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Temporal attentional capture: Effects of irrelevant singletons on rapid serial visual search

POLLY DALTON
University of Oxford, Oxford, England

and

NILLI LAVIE
University College London, London, England

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, since 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 (vs. absence) of a color singleton lengthened response times on the size discrimination task, suggesting that irrelevant singletons can lead to a temporal attentional capture.

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 may, therefore, 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 toward stimuli in nontarget locations produces performance costs, as has been 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.

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A few recent studies have provided 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, since the singleton distractors in this study were spatially separated from the 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 msec of the first (e.g., Broadbent & Broadbent, 1987; Raymond, Shapiro, & Arnell, 1992). Thus, attentional allocation toward 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 the items were presented in a central RSVP stream. However, since participants respond primarily to the first target and only later to the second target, the AB is likely to involve both response- and memory-related effects (e.g., Jolicœur, 1998). Moreover, most of the AB research assesses the consequences of attending deliberately to target stimuli and, as such, does not provide information about the involuntary capture of attention.

Recent findings from the AB paradigm that an ignored first target or additional singleton (e.g., a colored box around a nontarget 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, 2006;

Wee & Chua, 2004). However, in all these studies, reliable performance costs were produced only by items that were defined on the same dimension as the targets (e.g., they were both color singletons; see also Ghorashi, Zuvic, Visser, & Di Lollo, 2003).[1] Therefore, these results 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 the targets were defined on a different dimension (e.g., intensity). However, whereas hearing tends to prioritize temporal information, vision operates more on spatial coordinates, 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

In this experiment, we asked whether an irrelevant color singleton would capture attention during an RSVP search task. The participants searched visual letter sequences for targets that were either larger or smaller than the rest of the letters. On 50% of the 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

The participants in all the experiments were paid students (18–35 years of age). All reported normal or corrected-to-normal vision. Eight participants took part in this experiment.

Stimuli and Procedure

The experiments were created and run on a PC using E-Prime (Psychology Software Tools, Pittsburgh). Each sequence started with a black fixation cross presented at the center of the screen for 500 msec, followed by a 50-msec 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 msec, followed by a 70-msec blank screen. At a viewing distance of 60 cm, nontargets and singletons subtended a visual angle of 1.4º × 1.4º, large targets subtended 1.7º × 1.7º, and small targets subtended 1.1º × 1.1º. The participants were requested to respond with a keypress: 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 the words *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 3,000 msec if no response had been 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 the trials, directly before or after the target with equal probability. All the letters were presented against a white background. The nontargets and targets were black for half the participants (red for the other half), and the singletons were red for these participants (black for the other half). The participants were asked to focus on letter size and to 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

A preliminary analysis of all three experiments indicated that the between-subjects factor of target color (red vs. black) did not interact with the factor of singleton presence (vs. absence) ($p > .30$ for all comparisons). All the data are thus pooled across target color. In all the experiments, incorrect responses were excluded from the response time (RT) analysis, as were RTs longer than 1,500 msec. 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).

Response Times

A two-way within-subjects ANOVA using these factors revealed a significant main effect of singleton presence [$F(1,7) = 7.40$, $MS_e = 14{,}573.09$, $p < .05$]. Target RTs were longer on singleton-present trials ($M = 426$ msec) than on singleton-absent trials ($M = 384$ msec), 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 ($M = 377$ msec) than when it was small ($M = 433$ msec) [$F(1,7) = 7.64$, $MS_e = 25{,}254.60$, $p < .05$]. This is in line with previous research demonstrating an advantage for large targets among small nontargets, in comparison 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 [$F(1,7) = 1.98$, $MS_e = 1{,}979.31$, $p = .20$].

Table 1
Averages of Participants' Mean Response Times (RTs, in Milliseconds, With Standard Errors) and Mean Error Rates (%E) for Experiment 1 as a Function of Singleton Presence and Target Type

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

A further one-way within-subjects ANOVA on the data from singleton-present trials revealed a significant effect of singleton position (before vs. after the target), so that responses were slower when the singleton occurred before (M = 449 msec) versus after (M = 400 msec) the target [$F(1,7) = 9.01$, $MS_e = 9{,}381.38$, $p < .05$]. Indeed, RTs when the singleton occurred after the target were not significantly different from RTs when the singleton was absent [M = 383 msec; $t(7) = 1.14$, $p = .29$]. Thus, the appearance of a singleton before the target was more damaging to target processing than was 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 finding of a significant capture effect by singletons at Position 2 [M effect = 56 msec; $t(7) = 2.44$, $p < .05$] that was not significantly different ($F < 1$) from the effects of singletons at the potential Target Position 3 [M effect = 78 msec; $t(7) = 2.32$, $p = .05$] 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 trends similar to those for the RTs (see Table 1).

A further one-way within-subjects 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 (M = 8%) the target [$F(1,7) = 4.94$, $MS_e = 36.00$, $p = .062$]. Error rates in the latter condition were very similar to error rates when the singleton was absent (M = 8.5%). Thus, as for the RTs, the singleton appeared to cause more interference when it appeared before, rather than after, the target.

In conclusion, the present experiment showed 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 have been due to attentional capture by the irrelevant color singleton. However, since 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, so 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.

The participants in Experiments 2A and 2B carried out the size discrimination task used in Experiment 1. As in Experiment 1, all the stimuli were in the same color on 50% of the trials; but unlike in Experiment 1, the stimuli alternated between the target color and a distractor color on the remaining 50% of the 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 were due to contrast effects, they should therefore persist in the alternation condition. By contrast, if the interference effects were 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 8 in Experiment 2B.

Stimuli and Procedure

The equipment and stimuli were the same as those described in Experiment 1. Targets and nontargets were black for half the participants (red for the other half), and the 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 the 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, the sequences consisted of either six or seven letters, with equal probability, in Experiment 2A. Similarly, the sequences in Experiment 2B consisted of either four or five letters, with equal probability. The 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 Experiments 2A and 2B as a function of alternation condition (alternation absent vs. present) and target type (large vs. small).

Experiment 2A

RTs. A two-way within-subjects ANOVA using these factors showed no significant main effects or interactions ($p > .20$ for all comparisons). It is especially impor-

Table 2
Averages of Participants' Mean Response Times (RTs, in Milliseconds, With Standard Errors) and Mean Error Rates (%E) for Experiments 2A and 2B as a Function of Alternation Condition and Target Type

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

tant that there was no main effect of the presence (M = 290 msec) versus absence (M = 292 msec) of the color alternation ($F < 1$).

A between-experiment ANOVA confirmed that the singleton effect in Experiment 1 (M = 42 msec) was significantly larger than the null color alternation effect in Experiment 2A (M = −2 msec) [$F(1,14) = 5.17$, MS_e = 3,211.61, $p = .039$]. Thus, the singleton interference effect in Experiment 1 cannot be explained in terms of simple color contrast effects.

The between-experiment ANOVA also found a significant main effect of experiment, so that RTs were shorter in the present experiment (M = 286 msec) than in Experiment 1 (M = 402 msec) [$F(1,14) = 10.12$, $p < .01$]. 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 the participants to prepare more effectively for the subsequent target presentation, leading to shorter target RTs. For this reason, Experiment 2B used shorter sequences, with the aim of reducing performance to a level comparable to that in Experiment 1.

Errors. A two-way within-subjects 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 [$F(1,7) = 3.38$, MS_e = 9.03, $p = .11$]. Note that any trend toward a higher error rate for large targets in the absence (vs. presence) of the alternation (see Table 2) is in the direction opposite to that of 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 the previous experiments, there was a trend for faster responses to large targets than to small targets [$F(1,7) = 3.61$, MS_e = 2,070.14, $p = .10$]. Critically, once again, there was no effect for the presence (M = 331 msec) versus absence (M = 338 msec) of color alternation ($F < 1$).

A between-experiment ANOVA confirmed that the singleton effect found in Experiment 1 (M = 42 msec) was significantly larger than the null effect of color alternation in Experiment 2B (M = −7 msec) [$F(1,14)$ = 7.35, MS_e = 547.72, $p = .017$]. Thus, the present experiment replicated 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 msec) and the present experiment (M = 334 msec) [$F(1,14) = 2.7$, MS_e = 26,874.79, $p = .12$].[2] In fact, the nonsignificant numerical trend is an overestimation, due to the inclusion of trials in which the singleton/alternation is present (since 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 msec for Experiment 1 and 338 msec 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 toward a main effect of target type [$F(1,7) = 4.20$, MS_e = 11.32, $p = .08$], suggesting, as in the previous experiments, that the 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 to that in 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's 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 served as targets (producing an AB; e.g., Raymond et al., 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 et al., 2001; Maki & Mebane, 2006). 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, since 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 toward the singleton.

Nevertheless it is possible that the capture we have found might be open to top-down influences. For example, the participants in the present experiments may have adopted a *singleton detection strategy* (Bacon & Egeth, 1994), searching for any singleton item, meaning that both color (nontarget) 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 have clearly established 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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NOTES

1. An irrelevant singleton (an abruptly onset shape in search for color targets) was presented in one of these experiments (Wee & 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.

2. We note that there was no difference ($F = 1$) in overall mean RTs 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 in Experiment 1; M from five-letter trials in Experiment 2B = 324 msec).

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