Temporal Attentional Capture: Effects of Irrelevant Singletons on Rapid Serial Visual Search

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Abstract

The presence of a unique yet irrelevant 'singleton' in visual search or spatial cuing tasks is typically associated with performance costs, suggesting that singletons tend to capture attention. However, as singletons have always been spatially separated from targets in previous experiments, it remains unclear whether an irrelevant visual singleton that occurs at the same spatial location as the target but at a different point in time can produce temporal capture of attention. Here we asked participants to search visual sequences at fixation for targets defined by size (larger or smaller than the nontargets). The presence (versus absence) of a color singleton slowed reaction times on the size discrimination task, suggesting that irrelevant singletons can lead to a temporal attentional capture.

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In order to behave effectively in a complicated world, people must be able to focus their attention on goal-relevant stimuli at the expense of irrelevant ones. However, it is also important that attention can be captured by irrelevant stimuli when they are unique and so may signal potentially important changes in the environment. A central line of attention research has investigated attentional capture by such unique yet task-irrelevant 'singleton' stimuli.

It has long been established that attentional allocation towards stimuli in non-target locations produces performance costs, as shown in spatial cuing studies (e.g. Jonides, 1980; Posner, Nissen & Ogden, 1978) as well as in studies of attentional capture by a 'singleton' item presented within a visual search display (e.g. Jonides & Yantis, 1988; Theeuwes, 1992). Both these areas of research address the consequences of paying attention to irrelevant spatial locations. More recently, research has begun to address the effects of attentional allocation to irrelevant temporal positions. However, very little previous research has investigated the possibility of attentional capture by stimuli appearing at irrelevant temporal positions. Here we ask whether a unique yet irrelevant singleton can produce temporal attentional capture during a rapid serial visual presentation (RSVP) search task.

A few recent studies provide some evidence that attentional allocation to items presented at irrelevant temporal positions can lead to performance costs. For example, Folk, Leber and Egeth (2002) have shown attentional capture in an RSVP task by color singleton distractors flanking the central RSVP letters. However, as the singleton distractors in this study were spatially separated from targets, it is not clear whether the capture effects were due to diversion of attention to an irrelevant spatial location (i.e. spatial attentional capture) or to an irrelevant temporal position (i.e. temporal attentional capture) or both.

Research into the attentional blink (AB) has shown that attending to (rather than ignoring) the first of two targets can prevent participants from detecting the second, as long as the second target occurs within 500 ms of the first (e.g. Broadbent & Broadbent, 1987; Raymond, Shapiro & Arnell, 1992). Thus attentional allocation towards one item in a serial stream can interfere with processing of an item at a different point in the stream. These results cannot be explained in terms of spatial attention because all items are presented in a central RSVP stream. However, as participants respond primarily to the first target and only later to the second target, the attentional blink is likely to involve both response- and memory-related effects (e.g. Jolicoeur, 1998). Moreover, most of the AB research assesses the consequences of attending deliberately to target stimuli, and as such does not provide information about involuntary capture of attention.

Recent findings from the attentional blink paradigm that an ignored first target or additional singleton (e.g. a colored box around a non-target letter) can interfere with recall of the second target are more informative about the possibility of involuntary temporal attentional capture (e.g. Chun, 1997; Folk, Leber & Egeth, 2001; Maki & Mebane, in press; Wee and Chua, 2004). However in all these studies, reliable performance costs were only produced by items that were defined on the same dimension as the targets (e.g. they were both color singletons; see also Ghorashi et al., 2003, Note

1). These results therefore cannot speak to the possibility of involuntary temporal attentional capture by a singleton distractor defined on a task-irrelevant dimension.

We have recently demonstrated temporal attentional capture by such task-irrelevant auditory singletons during sequential auditory search (Dalton & Lavie, 2004). Irrelevant auditory singleton distractors (i.e. sounds that were unique on one dimension, e.g. frequency) captured attention even though targets were defined on a different dimension (e.g. intensity). However, whereas hearing tends to prioritise temporal information, vision operates more on spatial co-ordinates and it is therefore unclear whether analogous temporal visual attentional capture effects can be found.

We used a visual-search attentional capture task, in which unique singleton items typically attract attention despite being irrelevant to the task. However we modified the task to present both target and nontarget stimuli in a sequential stream rather than in a spatial array. Any evidence of a cost due to singletons presented at a different temporal position from the target, but at the same spatial location, would suggest pure temporal capture of attention.

Experiment 1

This experiment asked whether an irrelevant color singleton would capture attention during a RSVP search task. Participants searched visual letter sequences for targets that were either larger or smaller than the rest of the letters. On 50% of trials an irrelevant color singleton was presented (e.g. a red letter among black). Any cost to target detection in the presence (vs. absence) of the singleton would be suggestive of attentional capture.

Method

Participants. Participants in all experiments were paid students (aged 18-35). All reported normal or corrected-to-normal vision. Eight participants took part in this experiment.

Stimuli & Procedure. The experiments were created and run on a PC using E-Prime (Psychology Software Tools, Inc., Pittsburgh, PA). Each sequence started with a black fixation cross presented at the center of the screen for 500 ms, followed by a 50 ms blank screen. A sequence of five uppercase letter Ns was then presented, one after another at the center of the screen. Each appeared for 60 ms, followed by a 70 ms blank screen. At a viewing distance of 60cm, nontargets and singletons subtended a visual angle of 1.4° x 1.4°, large targets subtended 1.7° x 1.7° and small targets subtended 1.1° x 1.1. Participants were requested to respond with a key press: 1 for large target or 2 for small target, using the index and middle fingers of the right hand respectively, upon presentation of a question mark at the center of the screen at the end of each sequence. A feedback screen displaying either the word Correct (in blue), Incorrect (in red) or No response detected (in red) was presented at the end of each trial, either after a response had been collected or after 3000 ms if no response was made.

Targets appeared on every trial and were equally likely to be large or small and in the third or fourth position. Irrelevant distractor singletons appeared on 50% of trials, directly before or after the target with equal probability. All letters were presented against a white background. Nontargets and targets were black for half the participants (red for the other half) and singletons were red for these participants (black for the other half). Participants were asked to focus on letter size and ignore any variation in other dimensions. They were informed that some distractor items of a different color would occur and were warned that their performance might be harmed if they failed to ignore these distractors. A short practice block of 16 trials preceded two experimental blocks, each containing 80 trials.

Results

Preliminary analysis of all three experiments indicated that the between-participants factor of target color (red vs. black) did not interact with the factor of singleton presence (vs. absence), $p > .30$ for all comparisons. All data are thus pooled across target color. In all experiments, incorrect responses were excluded from the RT analysis, as were RTs longer than 1500 ms. Table 1 presents mean RTs and error rates across participants as a function of singleton presence (present vs. absent) and target type (large vs. small).

---------------------------------Table 1 about here---

RTs. A two-way within-participants ANOVA using these factors revealed a significant main effect of singleton presence, $F(1,7) = 7.40$, $MSE = 14573.09$, $p < .05$. Target RTs were slower on singleton present trials ($M = 426$ ms) than on singleton absent trials ($M = 384$ ms), suggesting that the color singleton captured attention despite being irrelevant to the task. There was also a main effect of target type indicating that responses were faster when the target was large ($M = 377$ ms) than when it was small ($M = 433$ ms), $F(1,7) = 7.64$, $MSE = 25254.60$, $p < .05$. This is in line with previous research demonstrating an advantage for large targets among small nontargets compared with small targets among large nontargets in spatial visual search (e.g. Treisman & Gormican, 1988). The factors of singleton presence and target type did not interact significantly, $F(1,7) = 1.98$, $MSE = 1979.31$, $p = .20$.

A further one-way within-subjects ANOVA on data from singleton present trials revealed a significant effect of singleton position (before vs. after the target) such that responses were slower when the singleton occurred before ($M = 449$ ms) versus after the target, $M = 400$ ms, $F(1,7) = 9.01$, $MSE = 9381.38$, $p < .05$. Indeed, RTs when the singleton occurred after the target were not significantly different from RTs when the singleton was absent ($M = 383$ ms, $t(7) = 1.14$, $p = .29$). Thus the appearance of a singleton before the target was more damaging to target processing than the appearance of a singleton after the target. This may be due to some target processing occurring without competition when the singleton occurs after the target.

Finally, to confirm that capture could be found from singletons at entirely irrelevant temporal positions, we looked separately at the effects of singleton presence (absent vs. present) for singletons in serial position 2 (where the target never occurred) and singletons in serial position 3 (where the target could occur). The findings of a significant capture effect by singletons at position 2 (M effect = 56 ms, $t(7) = 2.44$, $p < .05$) which was not significantly different ($F < 1$) from the effects of singletons at the potential target position 3 (M effect = 78 ms, $t(7) = 2.32$, $p = .05$) indicates that the capture effects were not restricted to singletons occurring in potential target positions and thus cannot be attributed to voluntary allocation of attention to those positions. We note nevertheless that the nonsignificant numerical trend might suggest that voluntary attentional allocation can increase the magnitude of singleton interference.

Errors. The two-way error ANOVA with the factors of singleton presence and target type revealed no significant main effects or interactions ($p > .20$ for all comparisons). Note, however, that the error rates showed similar trends to the RTs (see Table 1).

A further one-way within-participants ANOVA on error data from singleton present trials using the factor of singleton position (before vs. after the target) revealed a trend for a higher error rate when the singleton occurred before ($M = 11\%$) versus after the target, $M = 8\%$, $F(1,7) = 4.94$, $MSE = 36.00$, $p = .062$. Error rates in the latter condition were very similar to error rates when the singleton was absent ($M = 8.5\%$). Thus, as in the RTs, the singleton appeared to cause more interference when it appeared before rather than after the target.

In conclusion, the present experiment found significant interference due to the presence of an irrelevant color singleton in an RSVP discrimination task. This finding is suggestive of attentional capture by the irrelevant singleton.

Experiment 2

We have argued that the interference found in Experiment 1 is likely to be due to attentional capture by the irrelevant color singleton. However, as the singleton in Experiment 1 always appeared either directly before or directly after the target, it is possible that this interference might have been a result of contrast effects, such that it might be easier to judge target size in comparison with a nontarget of the same color than with a nontarget (singleton) of a different color. Experiments 2A and 2B were designed to examine this alternative account.

Participants in Experiments 2A and 2B carried out the size discrimination task used in Experiment 1. As in Experiment 1, all stimuli were in the same color on 50% of trials, but unlike Experiment 1 stimuli alternated between the target color and a distractor color on the remaining 50% of trials. On these color alternation trials the target was presented in between two items of a different color and if the interference effects seen in Experiment 1 are due to contrast effects, they should therefore persist in the alternation condition. By contrast, if the interference effects are due to attentional capture by the presence of a unique color singleton, they should be eliminated in the alternation condition. Experiment 2A used sequences of six or seven letters whereas Experiment 2B used sequences of four or five letters (for reasons described below).

Method

Participants. Eight new participants took part in Experiment 2A and a further eight in Experiment 2B.

Stimuli & procedure. The equipment and stimuli were the same as described in Experiment 1. Targets and nontargets were black for half the participants (red for the other half) and distractors were red for these participants (black for the other half). On 50% of the trials, sequences were made up only of nontargets and targets so that each sequence was presented in the target color only. On the remaining 50% of trials, the letters alternated in color between the target color and the irrelevant distractor color. Alternating sequences were just as likely to start with the distractor color as with the target color. In order to avoid any contingency between the color of the first letter in the sequence and subsequent target position, sequences consisted of either six or seven letters, with equal probability, in Experiment 2A. Similarly, sequences in Experiment 2B consisted of either four or five letters with equal probability. Targets were equally likely to be large or small. In Experiment 2A they appeared on every trial in the fourth or fifth position of the six-letter sequences and in the fifth or sixth position of the seven-letter sequences. In Experiment 2B they appeared on every trial in the second or third position of the four-letter sequences and in the third or fourth position of the five-letter sequences. All other aspects were the same as in Experiment 1.

Results and Discussion

Table 2 presents mean RTs and error rates for Experiment 2A and 2B as a function of alternation condition (alternation absent vs. present) and target type (large vs. small).

---------------------------------Table 2 about here---

Experiment 2A

RTs. A two-way within-subjects ANOVA using these factors found no significant main effects or interactions ($p > .20$ for all comparisons). It is especially important that there was no main effect of the presence (M = 290 ms) versus absence (M = 292 ms) of the color alternation ($F < 1$).

A between-experiments ANOVA confirmed that the singleton effect in Experiment 1 (M = 42 ms) was significantly larger than the color alternation effect in Experiment 2A (M = -2 ms), $F(1,14) = 5.17$, $MSE = 3211.61$, $p = .039$. Thus the singleton interference effect of Experiment 1 cannot be explained in terms of simple color contrast effects.

The between-experiment ANOVA also found a significant main effect of experiment, such that RTs were faster in the present experiment (M = 286 ms) than in

Experiment 1 (M = 402 ms), $F(1,14) = 10.12$, $p < .01$. As can be seen in Tables 1 and 2, this effect was found in the absence as well as the presence of the singleton or color alternation. This may be because the present experiment used stimulus sequences of six or seven items, whereas Experiment 1 used sequences of five items. Although the additional items in the present experiment were presented at the beginning of the sequences (so that the time in between the appearance of the target and the response window was the same in both experiments), it is possible that the longer sequences used here allowed participants to prepare more effectively for the subsequent target presentation, leading to faster target RTs. For this reason, Experiment 2B used shorter sequences, with the aim of reducing performance to a level comparable with that of Experiment 1.

Errors. A two-way within-participants ANOVA with the factors of alternation condition and target type showed no main effect of either factor ($p > .20$ for both comparisons). The interaction between alternation presence and target type was not significant, $F(1,7)=3.38$, MSE = 9.03, $p = .11$. Note that any trend towards a higher error rate for large targets in the absence (vs. presence) of the alternation (see Table 2) is in the opposite direction to the singleton interference effect, and in any case this trend was not significant, $t(7) = 1.70$, $p = .13$.

Experiment 2B

RTs. A two-way within-subjects ANOVA revealed no significant main effects or interactions ($p > .09$ for all comparisons). As in previous experiments, there was a trend for faster responses to large targets than to small targets, $F(1,7) = 3.61$, MSE = 2070.14, p

= .10. Critically, once again there was no effect for the presence (M = 331 ms) versus absence (M = 338 ms) of color alternation, F<1.

A between-experiment ANOVA confirmed that the singleton effect found in Experiment 1 (M = 42 ms) was significantly larger than the null effect of color alternation in Experiment 2B (M = -7 ms), F(1,14) = 7.35, MSE = 547.72, p = .017. Thus the present experiment replicates the results of Experiment 2A, suggesting that the singleton interference effects observed in Experiment 1 were due to the presence of a single unique item and cannot be explained in terms of lower-level contrast effects. Importantly, unlike in Experiment 2A, there was no systematic difference in RTs between Experiment 1 (M = 402 ms) and the present experiment (M = 334 ms), F(1,14) = 2.7, MSE = 26874.79, p = .12. (Note 2). In fact, the nonsignificant numerical trend is an overestimation, due to the inclusion of trials in which the singleton/alternation is present (as these trials elevated the RTs in Experiment 1, due to the singleton cost, but did not do so in Experiment 2B). Removal of these trials gives overall mean RTs of 384 ms for Experiment 1 and 338 ms for Experiment 2B, which are not significantly different from each other (t(14)=1.25, p = .23).

Errors. A two-way within-subjects error ANOVA with the factors of alternation condition and target type showed no main effect of alternation condition and no interaction between alternation condition and target type (F < 1 for both comparisons). There was a trend towards a main effect of target type (F(1, 7) = 4.20, MSE = 11.32, p = .08) suggesting, as in previous experiments, that participants made more errors when the target was small (M = 9.9%) than when it was large (M = 7.5%). Importantly, error rates in the present experiment (M = 8.7%) did not differ significantly from error rates in

Experiment 1 (M = 8.9%), indicating, in line with the RT results, that the shorter sequences used here did in fact reduce performance to a level comparable with that of Experiment 1.

Overall, Experiments 2A and 2B have shown that color alternation in the visual search sequences used here does not produce reliable interference. This suggests that the interference effect found in Experiment 1 is likely to have been due to the presence of a unique color singleton, rather than simply to lower-level factors associated with color contrast effects.

General Discussion

The present study provides the first demonstration of pure temporal attentional capture by singletons defined on a task-irrelevant dimension. This capture effect critically depended on the distractor being a singleton, and could not be attributed to color contrast effects (Experiment 2).

In all previous examinations of potential capture of attention in temporal search, performance costs were produced by singletons that either served as targets (producing an AB, e.g. Raymond, Shapiro & Arnell, 1992) or were presented in a different spatial position (e.g. Folk et al., 2002; Wee & Chua, 2004) or were defined on the target dimension (e.g. Chun, 1997; Folk, Leber and Egeth, 2001; Maki & Mebane, in press). The present results therefore provide the first demonstrations of pure temporal attentional capture by singletons defined on a task-irrelevant dimension. Moreover, capture effects here generalized to singletons in ‘unattended’ serial positions (where the target could never appear) and those positions should not have been attended voluntarily as singletons did not serve as valid cues for target position (occurring before targets on only 25% of the trials). Thus the present results are likely to reflect capture of attention, rather than voluntary attentional allocation towards the singleton.

Nevertheless it is possible that the capture we have found might be open to top-down influences. For example, subjects in the present experiments may have adopted a ‘singleton detection strategy’ (Bacon & Egeth, 1994), searching for any singleton item, meaning that both color (non-target) and size (target) singletons would have been prioritized. This possibility is currently under investigation in our lab.

Overall, although many previous studies have demonstrated that irrelevant singletons can capture visual attention if they appear as part of a spatial array, here we clearly establish such singleton capture of attention in the temporal domain. These results thus strengthen previous claims that the visual system is tuned to detecting items that are unique against the background stimulation yet irrelevant to an ongoing task.

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Footnote 1. An irrelevant singleton (an abruptly-onset shape in search for color targets) was presented in one of these experiments (Wee and Chua, 2004, Experiment 1). However this did not produce clear capture effects. By contrast, the effects of singletons that shared the target feature or were presented at a different spatial location from the rest of the stream were clear and reliable.

Footnote 2. We note that there is no difference (F = 1) in overall mean RT between Experiments 1 and 2B even when the analysis is restricted to the five-letter trials from Experiment 2B (which are directly comparable to those of Experiment 1; M from five-letter trials in Experiment 2B = 324 ms).

Table 1

Averages of participants' mean RTs in ms (RT) and mean error rates (%E), with standard errors (SE) for Experiment 1 as a function of singleton presence and target type

	Singleton presence						Interference	
	Absent (A)			Present (P)			(P-A)	
Target	RT	SE	%E	RT	SE	%E	RT	%
Large	**363**	30	7	**390**	37	8	**27**	1
Small	**404**	48	10	**462**	45	11	**58**	1

Table 2

Averages of participants' mean RTs in ms (RT) and mean error rates (%E), with standard errors (SE) for Experiments 2A and 2B as a function of alternation condition and target type

		Alternation condition						Interference	
		Absent (A)			Present (P)			(P-A)	
Experiment	Target	RT	SE	%E	RT	SE	%E	RT	%
2A	Large	**282**	27	3	**278**	29	1	**-4**	-2
	Small	**298**	28	2	**306**	41	2	**8**	0
2B	Large	**337**	49	8	**316**	42	7	**-21**	-1
	Small	**339**	49	11	**346**	47	9	**7**	-2