Psychophysiology, 48 (2011), 784–787. Wiley Periodicals, Inc. Printed in the USA.

DOI: 10.1111/j.1469-8986.2010.01145.x

BRIEF REPORT

Attentional capture by size singletons is determined by top-down search goals

MONIKA KISS AND MARTIN EIMER
Department of Psychology, Birkbeck College, University of London, London, UK

Abstract

The question whether attentional capture by salient visual stimuli is driven by bottom-up salience or is contingent on top-down task set is still under dispute. We show that the ability of size singletons to capture attention is determined by current search goals. Participants searched for small or large target singletons among medium-size distractors. Attentional capture by small or large size singleton cues that preceded target search displays was reflected by spatial cueing effects and N2pc components. These effects were observed only when these cues matched the current target-defining feature, but not for physically identical but mismatching cues. Results demonstrate that attentional capture by size singletons is not driven by bottom-up salience, but is controlled by feature-specific task settings.

Descriptors: Visual selection, Top-down control, Event-related potentials (ERPs), N2pc

Attentional selection of visual objects can occur either in a stimulus-driven (bottom-up) or in a goal-directed (top-down) fashion, but the contributions of bottom-up and top-down factors are still under debate. Some have argued that perceptually unique visual stimuli such as color singletons capture attention due to their bottom-up salience, irrespective of current task set (Theeuwes, 1991, 2010). Others have claimed that attentional capture by visual singletons is contingent on top-down task settings (e.g., Folk, Remington, & Johnston, 1992). A third view (Bacon & Egeth, 1994) proposes that the impact of bottom-up and top-down factors on attentional capture depends on generalized search strategies. When search targets are feature singletons, participants adopt a *singleton detection* mode (i.e., search for any feature discontinuity irrespective of its value), resulting in attentional capture by salient but task-irrelevant singletons. When targets are non-singletons, this default search strategy is not available. A more finely tuned *feature search* mode is required, and singletons that lack target-matching features do not capture attention. However, the fact that target color-contingent attentional capture effects were found during search for color singletons (Folk & Remington, 1998) is inconsistent with the assumed default status of singleton search (see also Eimer & Kiss, 2010).

Task-set contingent attentional capture has been demonstrated for a number of different stimulus features, including color, shape, apparent motion, and abrupt onset. However, the role of top-down task sets in attentional capture by *size* singletons has not yet been investigated systematically. Recent behavioral evidence has suggested that task-irrelevant large size singletons attract attention in a bottom-up salience-driven fashion (Proulx & Egeth, 2008), which could reflect an important limit in the top-down control of attentional selectivity. To investigate attentional capture by size singletons, the present experiment employed spatial cueing procedures similar to those used by Folk et al. (1992). Participants searched for a large or small target bar that was presented among medium-size distractors (Figure 1, left), with target size varied across blocks. Search displays were preceded by cue arrays that contained one item that was smaller or larger than the background items, or one location where an item was left out ("nothing" cue). These size cues were spatially uninformative with respect to target location, and the three cue types were presented in random order. Attentional capture by size singleton cues should be reflected by behavioral spatial cueing effects (faster response times (RTs) to targets at cued as compared to uncued locations). We also measured the N2pc component to cue arrays as an electrophysiological marker of attentional capture. The N2pc is an enhanced negativity over posterior scalp electrodes contralateral to the side of attended stimuli (Luck & Hillyard, 1994; Eimer, 1996), and has recently been established as an index of rapid attentional capture in visual search (Hickey, McDonald, & Theeuwes, 2006; Eimer & Kiss, 2008, 2010).

If participants adopt a size-specific task set when searching for small or large targets, size cues should capture attention in a task-contingent fashion. Capture effects should be found for small cues during search for small targets, and for large cues in blocks with large targets, but not for cues that do not match the current target-defining feature. In contrast, if participants chose to adopt a singleton detection mode, or if attentional capture by all size singletons was driven by bottom-up salience, any size discontinuity regardless of its sign should capture attention, resulting in spatial cueing effects and N2pc components to small and large

This research was supported by the Biotechnology and Biological Sciences Research Council (BBSRC), UK.
Address correspondence to: Monika Kiss, Department of Psychology, Birkbeck College, University of London, Malet Street, London WC1E 7HX, UK. E-mail: m.kiss@bbk.ac.uk

cues, regardless of whether participants search for small or large targets. A third possibility is that only large, but not small, size singleton cues capture attention in a stimulus-driven fashion due to their higher signal strength (Proulx & Egeth, 2008). In this case, task-set contingent capture should be observed only for small cue arrays (see also Treisman & Gormican, 1988, for asymmetries between search for large vs. small target singletons).

"Nothing" cues were included to explore the possibility that the absence of a stimulus in the cue array might be attentionally equivalent to an (infinitesimally) small size cue. In this case, a size-specific top-down task set could result in attentional capture by "nothing" cues during search for small targets, but not in blocks with large targets.

Method

Participants

Twelve right-handed volunteers (six males; mean age 24.9 years) with normal or corrected vision were tested.

Stimuli and Procedure

Stimuli were presented on an LCD monitor against a black background. In each trial, circular cue arrays preceded circular target arrays (Figure 1). Search arrays contained six gray bars that were randomly oriented horizontally or vertically, at a distance of 4.1° from a central fixation point. In separate blocks, the target bar was either smaller (0.2° × 0.4° visual angle) or larger (0.6° × 1.2°) than the distractors (0.4° × 0.8°). Targets appeared equiprobably and randomly at one of the four locations on the left or right side, but never at the top or bottom location. Cue arrays contained five or six gray items composed of four dots. In two-thirds of trials, one item was either smaller (0.2° × 0.2°) or larger (0.6° × 0.6°) than the others (0.4° × 0.4°). In the remaining third, one item was left out ("nothing" cue). All three cue types appeared randomly and equiprobably at one of the four left or right locations, but never at the top or bottom, and were spatially uninformative with respect to the location of subsequent targets. All stimuli were equiluminant gray (10.3 cd/m^2).

Cue and search displays were each presented for 50 ms, separated by a 150-ms blank interval. The interval between search array offset and the onset of the next cue array was 1450 ms. Participants had to detect small or large target bars and report their orientation (vertical or horizontal) by pressing one of two response buttons with their left or right index finger as fast and accurately as possible while maintaining central fixation. Large and small bars served as targets in eight successive experimental blocks, with task order counterbalanced across participants. Each block contained 96 trials.

EEG Recording and Analysis

Electroencephalogram (EEG) was DC-recorded from 23 scalp electrodes at standard positions of the extended 10/20 system

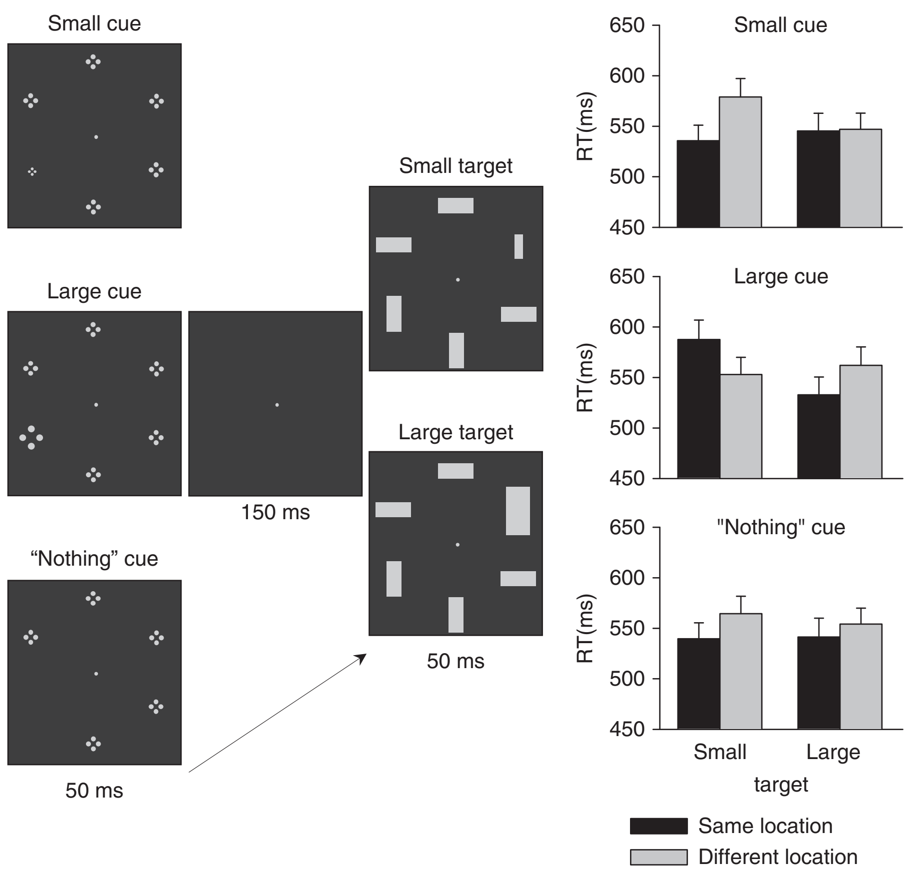

Figure 1. Left: Stimulus set-up and trial structure. Spatially uninformative small, large, or "nothing" cues preceded search arrays containing a size singleton target. Small and large targets were presented in separate blocks. Right: Mean correct response times in trials with small, large, and "nothing" cues, shown separately for blocks with small and large targets, and trials where cue and target singletons were presented at the same location (black bars) or at different locations (gray bars). Error bars depict standard errors of the mean.

(500 Hz sampling rate; 40 Hz low-pass filter; 50 Hz notch filter, no additional off-line filtering) with a left-earlobe reference, was re-referenced offline to averaged earlobes, and segmented into epochs from 100 ms before to 500 ms after cue onset. Trials containing saccades, blinks, or muscle artifacts (horizontal electrooculogram channel exceeding $\pm$ 30 μV; vertical electrooculogram channel $\pm$ 60 μV; all other channels $\pm$ 80 μV), and trials with incorrect responses were removed from analysis. Average waveforms were computed relative to a 100-ms pre-cue baseline. The N2pc in response to the cue was quantified at lateral posterior electrode sites PO7 and PO8 (where this component is typically maximal) on the basis of event-related potential (ERP) mean amplitudes measured in the 200–300 ms interval after cue onset. Greenhouse-Geisser corrections for nonsphericity were applied where appropriate.

Results

Behavioral Data

Spatial cueing effects indicative of attentional capture (faster RTs to targets at cued vs. uncued locations) were present for small and large cues during search for small and large targets, respectively, but not vice versa (Figure 1, right panel). For "nothing" cues, spatial cueing effects were present regardless of target size. A three-way analysis of variance (ANOVA) on mean RTs with the factors cue type (small, large, "nothing"), task (small vs. large target) and cue-target location (same vs. different) confirmed these observations. A main effect of cue type, $F(2,22) = 7.4$, $p < .01$, reflected overall slower RTs in trials with large cues. A main effect of cue-target location, $F(1,11) = 27.3$, $p < .001$, showed that RTs were faster when cue and target appeared at the same location relative to different locations. There was no main effect of task, $F < 1$. Most importantly, an interaction between cue type, task, and cue-target location, $F(2,22) = 25.4$, $p < .001$, demonstrated that spatial cueing effects differed across different combinations of cue type and task instruction.

Separate ANOVAs were conducted for each cue type. For small cues, a main effect of cue-target location, $F(1,11) = 17.7$, $p < .001$, was accompanied by a task $\times$ cue-target location interaction, $F(1,11) = 10.2$, $p < .01$. Small cues triggered spatial cueing effects during search for small targets, $t(11) = 3.8$, $p < .01$, but not in blocks with large targets, $t < 1$. For large cues, there was no main effect of cue-target location, $F < 1$, but a task $\times$ cue-target location interaction, $F(1,11) = 57.3$, $p < .001$. Large cues triggered spatial cueing effects indicative of attentional capture in blocks with large targets, $t(11) = 6.2$, $p < .001$, and inverted spatial cueing effects (faster RTs for targets at uncued locations) in blocks with small targets, $t(11) = -4.6$, $p < .001$. For "nothing" cues, a main effect of cue-target location, $F(1,11) = 31.8$, $p < .001$, did not interact with task, $F(1,11) = 1.6$, $p = .23$. These cues elicited spatial cueing effects during search for small and large targets, $t(11) = 4.0$ and 2.5, respectively, $p < .002$ and .028. Error rates were low (4.3% and 3.7% for blocks with small and large targets, respectively). There were no reliable effects of task, cue type, or cue-target location on error rates.

ERP Data

Figure 2 shows ERPs at lateral posterior electrodes PO7/8 contralateral and ipsilateral to the visual hemifield of a size cue, separately for all cue types, and for blocks with small or large targets. An N2pc was elicited by small and large cues only when they matched the current target-defining feature. For "nothing" cues, an N2pc was present during search for small and for large targets. An ANOVA conducted on N2pc mean amplitudes for the factors cue type (small, large, "nothing"), task (small vs. large target), cue side (left vs. right), and contralaterality (electrode contralateral vs. ipsilateral to the cue) obtained a main effect of contralaterality, $F(1,11) = 28.8$, $p < .001$, and a cue type $\times$ task $\times$ contralaterality interaction, $F(2,22) = 12.9$, $p < .001$. Separate ANOVAs were conducted for each cue type. For small cues, there was a main effect of contralaterality, $F(1,11) = 13.3$, $p < .01$, and a task $\times$ contralaterality interaction, $F(1,11) = 20.7$, $p < .001$. Follow-up analyses confirmed the presence of an N2pc to small cues during search for small targets, $F(1,11) = 19.1$, $p < .001$, but not in blocks with large targets, $F(1,11) = 1.3$, $p = .28$. For large cues, there was no main effect of contralaterality, $F < 1$, but a target type $\times$ contralaterality interaction, $F(1,11) = 8.8$, $p < .05$. An N2pc was triggered by large cues during search for large targets, $F(1,11) = 5.6$, $p < .05$. In blocks with small targets, the tendency for a polarity-inverted N2pc was not reliable, $F(1,11) = 3.1$, $p = .11$. For "nothing" cues, there was a main effect of contralaterality, $F(1,11) = 34.5$, $p < .001$, but no target type $\times$ contralaterality interaction, $F < 1$. Follow-up analyses confirmed that an N2pc was triggered by "nothing" cues during

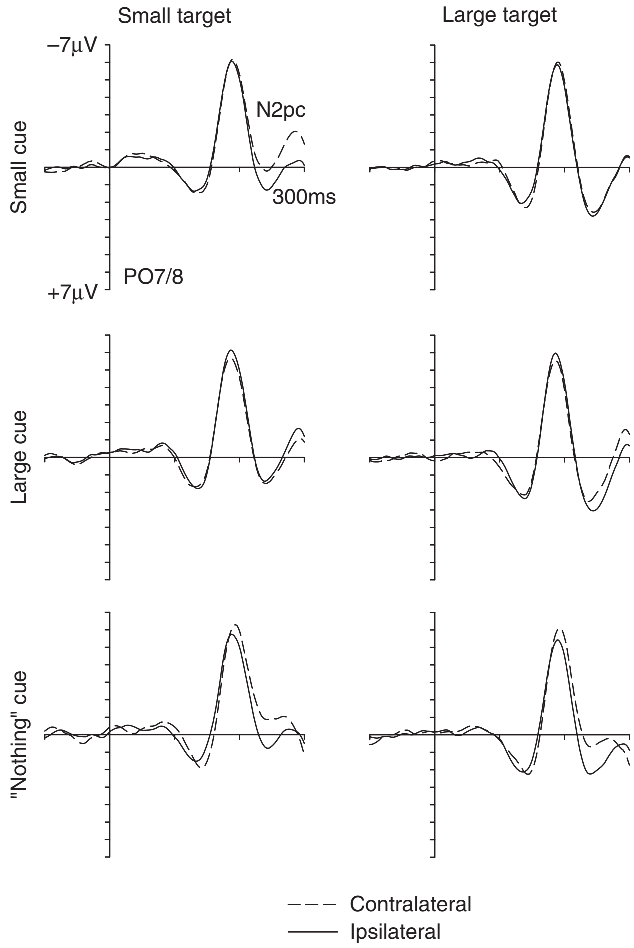

Figure 2. Grand average ERPs obtained in response to cue arrays at lateral posterior electrodes PO7 and PO8 contralateral (dashed lines) and ipsilateral (solid lines) to the side of the size singleton cue. Waveforms are shown separately for small, large, and "nothing" cues, and for blocks with small or large target bars.

search for small bars, $F(1,11) = 36.3$, $p < .001$, and large bars, $F(1,11) = 19.3$, $p < .001$.

Discussion

The current findings demonstrate that the ability of task-irrelevant size singletons to capture attention is determined by participants' size-specific search intentions. A unique small or large item presented among uniform medium-size stimuli captured attention, as reflected by an N2pc and behavioral spatial cueing effects, only when its relative size matched the size of the current search target. No reliable N2pc components or cueing effects indicative of attentional capture were obtained for non-matching size cues (small cues in blocks with large targets, and vice versa). These behavioral and ERP results observed for small or large singleton cues during search for small or large target items provide clear-cut evidence that attentional capture by size singletons is mediated by feature-specific top-down task sets. While inverted behavioral spatial cueing effects (faster RTs for targets at uncued locations) for large cues in blocks with small targets are likely due to a contribution of forward masking on trials where a small target was preceded by a large cue at the same location, the presence of an N2pc to large cues in blocks with large targets, and its absence with small targets, demonstrates task-set contingent attentional capture.

Because search targets were size singletons, participants could in principle have chosen to adopt a feature-unspecific singleton detection mode ("any size difference, regardless of its value"). Attentional capture could also have been driven exclusively by the bottom-up salience of size singletons, irrespective of current search goals. In both cases, N2pc components and spatial cueing effects triggered by small or large cues should have remained unaffected by top-down task set, which was clearly not the case. There was also no asymmetry of task-set contingent attentional capture effects between large and small cue arrays, demonstrating that the higher bottom-up salience of large singleton cues did not override the impact of top-down search goals. In summary, these results extend previous findings from experiments on task-set contingent attentional capture (Folk et al., 1992; Folk & Remington, 1998; Eimer & Kiss, 2008, 2010) by demonstrating that attentional capture by size singletons is under full top-down control.

A different pattern of results was obtained for "nothing" cues. These cues produced spatial cueing effects and triggered an N2pc regardless of whether participants searched for small or large targets, suggesting that they captured attention in a task-set independent fashion. However, these findings must be interpreted with caution. On same-location trials, targets were presented at previously unoccupied locations, and faster RTs on these trials could therefore have resulted from the absence of any forward masking by cue array items, or because the search item at the previously empty location captured attention because it was treated as a new object (e.g., Yantis & Jonides, 1996). The N2pc in response to "nothing" cues could in principle have been affected by the sensory imbalance between hemifields that is inherent in the spatial arrangement of these cues, and that was reflected by a small latency shift of the contralateral P1. Further research is required to rule out these possibilities, and to confirm that the absence of a stimulus in a structured visual display triggers salience-driven bottom-up attentional capture.

In summary, the present study has demonstrated that the ability of size singleton stimuli to capture attention is subject to top-down control, that this type of task-set contingent attentional capture is determined by the relative size of these stimuli against their background, and that it can be observed both for large and for small size singletons.

REFERENCES

Bacon, W. F., & Egeth, H. E. (1994). Overriding stimulus-driven attentional capture. *Perception & Psychophysics*, *55*, 485–496.

Eimer, M. (1996). The N2pc component as an indicator of attentional selectivity. *Electroencephalography and Clinical Neurophysiology*, *99*, 225–234.

Eimer, M., & Kiss, M. (2008). Involuntary attentional capture is determined by task set: Evidence from event-related brain potentials. *Journal of Cognitive Neuroscience*, *20*, 1423–1433.

Eimer, M., & Kiss, M. (2010). Top-down search strategies determine attentional capture in visual search: Behavioral and electrophysiological evidence. *Attention, Perception & Psychophysics*, *72*, 951–962.

Folk, C. L., & Remington, R. W. (1998). Selectivity in distraction by irrelevant featural singletons: Evidence for two forms of attentional capture. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 847–858.

Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 1030–1044.

Hickey, C., McDonald, J. J., & Theeuwes, J. (2006). Electrophysiological evidence of the capture of visual attention. *Journal of Cognitive Neuroscience*, *18*, 604–613.

Luck, S. J., & Hillyard, S. A. (1994). Spatial filtering during visual search: Evidence from human electrophysiology. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 1000–1014.

Proulx, M. J., & Egeth, H. E. (2008). Biased competition and visual search: The role of luminance and size contrasts. *Psychological Research*, *72*, 106–113.

Theeuwes, J. (1991). Cross-dimensional perceptual selectivity. *Perception & Psychophysics*, *50*, 184–193.

Theeuwes, J. (2010). Top-down and bottom-up control of visual selection. *Acta Psychologica*, *135*, 77–99.

Treisman, A. M., & Gormican, S. (1988). Feature analysis in early vision: Evidence from search asymmetries. *Psychological Review*, *95*, 15–48.

Yantis, S., & Jonides, J. (1996). Attentional capture by abrupt onsets: New perceptual objects or visual masking? *Journal of Experimental Psychology: Human Perception and Performance*, *22*, 1505–1513.

(Received May 17, 2010; Accepted August 18, 2010)