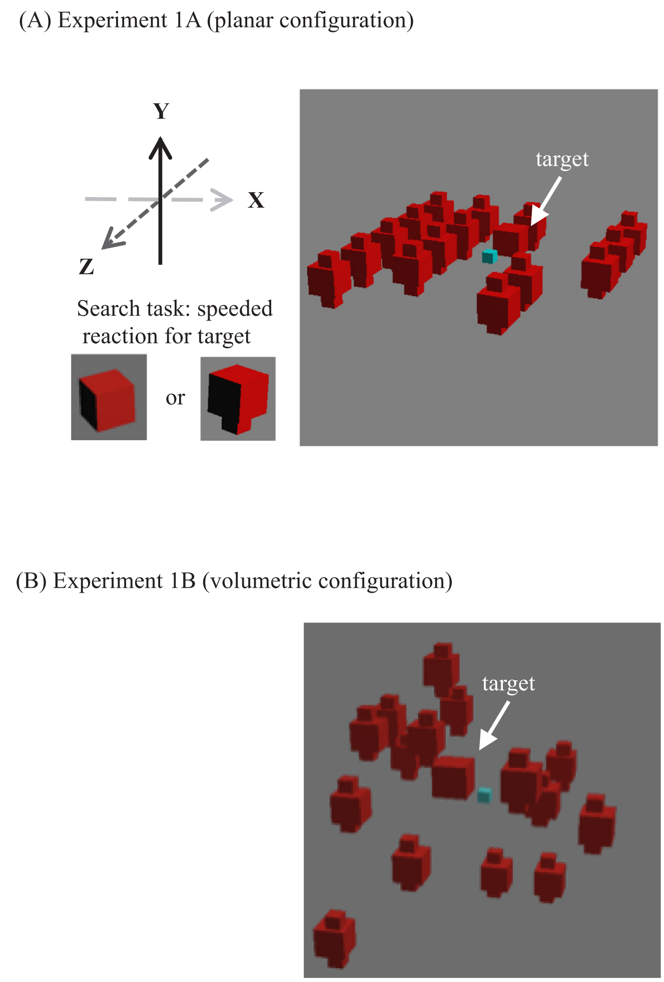

Fig. 1. Examples of the search displays in Experiment 1. (A) Experiment 1A (planar configuration). The items were presented at pseudo-randomly chosen locations within an invisible 5 × 5 matrix on the X-Z plane. The observers were requested to search for the target and to judge whether it had a dot. (B) Experiment 1B (volumetric configuration). The items were volumetrically distributed in 3D coordinates; the X, Y, Z locations of the items were pseudo-randomly chosen within an invisible 5 × 5 × 5 matrix in the X-Y-Z volume.

The observer was requested to search for the target and to judge whether it had a dot; s/he was asked to press the "6" key on the number-pad keyboard to indicate the presence of the dot or the "4" key to indicate its absence. Reaction time was measured. At the end of each trial, observers received visual feedback about their performance (the RT and the correctness of the response). When the RT was longer than 10,000 ms or when the response was incorrect, a feedback tone (1000-Hz) was provided. Pressing the "5" key triggered the next trial.

2.1.3. Design and procedure

In each of Experiments 1A and 1B, we used a 3 × 3 within-subject factorial design: three search types ("preview," "full," and "half;" Fig. 2, panels A, B, and C, respectively), and three set sizes (4, 8, and 16 items). In the "preview" condition, a trial was initiated by the presentation of a fixation dot for 1000 ms; after that, half of the distractors were presented first, followed by the new items (i.e., the search target and the

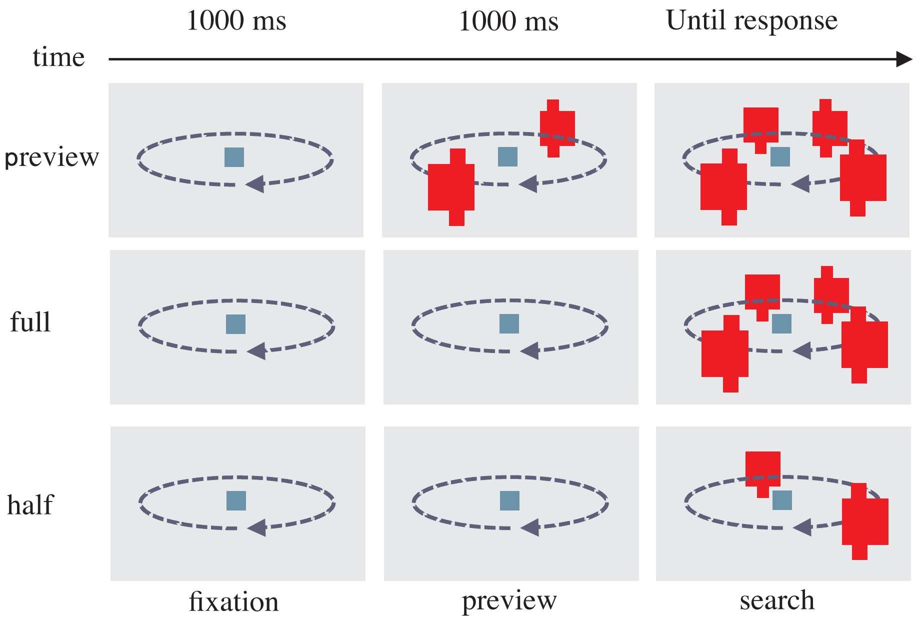

Fig. 2. Schematic diagrams of the stimulus sequences in Experiment 1. (A) "Preview" condition. The old items appeared, followed by the onset of the new items 1000 ms later. (B) "Full" condition. All items appeared simultaneously. (C) "Half" condition. Items that served as the new items in the "preview" condition appeared simultaneously, but there were no previewed items.

remaining half of the distractors) with a stimulus-onset asynchrony of 1000 ms. The target was always present as one of the new items. In the "full" and "half" conditions, the fixation dot was presented for 2000 ms, after which all items appeared simultaneously. In the "half" condition, the number of the items was halved from the actual set size of the "full" condition—thus, when the nominal set size was 4, 8, or 16, the number of presented items was 2, 4, or 8, respectively. All the items and the fixation point rigidly rotated about a common rotation axis (Y-axis) at a constant rotation speed of 10 rpm, with their rotation direction, clockwise or counter-clockwise, varying across trials; thus, all the cubes rotated about the same Y-axis in a fixed way. The rotation continued throughout each trial. Experiments 1A and 1B were conducted in separate sessions run on the same day, and the order of them was counterbalanced across observers.

In each of Experiments 1A and 1B, each participant completed 15 blocks of trials (five blocks each for the three search types, and the orders of search types were counterbalanced across participants). Each block consisted of 24 trials (eight for each set size), resulting in 40 trials for each combination of set size and search type. Experimental blocks were preceded by three 24-trial practice blocks per search type condition.

2.1.4. Data analysis

For each participant, the average RT and correct response rate were calculated for each condition. RTs for incorrect responses, those below 200 ms, and those above 10,000 ms (timeout) were considered as errors. In addition, outliers, determined by the modified recursive cut-off procedure (Van Selst & Jolicoeur, 1994), were excluded from the analysis (2.55% of all trials in Experiments 1–3). The hallmark of the preview benefit is that the slope of the "preview" condition is significantly smaller than that of the "full" condition. Also, the maximal preview benefit is attained if the search slope under the "preview" condition is the same as that under the "half" condition. We performed a repeated-measures analysis of variance (ANOVA) for RT to examine whether the preview benefit was observed under each experiment.

2.2. Results

For all experiments, search function statistics (search slopes and intercepts) are summarized in Table 1; and mean error rates are shown in Table 2. Mean RT for visual search as a function of set size for Experiments 1A and 1B are shown in Fig. 3, panels A and B, respectively.

Table 1
Search function statistics for Experiments 1–3.

Experiment and display	Slope (ms/item)			Intercept (ms)		
	Full	Preview	Half	Full	Preview	Half
Experiment 1						
1A (planar configuration)	53.8	40.9	18	486	472	569
1B (volumetric configuration)	46.7	31.6	16.5	505	497	574
Experiment 2						
2A (planar configuration)	54.2	39.7	35.3	497	511	579
2B (volumetric configuration)	47	35.4	33.9	535	487	550
Experiment 3						
3A (planar configuration)	52.6	36.7	33.2	547	532	571
3B (volumetric configuration)	41.9	28.3	25.7	593	580	596

Table 2
Mean error rates (%) for Experiments 1–3.

Experiment and display	Full			Preview			Half		
	4	8	16	4	8	16	2(4)	4(8)	8(16)
Experiment 1									
1A (planar configuration)	2.5	3.8	4.2	4.2	5.4	8.1	4	4	5.4
1B (volumetric configuration)	2.7	3.3	4.2	4.4	4.2	5.6	4.2	4.2	4.2
Experiment 2									
2A (planar configuration)	2.1	2.1	1.5	2.9	2.1	5.2	1.5	2.1	1.9
2B (volumetric configuration)	1.7	1.9	2.5	2.5	4.2	3.1	2.3	2.1	1.3
Experiment 3									
3A (planar configuration)	2.7	2.5	4.8	3	1.8	6.8	1.6	1.8	3.9
3B (volumetric configuration)	3	2.3	3.2	4.8	2.3	5.5	1.6	1.8	1.6

The error rates had the same trend as the RT and did not suggest the presence of any speed-accuracy trade-offs. Therefore, we do not further report the statistical results for error rates.

2.2.1. Experiment 1A (planar configuration)

A 3 × 3 ANOVA for RT with search type (the "preview," "full," and "half" conditions) and set size (4, 8, and 16) as within-subject factors identified significant main effects of search type ($F_{2,\ 22} = 91.67$,

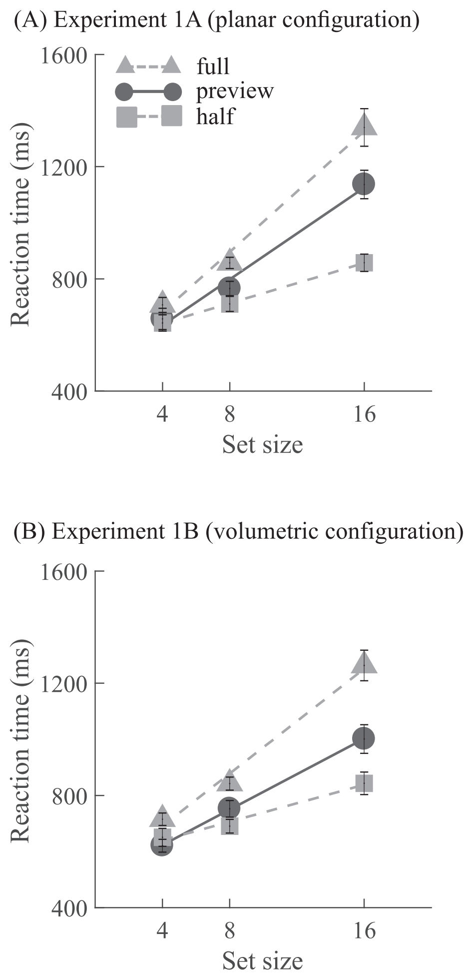

Fig. 3. Mean reaction times as a function of set size under the "preview," "full," and "half" conditions in (A) Experiments 1A (planar configuration) and (B) 1B (volumetric configuration). Error bars indicate standard error.

$p < .001$, $\eta^2p = .89$) and set size ($F_{2,\ 22} = 169.78$, $p < .001$, $\eta^2p = .94$), as well as a significant interaction ($F_{4,\ 44} = 22.63$, $p < .001$, $\eta^2p = .67$), showing that the search slopes differed across the three conditions. Thus, we performed two separate two-way within-subject ANOVAs, as is commonly implemented in preview search studies for detailed comparisons between the search types; the RT data were compared between the "preview" condition and each of the two ("full" and "half") baseline conditions. In a comparison between the "preview" and "full" conditions, main effects of search type ($F_{1,\ 11} = 32.19$, $p < .001$, $\eta^2p = .75$) and set size ($F_{2,\ 22} = 137.53$, $p < .001$, $\eta^2p = .93$) were significant. The interaction between search type and set size was also significant ($F_{2,\ 22} = 4.47$, $p = .024$, $\eta^2p = .29$), revealing the presence of preview benefit. In a comparison between the "preview" and "half" conditions, main effects of search type ($F_{1,\ 11} = 49.4$, $p < .001$, $\eta^2p = .82$) and set size ($F_{2,\ 22} = 136.17$, $p < .001$, $\eta^2p = .93$) were significant. The interaction was also significant ($F_{2,\ 22} = 36.65$, $p < .001$, $\eta^2p = .77$). These results demonstrated that there was an imperfect but reliable preview benefit when the items were confined within the X-Z plane and rigidly rotated about the vertical axis.

2.2.2. Experiment 1B (volumetric configuration)

As in Experiment 1A, a 3 × 3 ANOVA identified significant main effects of search type ($F_{2,\ 22} = 30.68$, $p < .001$, $\eta^2p = .74$) and set size ($F_{2,\ 22} = 208.14$, $p < .001$, $\eta^2p = .95$), as well as a significant interaction ($F_{4,\ 44} = 25.5$, $p < .001$, $\eta^2p = .7$). Thus, we performed two separate two-way within-subject ANOVAs. In a separate comparison between the "preview" and "full" conditions, main effects of search type ($F_{1,\ 11} = 25.04$, $p < .001$, $\eta^2p = .69$) and set size ($F_{2,\ 22} = 207.85$, $p < .001$, $\eta^2p = .95$) were significant. The interaction was also significant ($F_{2,\ 22} = 9.84$, $p < .001$, $\eta^2p = .47$). In a comparison between the "preview" and "half" conditions, main effects of search type ($F_{1,\ 11} = 9.57$, $p = .01$, $\eta^2p = .47$) and set size ($F_{2,\ 22} = 101.62$, $p < .001$, $\eta^2p = .90$) were significant. The interaction was also significant ($F_{2,\ 22} = 21.39$, $p < .001$, $\eta^2p = .66$). These results demonstrated that there was an imperfect, but reliable, preview benefit when the items were more freely distributed in 3D coordinates and rigidly rotated about the vertical axis.

One potential artifact in Experiment 1 was a difference in the frequency of occlusion. The target could be occluded by some of the distractors more frequently as set size increased. Therefore, the occlusion of the target occurred more frequently in the "preview" and "full" conditions, than in the "half" condition. Such occlusion might have induced the apparent difference in slopes between the "preview" and "half" conditions. Thus, in Experiment 2, the "half" condition was replaced by the "half silhouette" condition, in which black items were added to the stimulus set in the "half" condition to control the difference in occlusion frequencies among conditions. That is, the total number of visible items (the number of red and black items) was the same as in the "full" and "preview" conditions, but the number of red items, only within which the search was to be made, was the same as in the "half" condition. Because the target's color (red) was instructed in advance, the best search strategy was to restrict the search within red items, ignoring all the black items. In more conventional visual search paradigms, a number of studies have convincingly demonstrated that observers can exert such feature-based exclusion using color cues, as if items to be ignored did not exist on the display (e.g., Egeth, Virzi, & Garbart, 1984a, 1948b). If the apparent imperfection of preview benefit were solely due to the artifact of occlusion, the search slopes would be indistinguishable between the "preview" and "half silhouette" conditions because the frequency of occlusion was equalized between them.

3. Experiment 2

3.1. Methods

Twelve adults (5 females; mean age = 25 years) participated. Written informed consent was obtained from all participants. Two configurations (planar and volumetric configurations for Experiments 2A and 2B, respectively) were used. The stimuli and procedure were essentially the same as those in Experiment 1, except that the "half" condition was replaced to the "half silhouette" condition (Fig. 4). In this condition, red and black (R:G:B = 0:0:0) items were presented, but the observers were requested to search for a target in red; thus, all the black items were to be excluded from the search using the color cue. The number of red items was the same as in the "half" condition in Experiment 1 (2, 4, and 8 items), but the same number of black items was added, meaning that the total number of red and black items was the same as in the "full" and "preview" conditions (4, 8, and 16 items). Experiments 2A and 2B were conducted in separate sessions run on the same day, and the order of them was counterbalanced across observers.

3.2. Results

The search functions for Experiments 2A and 2B are shown in Fig. 5, panels A and B, respectively.

3.2.1. Experiment 2A (planar configuration)

A 3 × 3 ANOVA identified significant main effects of search type ($F_{2,\ 22} = 22.88$, $p < .001$, $\eta^2p = .68$) and set size ($F_{2,\ 22} = 126.93$, $p < .001$, $\eta^2p = .92$), as well as a significant interaction ($F_{4,\ 44} = 7.71$, $p < .001$, $\eta^2p = .41$), revealing that the search slopes differed across

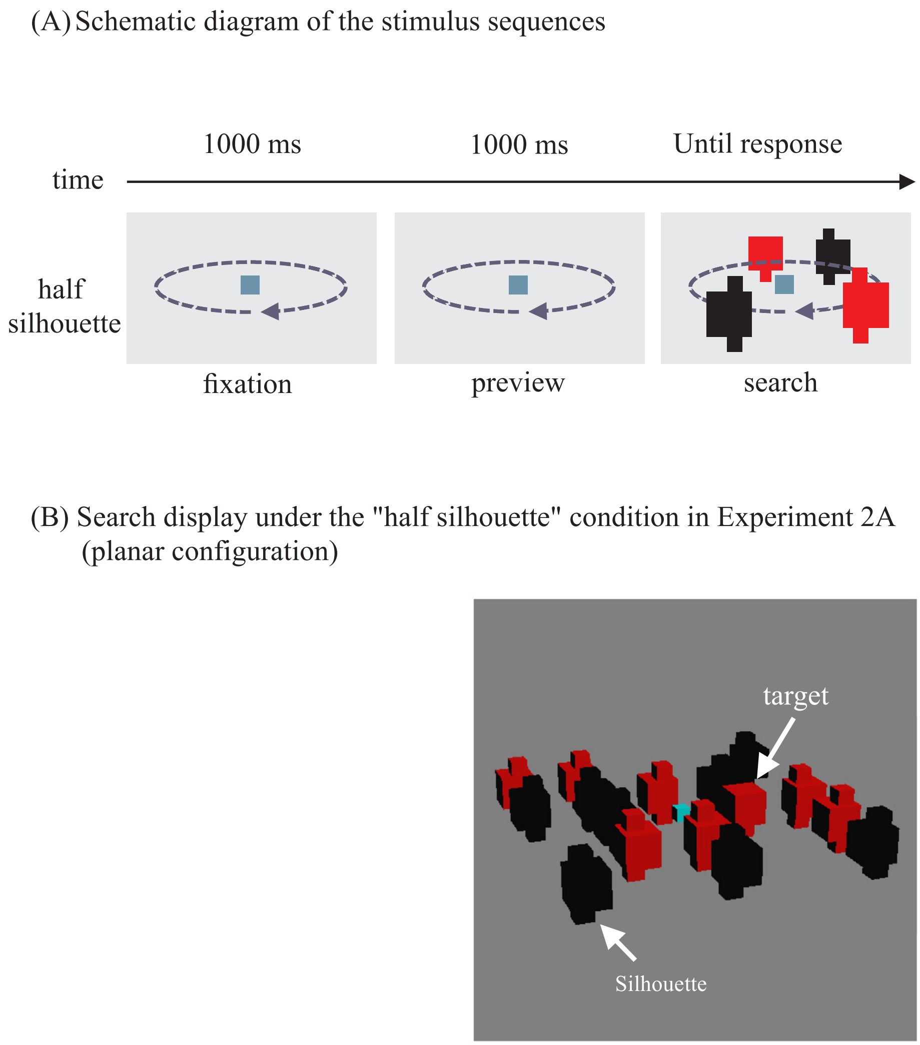

Fig. 4. Stimuli of Experiment 2. (A) Schematic diagrams of the stimulus sequences under the “half silhouette” condition. Red and black items were presented simultaneously but the observers were requested to search for a target in red. The number of the red items was the same as in the “half” condition in Experiment 1. (B) An example of the search displays under the “half silhouette” condition in Experiment 2A (planar configuration). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the three conditions. We performed two separate two-way within-subject ANOVAs; in a comparison between the “preview” and “full” conditions, main effects of search type ($F_{1,\ 11} = 41.03$, $p < .001$, $\eta^2p = .79$) and set size ($F_{2,\ 22} = 122.18$, $p < .001$, $\eta^2p = .92$) were significant. The interaction between search type and set size was also significant ($F_{2,\ 22} = 6.81$, $p = .005$, $\eta^2p = .38$), indicating the presence of preview benefit. In a comparison between the “preview” and “half silhouette” conditions, the main effect of set size was significant ($F_{2,\ 22} = 115.91$, $p < .001$, $\eta^2p = .91$) . In contrast, the main effect of search type ($F_{1,\ 11} = 3.11$, $p = .11$, $\eta^2p = .22$) and the interaction ($F_{2,\ 22} = 1.11$, $p = .35$, $\eta^2p = .09$) were not significant. These results demonstrated that the amount of preview benefit reached the maximal level.

3.2.2. Experiment 2B (volumetric configuration)

A 3 × 3 ANOVA identified significant main effects of search type ($F_{2,\ 22} = 28.91$, $p < .001$, $\eta^2p = .72$) and set size ($F_{2,\ 22} = 196.25$, $p < .001$, $\eta^2p = .95$), as well as a significant interaction ($F_{4,\ 44} = 3.38$, $p = .017$, $\eta^2p = .24$). In a separate comparison between the “preview” and “full” conditions, main effects of search type ($F_{1,\ 11} = 44.58$, $p < .001$, $\eta^2p = .80$) and set size ($F_{2,\ 22} = 126.33$, $p < .001$, $\eta^2p = .92$) were significant. The interaction was also significant ($F_{2,\ 22} = 3.61$, $p = .044$, $\eta^2p = .25$). In a comparison between the “preview” and “half silhouette” conditions, the main effect of set size was significant ($F_{2,\ 22} = 131.45$, $p < .001$, $\eta^2p = .92$). In contrast, the main effect of search type ($F_{1,\ 11} = 4.58$, $p = .06$, $\eta^2p = .29$) and the interaction ($F_{2,\ 22} = 0.1$, $p = .91$, $\eta^2p = .01$) were not significant. These results were essentially the same as those of Experiment 2A, namely, the amount of preview benefit reached the maximal level.

The results of Experiment 2 demonstrated that, both for the planar and volumetric configurations, the search slope in the “preview” condition was smaller than that in the “full” condition and equivalent to that in the “half silhouette” condition. This implied that the maximal preview benefit was observed when the difference in occlusion frequencies among conditions was controlled by using silhouette-looking items in a different color than the target’s (which were hence to be ignored). That is, it is likely that the apparent imperfection of preview benefit obtained in Experiment 1 was due to an artifact originating from occlusion frequencies.

The above conclusion drawn from Experiments 1 and 2 is based on the assumption that, in the “half silhouette” condition, participants would be able to ignore black items and search through just the red

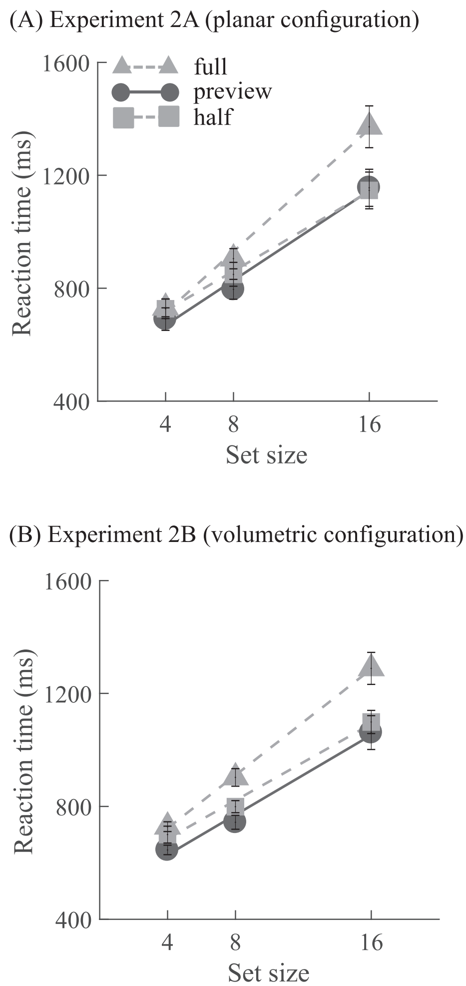

Fig. 5. Mean reaction times as a function of set size under the "preview," "full," and "half" conditions in (A) Experiments 2A (planar configuration) and (B) 2B (volumetric configuration). Error bars indicate standard error.

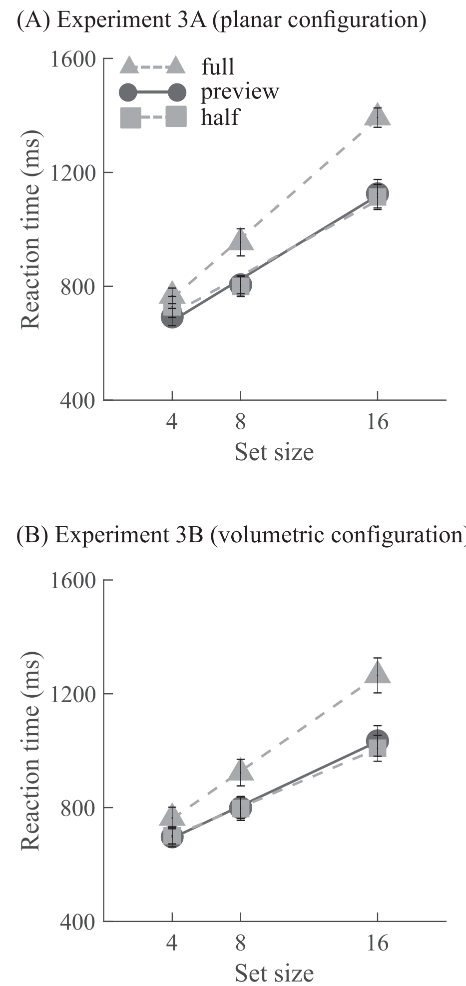

Fig. 6. Mean reaction times as a function of set size under the "preview," "full," and "half" conditions in (A) Experiments 3A (planar configuration) and (B) 3B (volumetric configuration). Error bars indicate standard error.

ones. However, one might argue that the display and stimuli used in the present study are quite different from those in previous studies that used stationary displays (e.g., Egeth, Virzi, & Garbart, 1984a, 1948b). Thus, it remains unclear whether the steeper search slope of the "half silhouette" condition in Experiment 2 than under the "half" condition in Experiment 1 originated from occlusion frequencies or the addition of more items to the display. In Experiment 3, we changed the background color from gray to black (i.e., the same color as the silhouette-looking items) in order to examine the effect of mere occlusion without additional search items.

4. Experiment 3

4.1. Methods

Twelve adults (10 females; mean age = 23.1 years) participated. Written informed consent was obtained from all participants. Two configurations (planar and volumetric configurations for Experiments 3A and 3B, respectively) were used. The stimuli and procedure were essentially the same as those in Experiment 2 except that the background color was changed from gray to black (R:G:B = 0:0:0); note that, in the "half silhouette" condition, the black items were now "added" on the black background and thus rendered invisible on their own, only occluding other visible items. Experiments 3A and 3B were conducted in separate sessions run on different days, with the order counterbalanced across observers. One participant had to be excluded from the analysis due to unacceptably poor task performance, based on the fact that the RTs in two of all conditions exceeded 3 SDs from the group mean. Therefore, the analyses were performed with data from 11 participants.

4.2. Results

The search functions for Experiments 3A and 3B are shown in Fig. 6, panels A and B, respectively.

4.2.1. Experiment 3A (planar configuration)

A 3 × 3 ANOVA revealed significant main effects of search type ($F_{2, 20} = 38.79$, $p < .001$, $\eta^2 p = .79$) and set size ($F_{2, 20} = 418.82$, $p < .001$, $\eta^2 p = .98$), as well as a significant interaction ($F_{4, 40} = 15.19$, $p < .001$, $\eta^2 p = .60$), demonstrating that the search slopes differed among the three conditions. We performed two separate two-way within-subject ANOVAs; in a comparison between the "preview" and "full" conditions, main effects of search type ($F_{1, 10} = 65.57$, $p < .001$, $\eta^2 p = .87$) and set size ($F_{2, 20} = 262.07$, $p < .001$, $\eta^2 p = .96$) were significant. The interaction between search type and set size was also significant ($F_{2, 20} = 19.45$, $p < .001$, $\eta^2 p = .66$), indicating the presence of preview benefit. In a comparison between the "preview" and "half silhouette" conditions, the main effect of set size was significant ($F_{2, 20} = 252.81$, $p < .001$, $\eta^2 p = .96$). In contrast, the main effect of search type ($F_{1, 10} = 0.19$, $p = .67$, $\eta^2 p = .02$) and the interaction ($F_{2, 20} = 1.28$, $p = .30$, $\eta^2 p = .11$) were not significant.

These results demonstrated that the amount of preview benefit reached the maximal level.

4.2.2. Experiment 3B (volumetric configuration)

A 3 × 3 ANOVA identified significant main effects of search type ($F_{2,\ 20} = 41.93$, $p < .001$, $\eta^2p = .81$) and set size ($F_{2,\ 20} = 108.65$, $p < .001$, $\eta^2p = .92$), as well as a significant interaction ($F_{4,\ 40} = 6.15$, $p < .001$, $\eta^2p = .38$), demonstrating that the search slopes differed among the three conditions. We performed two separate two-way within-subject ANOVAs; in a comparison between the "preview" and "full" conditions, main effects of search type ($F_{1,\ 10} = 208.25$, $p < .001$, $\eta^2p = .95$) and set size ($F_{2,\ 20} = 68.1$, $p < .001$, $\eta^2p = .87$) were significant. The interaction between search type and set size was also significant ($F_{2,\ 20} = 9.03$, $p = .002$, $\eta^2p = .47$), indicating the presence of preview benefit. In a comparison between the "preview" and "half silhouette" conditions, the main effect of set size was significant ($F_{2,\ 20} = 137.94$, $p < .001$, $\eta^2p = .93$). In contrast, the main effect of search type ($F_{1,\ 10} = 0.14$, $p = .71$, $\eta^2p = .01$) and the interaction ($F_{2,\ 20} = 0.5$, $p = .62$, $\eta^2p = .05$) were not significant. These results were essentially the same as those of Experiment 3A, namely, the amount of preview benefit reached the maximal level.

The pattern of results was consistent with that of Experiment 2, suggesting that the maximal preview benefit was observed when the difference in occlusion frequencies among conditions was controlled. In the present experiment's situation, task-relevant items were occasionally occluded but without the addition of more items to the display. Therefore, it was concluded that the apparent imperfection of preview benefit obtained in Experiment 1 was due to an artifact originating from occlusion frequencies.

5. Discussion

The purpose of the present study was to examine whether preview benefit occurs for search items distributed in 3D coordinates. Thus, we asked whether observers were able to ignore old items when the items were arranged in 3D coordinates and rigidly rotated around the vertical axis at a constant rotation velocity. Preview benefit indeed occurred in these situations, suggesting that the memory template used for preview benefit can store the spatial configuration of old items in 3D coordinates. Furthermore, preview benefit was observed not only when old items were confined within a planar configuration, but also when they were more freely, volumetrically distributed in 3D coordinates, suggesting that the memory template preserves the 3D spatial relationship of the old items. Watson (2001) argued that the spatial configuration of old distractors is coded as if it specifies a unitary object on the display, toward which inhibition occurs (see also Kunar, Humphreys, Smith, & Hulleman, 2003). From this perspective, the present findings may be viewed as suggesting that the configuration of old items is coded as a 3D rigid object in the memory template.

The present study further demonstrated that preview benefit can become maximal, i.e., the search can become as efficient as when all the old items are excluded from the search, if occlusion among the items is appropriately controlled. The target can be occluded more frequently as set size increases. Therefore, more target occlusions occurred in the "preview" and "full" conditions than in the "half" condition in Experiment 1. This undesirable imbalance was taken into consideration in the "half silhouette" condition (Experiments 2 and 3), in which "silhouette"-looking items—those items in a different color than the target's and thus to be ignored—provided the equal probability of target occlusion across conditions. The search performance for this condition was indistinguishable from that in the "preview" condition, meaning that the observers were able to ignore the previewed distractors in the "preview" condition as perfectly as they were able to ignore the black (to-be-ignored) distractors in the "half silhouette" condition. These findings are consistent with the results of previous study, in which preview benefit persisted when old items were once occluded by blocks and reappeared (Kunar, Humphreys, Smith, & Watson, 2003). It was speculated that the locations of old items might be coded in 3D space and such representations were maintained behind the blocks. Together with the present study, it is suggested that the memory template is applied to the locations in 3D coordinates and this template is maintained even when other objects occlude part of the 3D spatial configuration in the scene, based on which the memory template is created.

In the present study, 3D space was graphically rendered by using pictorial depth cues within items, and occlusion as well as structure-from-motion cues across items. In contrast, previous studies on preview benefit used binocular disparity to render depth planes (e.g., Dent et al., 2012; Dent et al., 2014). These studies used two depth surfaces defined by binocular disparity to examine whether inhibitory effects at the locations of old items affected the performance of search for the target that appeared at either the same or other depth plane. Target detection was impaired when the target appeared at a depth shared with a majority of old distractors, as if inhibition was carried over to the target from the locations of the distractors. Such an inhibitory carry-over effect was not observed in the present study; that is, a sufficiently large preview benefit occurred even though the target shared the same planar structure with distractors. More specifically, observers were able to search for the target within only new items, while the old distractors were effectively inhibited. One possible reason for this discrepancy is because old and new items were not split onto different depth planes in the present study. As pointed out by Olivers and Humphreys (2003), the visual marking system makes maximal use of available information. If old and new items are presented at different depths, the system may use depth information to maximize the capability of ignoring old distractors. On the other hand, if such information is unavailable, the system may rely on the spatial configuration cue to optimize the search.

In a study by Watson and Humphreys (1997), it was proposed that visual marking is applied to the locations of old items. Since then, this idea has been extended to the spatial configuration, rather than a collection of locations, as a coding scheme of the memory template; the extended idea has been verified through demonstrations that preview benefit persists even when the absolute locations of old items change, while keeping their relative configuration (Watson, 2001; Kunar, Humphreys, Smith, & Hulleman, 2003). It is argued that the memory template can keep track of the locations of old items by applying a transform that mentally rotates the template to keep it aligned with the current configuration of old distractors (e.g., Watson, 2001). The present study demonstrated that the memory template was also able to keep track of the locations of old items when the items rigidly rotated around the vertical axis in 3D coordinates. The visual system may be able to use the same strategy irrespective of the choice of the rotational axis, and even irrespective of any movement of the chosen rotational axis itself, as in the precession of a spinning toy top. Further investigation is absolutely necessary to clarify this issue of generalizability.

The present study demonstrated preview benefit in items rotating around a common axis. This finding is consistent with the hypothesis that the visual system can use higher-level representations, such as the 3D spatial configuration of items as an outcome of intricate depth processing, to form a memory template to inhibit the locations of old items. Indeed, brain imaging studies have demonstrated that successful ignoring of old distractors is associated with activation in the superior parietal lobule in preview search relative to a baseline search condition (e.g., Humphreys et al., 2004; Pollmann et al., 2003), suggesting that the superior parietal activation reflects the coding of a spatial map of old locations or a negative bias in selection itself (e.g., Watson, Humphreys, & Olivers, 2003). On the other hand, preview benefit is also shown to be correlated to reduced activations in early visual processing areas including V1 (Dent et al., 2011), making it likely that inhibition can also take place on a retinotopic map, which is inherently a 2D representation of the outer world, or in the "display" coordinates without depth variabilities. If this were the case, the relationship between the 3D memory template for old items and the neural inhibition at a 2D map could be formed by some feedback from higher cortical stages to lower-stage visual areas (Dent et al., 2011; Olivers, Smith, Matthews, & Humphreys, 2005). Further study is required for this topic, too.

The present findings are not compatible with a previous proposal that preview benefit occurs because of luminance increments generated at newly appearing objects or temporal segmentation between new and old items based on a certain signal of scene change. Strong versions of these attentional-capture and temporal-grouping hypotheses claim that mere change signals induced by the appearance of new items are sufficient for preview benefit to occur (Donk & Theeuwes, 2001; Jiang et al., 2002b). In the present 3D situation, however, some of the old and new items accidentally disappeared and reappeared due to occlusion. Therefore, observers could not easily use change signals concomitant with stimulus onsets to segment new and old items; in such a situation, the system may rely more on the memory template storing the spatial configuration of old items. On the other hand, the present results are consistent with the hypothesis that there is attentional capture by the sudden appearance of new objects (e.g., Yantis & Hillstrom, 1994). This view posits that an onset object captures attention because its appearance requires an immediate updating of visual short-term memory. Accordingly, it is possible that observers could ignore the changes by accidental occlusion and restrict the search within new onset items in the present situation. However, such an effect of attentional capture is limited to approximately five objects (e.g., Yantis & Hillstrom, 1994; Yantis & Jones, 1991); this limitation is much smaller than the effect of preview benefit (i.e., more than fifteen previewed items can be visually marked[2]; Jiang, Chun, & Marks, 2002a). Thus, the involvement of other attentional mechanisms is required to fully explain preview benefit.

The present study demonstrates that sufficient preview benefit remains when all items are graphically rendered in 3D coordinates, modestly mimicking real-life situations. In contrast, a recent study reports that no preview benefit emerges in more complex multi-element asynchronous dynamic (MAD) displays that are made to simulate real-world situations by including a combination of stationary, moving, and luminance-changing items (Kunar, Thomas, & Watson, 2017). As a possible explanation for this discrepancy, we would argue that the null result in Kunar et al. (2017) study was obtained because previewed distractors did not maintain fixed relative positions; that is, previewed distractors were moving in different directions at different velocities and changed directions at different times, making it more difficult for the visual system to develop and maintain a spatially stable representation of old items. Further studies are required to determine the necessary conditions of real-world situations that are compatible with preview benefit.

In sum, the present study examined whether previewed distractors can be excluded from inefficient search when items are graphically rendered in 3D coordinates. Preview benefit was robustly observed, and also maximized when the contribution of occlusion events is equalized across conditions, suggesting that the memory template stores the spatial configuration of old items in 3D coordinates.

Author notes

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2. Recent studies investigating how many items can be prioritized in the preview search (e.g., Watson & Kunar, 2012; Emrich, Ruppel, Al-Aidroos, Pratt, & Ferber, 2008) suggest that capacity limit depends on both task (single response or multiple responses) and stimulus properties (e.g., similarity between new and old items). Thus, we must carefully consider what process may account for data indicating the limitation of the prioritizing effect. To examine whether visual marking plays any role in addition to onset capture, the search performance for a target that always appears as a new item should be compared with the performance for a target that can appear equally as a new or old item, as was done by Osugi, Hayashi, and Murakami (2016).

References

Brainard, D. H. (1997). The psychophysics toolbox. *Spatial Vision, 10*, 433–436.

Chun, M., & Wolfe, J. M. (2001). Visual attention. *Blackwell handbook of perception* (pp. 272–310). Oxford, UK: Blackwell Publishers Ltd.

Egeth, H. E., Virzi, R. A., & Garbart, H. (1984a). Searching for conjunctively defined targets. *Journal of Experimental Psychology: Human Perception and Performance, 10*, 32.

Dent, K., Allen, H., & Humphreys, G. W. (2011). Comparing segmentation by time and by motion in visual search: An fMRI investigation. *Journal of Cognitive Neuroscience, 23*, 1710–1722.

Dent, K., Braithwaite, J. J., He, X., & Humphreys, G. W. (2012). Integrating space and time in visual search: How the preview benefit is modulated by stereoscopic depth. *Vision Research, 65*, 45–61.

Dent, K., Humphreys, G. W., He, X., & Braithwaite, J. J. (2014). Surface-based constraints on target selection and distractor rejection: Evidence from preview search. *Vision Research, 97*, 89–99.

Donk, M., & Theeuwes, J. (2001). Visual marking beside the mark: Prioritizing selection by abrupt onsets. *Perception and Psychophysics, 63*, 891–900.

Egeth, H. E., Virzi, R. A., & Garbart, H. (1984b). Searching for conjunctively defined targets. *Journal of Experimental Psychology: Human Perception and Performance, 10*(1), 32–39.

Emrich, S. M., Ruppel, J. D., Al-Aidroos, N., Pratt, J., & Ferber, S. (2008). Out with the old: Inhibition of old items in a preview search is limited. *Perception & Psychophysics, 70*, 1552–1557.

Humphreys, G. W., Kyllingsbæk, S. R., Watson, D. G., Olivers, C. N., Law, I., & Paulson, O. B. (2004). Parieto-occipital areas involved in efficient filtering in search: A time course analysis of visual marking using behavioural and functional imaging procedures. *Quarterly Journal of Experimental Psychology Section A, 57*, 610–635.

Jiang, Y., Chun, M. M., & Marks, L. E. (2002a). Visual marking: Dissociating effects of new and old set size. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28*, 293–302.

Jiang, Y., Chun, M. M., & Marks, L. E. (2002b). Visual marking: Selective attention to asynchronous temporal groups. *Journal of Experimental Psychology: Human Perception and Performance, 28*, 717–730.

Kleiner, M., Brainard, D., & Pelli, D. (2007). What's new in psychtoolbox-3? *Perception, 36* ECVP abstract supplement.

Kunar, M. A., & Humphreys, G. W. (2006). Object-based inhibitory priming in preview search: Evidence from the "top-up" procedure. *Memory & Cognition, 34*, 459–474.

Kunar, M. A., Humphreys, G. W., Smith, K. J., & Hulleman, J. (2003). What is "marked" in visual marking? Evidence for effects of configuration in preview search. *Perception & Psychophysics, 65*, 982–996.

Kunar, M. A., Humphreys, G. W., Smith, K. J., & Watson, D. G. (2003). When a reappearance is old news: Visual marking survives occlusion. *Journal of Experimental Psychology: Human Perception and Performance, 29*, 185–198.

Kunar, M. A., Thomas, S. V., & Watson, D. G. (2017). Time-based selection in complex displays: Visual marking does not occur in multi-element asynchronous dynamic (MAD) search. *Visual Cognition, 25*, 215–224.

Li, Z. (2002). A saliency map in primary visual cortex. *Trends in Cognitive Sciences, 6*, 9–16.

Liu, G., Austen, E. L., Booth, K. S., Fisher, B., Rempel, M. I., & Enns, J. T. (2005). Multiple object tracking is based on scene not retinal coordinates. *Journal of Experimental Psychology: Human Perception and Performance, 31*, 235–247.

Olivers, C. N., Smith, S., Matthews, P., & Humphreys, G. W. (2005). Prioritizing new over old: An fMRI study of the preview search task. *Human Brain Mapping, 24*, 69–78.

Olivers, C. N. L., & Humphreys, G. W. (2002). When visual marking meets the attentional blink: More evidence for top-down, limited-capacity inhibition. *Journal of Experimental Psychology: Human Perception and Performance, 28*, 22–42.

Olivers, C. N. L., & Humphreys, G. W. (2003). Visual marking inhibits singleton capture. *Cognitive Psychology, 47*, 1–42.

Olivers, C. N. L., Watson, D. G., & Humphreys, G. W. (1999). Visual marking of locations versus feature maps: Evidence from within-dimension defined conjunctions. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 52*, 679–715.

Osugi, T., Hayashi, D., & Murakami, I. (2016). Selection of new objects by onset capture and visual marking. *Vision Research, 122*, 21–33.

Osugi, T., Kumada, T., & Kawahara, J. I. (2009). The spatial distribution of inhibition in preview search. *Vision Research, 49*, 851–861.

Osugi, T., & Murakami, I. (2014). Previewing distractors reduces efficiency of visual processing at previewed locations. *Vision Research, 95*, 51–60.

Osugi, T., & Murakami, I. (2015). Onset of background dynamic noise attenuates preview benefit in inefficient visual search. *Vision Research, 112*, 33–44.

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision, 10*, 437–442.

Pollmann, S., Weidner, R., Humphreys, G. W., Olivers, C. N., Müller, K., Lohmann, G., ... Watson, D. G. (2003). Separating distractor rejection and target detection in posterior parietal cortex—An event-related fMRI study of visual marking. *NeuroImage, 18*, 310–323.

Shepard, R. N., & Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science, 171*(3972), 701–703.

Treisman, A., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12*, 97–136.

Van Selst, M., & Jolicoeur, P. (1994). A solution to the effect of sample size and skew on outlier elimination. *Quarterly Journal of Experimental Psychology, 47*, 631–650.

Viswanathan, L., & Mingolla, E. (2002). Dynamics of attention in depth: Evidence from multi-element tracking. *Perception, 31*, 1415–1437.

Watson, D. G. (2001). Visual marking in moving displays: Feature-based inhibition is not necessary. *Perception and Psychophysics, 63*, 74–84.

Watson, D. G., & Humphreys, G. W. (1997). Visual marking: Prioritizing selection for new objects by top-down attentional inhibition of old objects. *Psychological Review, 104*, 90–122.

Watson, D. G., & Humphreys, G. W. (1998). Visual marking of moving objects: A role for top-down feature based inhibition in selection. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 946–962.

Watson, D. G., & Humphreys, G. W. (2000). Visual marking: Evidence for inhibition using a probe-dot detection paradigm. *Perception and Psychophysics, 62*, 471–481.

Watson, D. G., Humphreys, G. W., & Olivers, C. N. (2003). Visual marking: Using time in visual selection. *Trends in Cognitive Sciences, 7*, 180–186.

Watson, D. G., & Kunar, M. A. (2010). Visual marking and change blindness: Moving occluders and transient masks neutralize shape changes to ignored objects. *Journal of Experimental Psychology: Human Perception and Performance, 36*, 1391–1405.

Watson, D. G., & Kunar, M. A. (2012). Determining the capacity of time-based selection. *Journal of Experimental Psychology: Human Perception and Performance, 38*, 350–366.

Wolfe, J. (1994). Guided search 2.0: A revised model of guided search. *Psychonomic Bulletin and Review, 1*, 202–238.

Yantis, S., & Hillstrom, A. P. (1994). Stimulus driven attentional capture: Evidence from equiluminant visual objects. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 95–107.

Yantis, S., & Jones, E. (1991). Mechanisms of attentional selection: Temporally-modulated priority tags. *Perception and Psychophysics, 50*, 166–178.

Yantis, S., & Jonides, J. (1984). Abrupt visual onsets and selective attention: Evidence from visual search. *Journal of Experimental Psychology: Human Perception and Performance, 10*, 601–621.