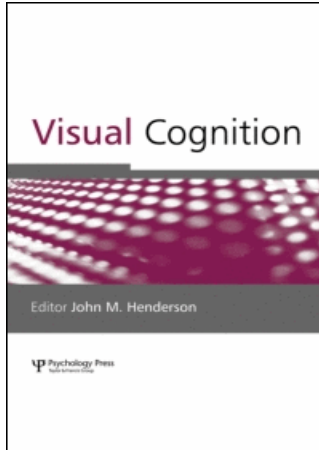


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Unique temporal change does not account for attentional capture by sudden onsets

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Unique temporal change does not account for attentional capture by sudden onsets

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There is a considerable debate about which stimulus characteristics are able to capture attention in a purely exogenous way. Von Mühlenen, Rempel, and Enns (2005) proposed that unique temporal change accounts for much attentional capture phenomena. Here we reexamine this account by differentiating between the reaction time costs and benefits caused by salient singletons appearing at different times relative to the target display. Specifically we postulate that benefits are indicative of attentional capture, whereas costs only indicate interference by heterogenous distractors, suggesting that the deployment of attention has been merely slowed rather than captured. We find that unique temporal change only increases search costs, and does not affect reaction time benefits. In addition, manipulations of top-down search set provide converging evidence that unique temporal change is not sufficient to cause features to capture attention in the same bottom-up manner as sudden onsets.

Attentional capture occurs when highly salient stimuli, which are irrelevant to our current task, draw our attention to them. Much research has focused on which specific features of stimuli capture attention most effectively (see Ruz & Lupianez, 2002, for a review). In general it has been found that suddenly appearing stimuli, or sudden onsets, capture attention in almost all situations, whereas colour changes or static colour or luminance singletons tend to be given less priority. One reason offered for the arguably unique ability of sudden onsets to capture attention is that they represent new visual objects, and some aspect of the process which may involve the creation of the new object file may provide an attentional interrupt (Yantis & Hillstrom, 1994).

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Despite the elegance of this explanation, it has been suggested that it could simply be the magnitude of spatial change which affords sudden onsets their unique ability to capture attention. For example, a stimulus that suddenly appears with the target array is also a large luminance change (Enns, Austen, Di Lollo, Rauschenberger, & Yantis, 2001), an unmasked feature (Gibson, 1996), and even a signal for subjects that the target array has appeared (Bacon & Egeth, 1994). Also, it has recently been demonstrated that if the sudden appearance of new objects is masked, they no longer capture attention (Franconeri, Hollingworth, & Simons, 2005).

However, von Mühlenen, Rempel, and Enns (2005) have recently suggested that it is not the magnitude of the spatial change per se, but its temporal uniqueness that causes attentional capture. They reason that static colour signals are processed by the slower parvocellular system, whereas sudden onsets are processed by the faster magnocellular system. This account explains why sudden onsets are apparently unique in capturing attention, and also leads to the specific prediction that other features should capture attention in a similar manner if they change at a time of temporal calm.

Von Mühlenen et al.'s (2005) experiments involved presenting colour changes, motion changes, and sudden onsets, either at the same time as target displays, or 150 ms before or after. The strongest capture was found when the features occurred 150 ms before the target displays, with more modest capture when features occurred 150 ms after. These findings suggest that the time at which a feature occurs may be more important than the nature of the feature itself, in contrast to a literature dominated by the investigation of feature types, specifically sudden onsets.

It is worth emphasizing that von Mühlenen et al. (2005) inferred capture when the search slopes were relatively flatter when targets were associated with the salient singletons, compared with the search slopes when singletons were associated with distractors. In other words, the "target" and "distractor" slopes were combined to form a "slope ratio" from which inferences were drawn. For example target and distractor singleton slope ratios differed little from 1:1 when singletons appeared at the same time as targets, and this means that the effect of increasing numbers of items in the search array was equivalent for both conditions, which suggests a serial search for both, and therefore no capture. In contrast, the target and distractor singleton search slope ratios for singletons appearing out of sync with the rest of the target array were generally greater than 2:1. Thus, search slopes for targets were considerably flatter when targets just happened to be associated with unique temporal change, than when distractors happened to change in a unique manner. This key finding has been taken to imply attentional capture by temporal uniqueness. However, two observations about this data invite caution. The first is that, by using this method, von

Mühlenen et al. were not able to find evidence of attentional capture by sudden onsets appearing at the same time as target arrays, a puzzling finding, considering that attentional capture by sudden onsets remains the primary and most robust finding in the field (Yantis & Jonides, 1984). The second aspect of the search slope ratio method that invites caution is its sole reliance on trials in which the singleton is associated with the target and trials in which the singleton is associated with a distractor. Critically, this means that search slope ratios can rise not just because a singleton is speeding search when associated with a target and genuinely capturing attention, but also if a singleton is slowing performance when associated with a distractor, even if it is not able to draw attention to itself. In this latter case, perhaps the singleton is making the search harder by creating a heterogeneous display, or causing some other form of nonspecific distraction that is interesting, but not attentional capture.

Although in von Mühlenen et al.'s (2005) search slopes were flatter in an absolute sense when capture was inferred, we are not convinced of the robustness of the search slope ratio method for inferring capture, and in the current research we develop a different method to index the role of unique temporal change. More specifically, we attempt to remove any ambiguity by inferring capture using a no-singleton baseline condition instead of slope ratios. Our "baseline" trials contain the same number of search elements as experimental trials but they are homogenous and contain no sudden onsets or colour singletons. The time it takes subjects to find targets on baseline trials can then be compared to their reaction times when the target displays of trials contain either a target singleton or distractor singleton. If a singleton is truly capturing attention it should lead to reaction times faster than baseline when associated with a target. However if the singleton is only slowing search when associated with a distractor, this seems to suggest a "filtering cost" (see Kahneman, Treisman, & Burkell, 1983), or simply the slowing of search caused by the heterogeneity of the display (Duncan & Humphreys, 1989). Importantly, a filtering cost does not involve any allocation of spatial attention, and can be thought of as nonspecific slowing caused by the complexity of the display. The difference is perhaps best illustrated by an analogy: If attentional capture occurs when a loud car horn to our left causes us to direct our gaze in that direction, a filtering cost occurs when a softer noise such as background talk-back radio hinders our performance on our main task, even when we never turn our attention to the radio. Thus, the introduction of a no-singleton baseline condition should allow us to determine whether factors like unique temporal change are actually decreasing the time taken to find singleton targets, and thus contributing to attentional capture, or merely slowing reaction times when singletons are associated with distractors.

In addition, we attempt to further establish genuine attentional capture by investigating its resistance to top-down control. Arguably, the notion of attentional capture is not simply one of priority or efficiency of search, as it also implies that the stimulus attracts attention to itself against the will of the observer. Previous research has clearly demonstrated the resistance of attentional capture by sudden onsets to top-down control, indeed, even making sudden onsets entirely task irrelevant may not eliminate their effects (Remington, Johnston, & Yantis, 1992). In the rare cases that top-down control has been effective in eliminating attentional capture by sudden onsets it has necessarily involved a reallocation of spatial attention, as opposed to a change in relevance or task set (Theeuwes, 1991; Yantis & Jonides, 1990). In contrast, attentional capture by task-irrelevant colour singletons has rarely been demonstrated to be so robust, with researchers frequently unable to find detect any influence (e.g., Gibson & Jiang, 1998; Jonides & Yantis, 1988; but see Theeuwes, 1992). We suspect that the weaker form of capture caused by colour singletons is more easily suppressed. However if unique temporal change plays an important role in attentional capture in all kinds of singleton, then it should not only increase the priority afforded to singletons, but also increase the resistance of the capturing process to top-down control.

We manipulated subjects' task sets to establish either a neutral task set in regard to singletons, or a task set to ignore singletons. This was achieved by manipulating the relevance of the singletons in two experimental conditions. In the "randomly relevant" condition, the location of both kinds of singleton were unrelated to the location of the targets. Specifically, both sudden-onset and colour-change singletons were associated with targets on only $1/n$ trials, when " n " is set-size. In this situation subjects had no reason to either attend to or ignore sudden onsets and colour changes. However, in the "rarely relevant" condition we introduce a stronger top-down task set by reducing the relevance of the singletons even further. In only around 4% of trials (two per block; $1/4n$, where n is set size) were singletons associated with the location of targets, and this effectively encouraged subjects to ignore the sudden onsets and colour changes outright. Subjects were explicitly told about these likelihoods and were instructed to ignore the unique singletons in order to maximize performance.

The temporal uniqueness of both sudden onsets and colour changes was manipulated by presenting sudden onsets and colour changes either 150 ms or 60 ms before target arrays, or at the same time as target arrays. While colour singletons of various forms have been shown to capture attention (e.g., Theeuwes, 1992; Turatto & Galfano, 2001), their ability to do so has rarely been demonstrated to be on par with that of sudden onsets

(e.g., Jonides & Yantis, 1988). However, if unique temporal change is the key feature leading to capture, then when colour changes¹ are presented 150 ms and 60 ms before the target arrays they should behave in much the same way as sudden-onsets and capture attention. Sudden-onsets however should capture attention at all times, but if unique temporal change plays a key role then perhaps this capture will be amplified when the sudden-onsets appear 60 ms and 150 ms before the target arrays.

Our innovative methods of establishing costs and benefits associated with these phenomena should allow us to corroborate our findings with those of von Mühlenen et al. (2005). If a form of singleton or manipulation of temporal uniqueness results actually in a processing benefit, a decrease the amount of time a target should be found relative to baseline, and attentional capture by unique temporal change can be inferred. On the other hand, if unique temporal change simply slows search when singletons are associated with distractors, then we will have only found evidence for some kind of nonspecific distraction or “filtering-cost”. It is important to understand that obtaining costs only and not benefits cannot simply indicate “erroneous capture” by distractors and not targets, since the items’ status as targets or distractors could not affect capture, simply because they would not be identified as such before attention is allocated.

In addition, if unique temporal change is contributing in a “bottom-up” manner, we expect that the temporal uniqueness of singletons should increase their resistance to top-down control. Specifically it should make both sudden onsets and colour changes harder to ignore when subjects are attempting to do so.

METHOD

Subjects

Fifty-nine undergraduate Psychology students participated in return for course credit. There were 20 males and 39 females, aged between 19 and 21.

Apparatus and stimuli

Search arrays consisted of black and red letters on a white background. Colour change stimuli were red. The X and Y CIE chromaticity coordinates for this red were .574 and .349. The black used had a mean luminance of 0.7 cd/m², the red 18.6 cd/m², and the white 88.0 cd/m². This does mean that

¹ The colour changes we implemented were accompanied by a slight luminance change, but since all stimuli were presented on a bright white background, we doubt the significance of this.

the “colour changes” were also luminance changes (a slight increment) but we doubt that this was consequential, considering that such a slight change between two low luminances occurred on the bright white background. Individual targets were 1.5 cm high and 0.9 cm wide on a screen approximately 65 cm away from the subjects’ eyes. Each individual target thus subtended a visual angle of 1.32×0.79 degrees. The display as a whole was $6 \text{ cm} \times 5.2 \text{ cm}$ resulting in a visual angle of 5.29×4.58 degrees. The display apparatus used was a 19-inch Trinitron monitor running with a refresh rate of 144 Hz at a resolution of 800×600 .

Design

The experiment was a 2 (top-down condition, $1/n$ vs. $1/4n$) $\times 2$ (type of capture, sudden onset vs. colour change) $\times 3$ (temporal uniqueness, -150 , -60 , 0) $\times 3$ (singleton target, baseline, singleton distractor). The top-down manipulation was made between subjects to prevent confusion, and the possible interference of task sets across blocks. Thirty-one subjects were allocated to the “random association” condition, where both sudden onsets and colour changes were associated with the target on only $1/n$ trials (where n is set size). In this condition subjects were explicitly told of this relationship, and were expected to maintain a neutral task set. The other 28 subjects were allocated to the “rare association” condition where both sudden onsets and colour changes were associated with the target on only two trials per block (approximately $1/4n$ trials, where n is set size). In this condition subjects were explicitly told of this relationship, and were both instructed and expected to actively ignore the sudden onsets and colour changes.

All other factors were manipulated within subjects. There were three types of block: Baseline blocks, colour-change blocks, and sudden-onset blocks.

Baseline blocks. Consisted of baselines appropriate to both sudden-onset and colour-change conditions. The baseline for colour-change trials consisted of six black placeholders followed by six black letters. The sudden-onset baseline consisted of seven black placeholders followed by seven black letters. Importantly, SOA was built into the baseline trials, so that even though no unique temporal changes occurred, the time between the presentation of the placeholders and the occurrence of the target arrays concurred with the SOA manipulations of the other conditions, resulting in baselines relevant to each. For example, a baseline to be compared with a trial where a unique temporal change occurred 60 ms before the target array, would have the presentation of placeholders lengthened by 60 ms. It is doubtful subjects even noticed this, and the baseline measures that resulted

varied little anyway, but it guaranteed a precise equivalency between the conditions.

Colour-change blocks. As shown in Figure 1, the colour-change trials consisted of six black placeholders followed by five black letters and one red letter. There could be “target-singleton” trials where the “E” or “H” target was red, or “target-distractor” trials where another letter was red, and the probability of each was determined by the top-down condition subjects were placed in (see previous section). Within each block, the occurrence of this red feature was randomized to occur either at the same time as the target display (SOA 0 ms) or 60 ms or 150 ms before.

Sudden-onset blocks. Also shown in Figure 1, the sudden-onset condition consisted of six black placeholders followed by seven letters, one of them being sudden onset. There could be “target-singleton” trials where the “E” or “H” target was the actual sudden onset, or “target-distractor” trials where another letter was the sudden onset, and the probability of each was determined by the top-down condition subjects were placed in (see previous section). Within each block, the occurrence of the sudden onset was randomized to occur either at the same time as the target display (SOA 0 ms) or 60 ms or 150 ms before.

Each subject was run in two baseline blocks, three colour-change blocks, and three sudden-onset blocks. Block order was counterbalanced by being presented in a random order for each subject. There were 72 trials per colour-change and baseline block, and 84 trials per sudden-onset block, making 612 trials in total.

Procedure

Subjects were told that the sudden-onset or colour-change stimulus was randomly associated with the target they were looking for, and so they could not use such features to help them perform the task. The task involved a visual search for the letters E and H, and subjects indicated which one was present with a keypress. One of the two targets was always present. Subjects were instructed to be as fast and as accurate as possible with an emphasis on accuracy.

Each trial consisted of the presentation of a fixation cross for 150 ms, followed by six or seven placeholders for 1000 ms, then the presentation of an additional placeholder, a red placeholder, or a continuation of the placeholders display for an additional 0, 60, or 150 ms. The search array then immediately appeared, and remained until the subject responded by a keypress to indicate that either “E” or “H” was present. Correct responses

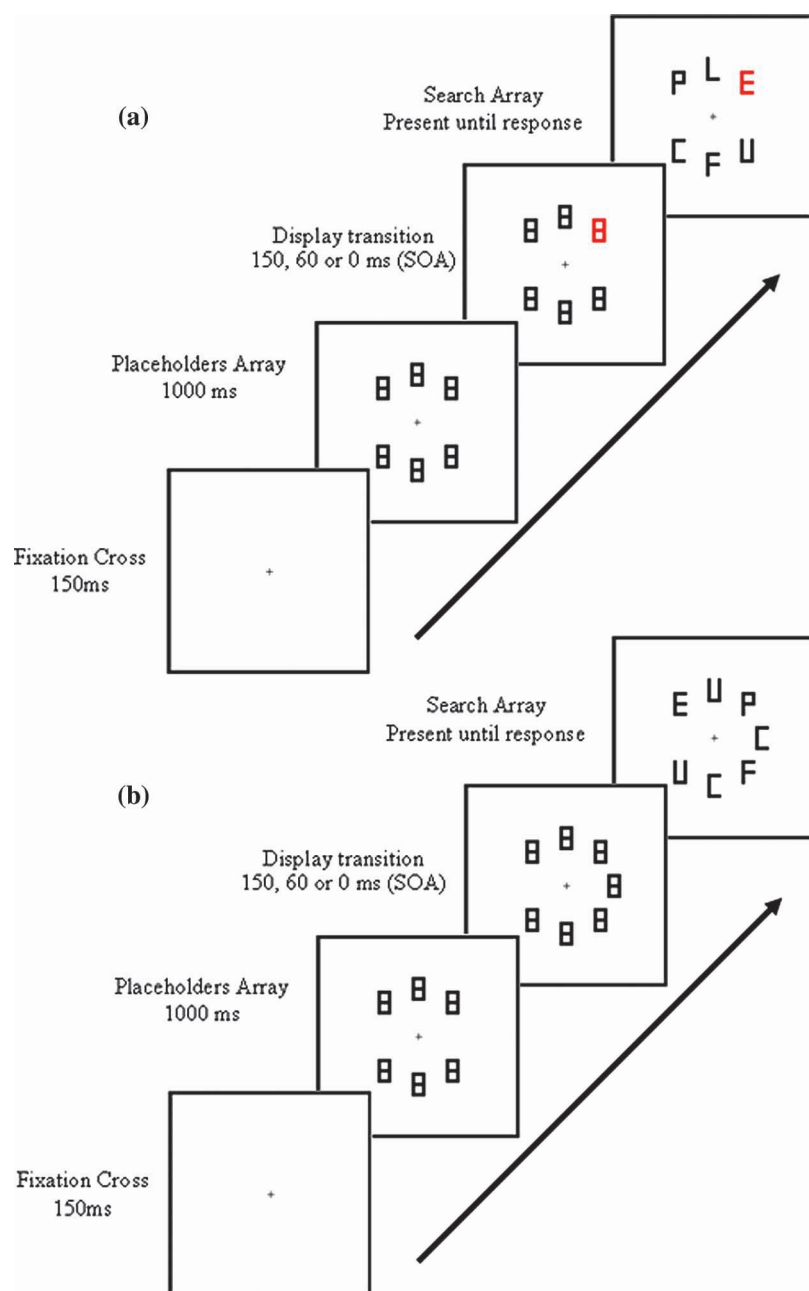


Figure 1. Sequence of frames for the (a) colour-change and (b) sudden-onset conditions. The two grey items in the top display were coloured red. To view this figure in colour, please see the online issue of the Journal.

resulted in a beep (100 ms) and incorrect responses resulted in a buzz (100 ms). A 600 ms pause then followed between trials. See Figure 1 for a representation of the trial sequence.

Before analysis, reaction times from incorrect responses ($< 5\%$ of trials), and reaction times shorter than 300 ms or longer than 1500 ms were removed ($< 2\%$ of trials).

RESULTS

Error rates and reaction times were initially analysed with single large ANOVAs containing all the factors. Reaction times were then analysed with separate ANOVAs for each condition.

Overall error-rate analysis

Errors for every subject made up less than 5% of all trials in all conditions. An overall ANOVA analysis of all error rates in all conditions revealed no significant differences. Importantly there was no difference in the number of errors in sudden-onset vs. colour-change trials, $p = .977$, $F(1, 57) = 0.001$, $MSE = 0.019$, no difference in the number of errors made across the SOA conditions, $p = .277$, $F(1, 57) = 1.206$, $MSE = 5.607$, and no difference in the number of errors made in the baseline, singleton-target, and singleton-distractor trials, $p = .410$, $F(1, 57) = 0.688$, $MSE = 25$. Given the small number of errors and the lack of significant findings, there was no evidence of a speed–accuracy tradeoff for any of the reaction time effects.

Overall reaction time analysis

Overall, colour-change trials were responded to faster than sudden-onset trials, $p < .000$, $F(1, 57) = 33.571$, $MSE = 165257$, not surprising considering target displays on colour change trials consisted of one fewer item compared to sudden onset trials. Also, reaction time costs (distractor-singleton trials vs. baseline) were significant overall, $p < .000$, $F(1, 57) = 50.686$, $MSE = 219528$, and interacted with top-down condition (neutral or set to ignore), such that costs were greater in the neutral condition, $p = .001$, $F(1, 57) = 11.723$, $MSE = 50773$. Reaction time benefits were not significant overall, $p = .320$, $F(1, 57) = 1.005$, $MSE = 18809$, but did interact with top-down condition, such that benefits were greater in the neutral conditions, $p = .006$, $F(1, 57) = 8.246$, $MSE = 154297$. Reaction time benefits were also significantly greater for sudden onsets overall, $p = .000$, $F(1, 57) = 16.222$, $MSE = 626059$, when compared to colour-change benefits, and

were also significantly reduced by top-down control, $p = .017$, $F(1, 57) = 6.099$, $MSE = 235356$. In contrast, reaction time costs did not differ between types of capture (sudden onset vs. colour change), $p = .882$, $F(1, 57) = 0.022$, $MSE = 220$, nor were these costs affected by top-down control, $p = .892$, $F(1, 57) = 0.018$, $MSE = 180$.

There was no overall effect of SOA (unique temporal change), nor did this factor interact with top-down condition or type of capture (all $ps > .05$). SOA (in a linear fashion: 0 ms vs. 150 ms) only interacted significantly overall with reaction time costs, $p < .000$, $F(1, 57) = 34.635$, $MSE = 75025$, and not with benefits, $p = .241$, $F(1, 57) = 1.405$, $MSE = 14705$.

With all the factors grouped together, few interaction contrasts showed significant differences. It was found that the type of capture (colour changes vs. sudden onsets) interacted with the level of reaction time benefit (singleton target vs. baseline), such that sudden-onset targets produced significantly greater benefits overall than colour-change targets, $p < .000$, $F(1, 57) = 16.222$, $MSE = 626059$. No other contrasts reached significance (all $ps > .05$). After the overall reaction time analysis, four follow-up ANOVAs were conducted for each condition to describe the more specific findings.

Neutral task set

Reaction times in sudden-onset and colour-change conditions were analysed with two separate ANOVAs. Figure 2 shows the average reaction times for the two types of capture assessed in the three SOA conditions.

Sudden onsets. Overall, sudden-onset targets were found significantly faster than baseline, $p = .007$, $F(1, 30) = 8.284$, $MSE = 87997$, and sudden-onset distractors slowed target search relative to baseline, $p < .000$, $F(1, 30) = 37.256$, $MSE = 254142$. There was no overall effect of SOA on performance in the sudden-onset conditions, linear: $p = .442$, $F(1, 30) = 0.607$, $MSE = 554$; quadratic: $p = .622$, $F(1, 30) = 0.248$, $MSE = 308$, and SOA only interacted with costs caused by sudden-onset distractors, such that costs rose with increasing SOA (see Figure 2), $p = .002$, $F(1, 30) = 11.834$, $MSE = 38402$.

Colour changes. Overall, colour-change targets were not found significantly faster than baseline, $p = .471$, $F(1, 30) = 0.532$, $MSE = 5546$, but colour-change distractors slowed target search relative to baseline, $p < .000$, $F(1, 30) = 38.21$, $MSE = 253104$. There was no overall linear effect of SOA on performance in the colour-change conditions, $p = .121$, $F(1, 30) = 2.547$, $MSE = 2011$, but there was a significant quadratic effect such that performance was slightly slower in the 0 and 150 ms SOA conditions

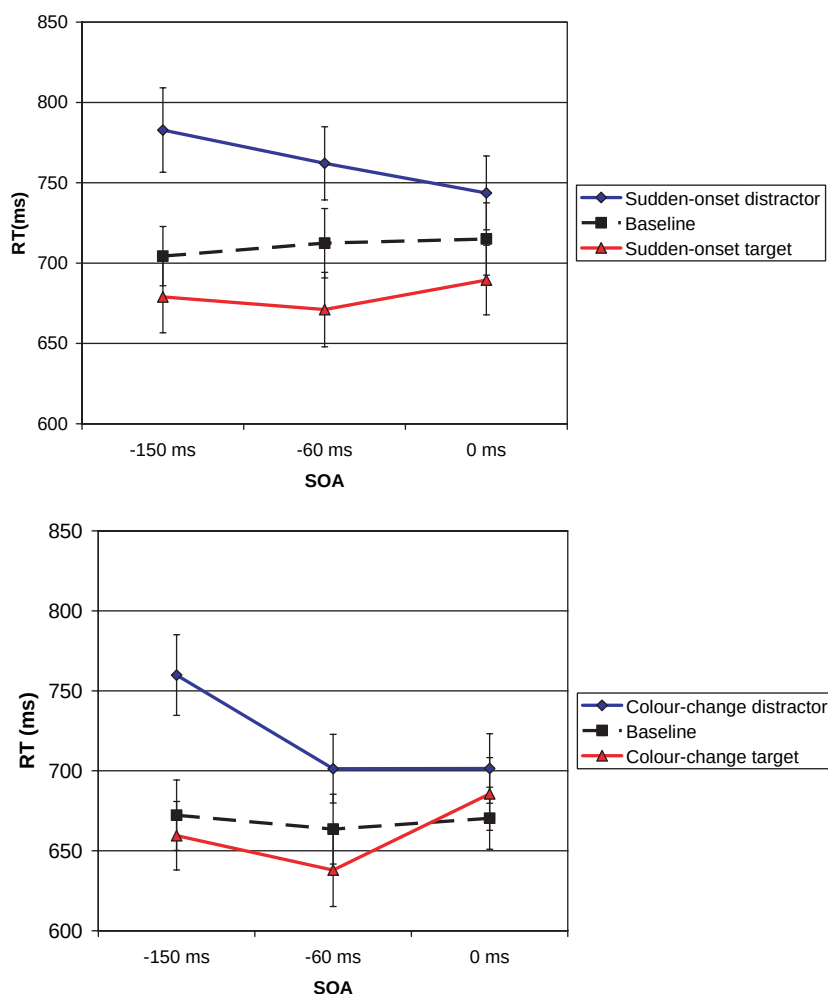


Figure 2. Reaction time results for the sudden-onset and colour-change conditions where the singletons were occasionally associated with targets ($1/n$ trials) and subjects were encouraged to maintain a neutral task set in regard to these features. SOA refers to the time prior to the target display the singletons appeared. Error bars are standard error estimates. To view this figure in colour, please see the online issue of the Journal.

when compared to the 60 ms condition (see Figure 2), $p = .005$, $F(1, 30) = 9.408$, $MSE = 11820$. SOA also interacted with the costs caused by colour-change distractors, $p = .001$, $F(1, 30) = 13.351$, $MSE = 49455$, such that costs rose with increasing SOA (see Figure 2). While a slight trend appears to show that benefits similarly rose with rising SOA, this effect missed out on significance, $p = .081$, $F(1, 30) = 3.268$, $MSE = 12174$. Quadratic trends

for costs, $p = .139$, $F(1, 30) = 2.309$, $MSE = 9607$, and benefits, $p = .09$, $F(1, 30) = 3.077$, $MSE = 14834$, also missed significance.

Task set to ignore singletons

Reaction times in sudden-onset and colour-change conditions were analysed with two separate ANOVAs. Figure 3 shows the average reaction times for the two types of capture assessed in the three SOA conditions.

Sudden onsets. Overall, sudden-onset targets were not found significantly faster than baseline, $p = .695$, $F(1, 27) = 0.157$, $MSE = 5574$; however, sudden-onset distractors slowed target search relative to baseline, $p = .036$, $F(1, 27) = 4.899$, $MSE = 31507$. There was no overall effect of SOA on performance in the sudden-onset conditions, linear: $p = .377$, $F(1, 27) = 0.805$, $MSE = 3204$; quadratic: $p = .707$, $F(1, 27) = 0.145$, $MSE = 396$, and SOA only interacted with costs caused by sudden-onset distractors, such that costs rose with increasing SOA (see Figure 3), $p = .008$, $F(1, 27) = 8.096$, $MSE = 30944$.

Colour changes. Overall, colour-change targets were found significantly slower than baseline, $p = .003$, $F(1, 27) = 10.667$, $MSE = 649264$, and while colour-change distractors also appeared to slow target search relative to baseline, this was not significant, $p = .075$, $F(1, 27) = 3.434$, $MSE = 24971$. There was no overall effect of SOA on performance in the colour-change conditions, linear: $p = .121$, $F(1, 27) = 2.547$, $MSE = 2011$; quadratic: $p = 0.418$, $F = 0.677$, $MSE = 4376$. SOA also interacted with the costs caused by colour-change distractors, $p = .013$, $F(1, 27) = 7.01$, $MSE = 33216$, such that costs rose with increasing SOA (see Figure 3). While a slight trend also appears to show that benefits fell with rising SOA, this did not approach significance, $p = .420$, $F(1, 27) = 0.670$, $MSE = 25287$. Quadratic trends for costs, $p = .399$, $F(1, 27) = 0.734$, $MSE = 2341$, and benefits, $p = .799$, $F(1, 27) = 0.066$, $MSE = 2341$, also missed significance.

DISCUSSION

In our approach we employed baseline trials which involved the same search for a specific target, but contained no singletons of any kind. By using the baseline reaction time, we could precisely determine whether the presence of the singleton had actually sped up search time when associated with a target, and therefore seemingly captured attention, or simply slowed search time when associated with a distractor, which could reflect some other form of distraction that did not involve the reallocation of attention.

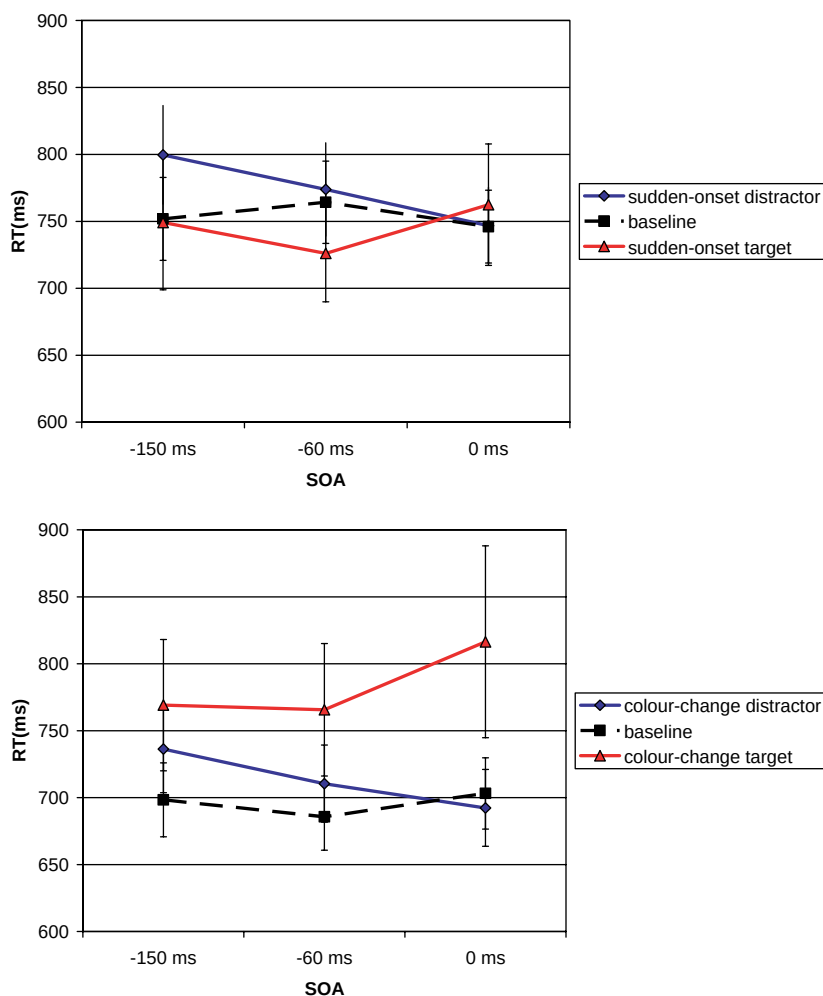


Figure 3. Reaction time results for the sudden-onset and colour-change conditions where the singletons were very rarely associated with targets ($1/4n$ trials) and subjects were encouraged to actively ignore these features. SOA refers to the time prior to the target display the singletons appeared. Error bars are standard error estimates. To view this figure in colour, please see the online issue of the Journal.

Our results provide compelling and coherent evidence against the claim that unique temporal change is critical to the mechanisms of bottom-up attentional capture. We found that the manipulation of temporal uniqueness increases the time required for both sudden-onset and colour-change distractors to be filtered out. However, since no effect on the time to find singleton targets in relation to baseline was found, it seems that unique

temporal change does not contribute to the ability of singletons to capture attention. This conclusion is in contrast to von Mühlenen et al.'s (2005), claim that unique temporal change plays a key role in attentional capture.

When our task encouraged subjects to maintain a neutral task set, attentional capture by task-irrelevant sudden onsets was found, as shown by the faster response times to targets which just happened to be sudden onsets. However, while colour-change distractors caused significant costs, the occurrence of a colour-change target did not speed performance. Certainly colour changes seem to have attracted attention more when they occurred either 60 or 150 ms before the target array, but unique temporal change seems only to have increased costs and not benefits. This could be taken as evidence that unique temporal change is making singletons harder to ignore when they occur as distractors, but is not making them more likely to capture attention when they are targets. This pattern of performance is the same for sudden onsets: Clearly the earlier, more "temporally unique" appearance of sudden onsets is increasing costs, but benefits are unaffected. This means that the more temporally unique the singletons are, the longer they take to filter out when associated with distractors, but temporally unique targets do not capture attention any more effectively. Therefore, we have consistently found that increasing temporal change in distractors slows reaction times, but increasing temporal change in targets does not draw attention to the targets any faster. Thus while the effects caused by unique change are certainly reliable, they appear to be merely increasing some kind of nonspecific distraction, and not playing a role in the effectiveness of a singleton to capture attention.

Results from the condition where subjects were strongly encouraged to ignore the singletons provide an even more compelling distinction between attentional capture effects and nonspecific filtering effects. When subjects were encouraged to ignore the singletons, attentional capture by both sudden onsets and colour changes was not found, as indicated by the lack of processing benefits on target-singleton trials. Although this failure to find capture may have been because of this reduced number of target-singleton trials in this condition, an influence of temporal change was still evident for singleton-distractor trials. Unique temporal changes appear to have led to slight increases in the costs caused by both sudden onsets and colour changes, with increasing SOA. Because these same trends have been observed in both attentional conditions, temporal uniqueness seems to be influencing attentional deployment in a bottom-up manner. However, this is not the same as to claim that unique temporal change is increasing attentional capture and its expected processing benefits.

In other words, unique temporal change only increased costs and not benefits; specifically, when singletons changed prior to the appearance of the target display, search was slowed when these singletons were associated with

distractors, but not made any faster when these singletons were associated with targets. Certainly the substantial costs caused by colour singletons, and the slight modulation of those costs by unique temporal change should be of further interest, and may later be implicated as a phenomenon likely to be associated with the actual reallocation of attention. These effects may be what Folk and Remington (1998) also described as a filtering cost when they referred to “two forms of attentional capture”, or what Todd and Kramer (1994) referred to as attentional “misguidance”, specifically in regard to colour singletons. In a similar manner, we consider that our current evidence implies that temporal change is not increasing the ability of stimuli to capture attention, and cause actual reallocation, but instead uniquely changing stimuli become harder to ignore, or “filter out”.

This is not the conclusion of von Mühlenen et al. (2005), who used search slope ratios to infer a special role for temporal change. Theoretically, there should be no conflict between the search slope and baseline control method, since a flat search slope, and a reaction time benefit, should both indicate that a salient singleton is being seen first. Realistically though, this will always be an issue of degree, since search slopes, including those obtained by von Mühlenen et al., are rarely completely flat, and the reaction time benefits we choose to infer capture from can only suggest that salient singletons are being detected faster than other items. Some time ago, Wolfe (1998) critically argued against relying on absolute search slope values to infer parallel-serial search dichotomies.

We are also able to sidestep this ambiguity in our current study by considering that stimuli which cause attentional capture should not just affect performance per se, but do this in an unavoidable, automatic manner. In one of our experimental conditions, we encouraged subjects to ignore potentially distracting singletons outright. Given the minute number of target singleton trials in these conditions, we hesitate to conclude that both kinds of capture were convincingly eliminated, but capture was not found as determined by reaction time benefits, and most importantly any benefits did not interact with the asynchronous presentation of the singletons. This suggests that unique temporal change did not contribute in any way to the ability of singletons to resist top-down control. However, we did find a reliable effect caused by unique temporal change, that is, a moderate increase in reaction time costs, with increasing asynchronicity; an effect that was almost unchanged from the first experiment where no obvious top-down task-set was established. Since unique temporal change did not even interact with such a dramatic change in top-down task set, let alone counteract it, we conclude the role of unique temporal change in attentional capture is not as pronounced as suggested by von Mühlenen et al. (2005).

Rather than referring to the “feature” of “unique temporal change” almost as an explanation, we suggest that it may simply be that singletons that appear either before or after target displays are more salient simply because there is less competition from surrounding items that do simultaneously change when the target display appears.² Von Mühlenen et al. (2005) seem all too aware of this account, as they explain the importance of the stimulus appearing at a time of “temporal calm”. However, it seems contradictory to attempt to account for the bottom-up phenomena of attentional capture by removing stimulus competition. Certainly if other sudden onsets are present, only a certain number will capture attention (see Yantis & Johnson, 1990), but if only one is present, and is destined to receive primary attentional priority, the fact that other items are changing and providing competition will dampen that effect on some trials, but is irrelevant in regard to the mechanism at work.

A far simpler “change-competition” hypothesis, not unlike that suggested some time ago by Miller (1989) and Watson and Humphreys (1995), seems to be all that is needed to account for these data. Attentional capture by sudden onsets did not interact with temporal uniqueness because sudden onsets were always going to receive attention first, whereas unique temporal change slowed search when both colour changes and sudden onsets were distractors because it made them more salient. However, it did not cause subjects to shift their attention to the singleton location as evidenced by the lack of observed benefits.

It is also clear from our results that sudden onsets capture attention in an entirely different manner to colour changes. If unique temporal change accounted for any component of bottom-up attentional capture, we ought to have found colour changes behaving in much the same manner, though not necessarily in the same magnitude, as sudden onsets. Instead, we found that colour changes became harder to filter out, and slowed the search process by a significant degree when temporally unique, but never captured attention, even when temporally unique. In contrast, sudden onsets reliably captured attention when randomly associated with targets, because on those trials targets were found significantly faster than baseline. This “no-singleton baseline” technique is a comparative approach in that if there is any overall speeding of reaction time on singleton-target trials it suggests attentional capture on at least some trials. By using the costs as a guide, we can assume that if a distractor captured attention it would slow the search by at least one item or possibly more, since attention would then need to be disengaged for the search to continue. Therefore, that benefits are of a similar magnitude suggests that singleton targets must be speeding the search by at least one

² Thanks to Steven Yantis for suggesting this interpretation.

item, and because attention does not then need to be disengaged, possibly more than one item.

The failure to find reliable reaction time benefits for colour changes though is not all that we base our distinction between the types of capture on. Intriguingly, the extent to which the two kinds of capture were subdued by top-down control differed significantly. When subjects were encouraged to ignore the salient singletons, benefits caused by sudden onsets on singleton-target trials were clearly subdued and not found to differ from baselines. In contrast, when subjects were encouraged to ignore colour-changes, colour-change target trials were actually responded to significantly slower than baselines at all three SOA's, which is a sure sign that capture has been more than eliminated, since these bright red targets took longer to find. Because such singleton targets were rare, this conclusion is based on a fairly small number of trials, and yet the total reversal of the effect observed with sudden onsets provides a good basis to conclude there is at least some important difference between the two types of capture.

As with many other studies, we can conclude that sudden onsets capture attention in a bottom-up fashion. Yet we remain cautious about interpreting these results as unambiguous support for Yantis and Hillstrom's (1994) "new-object" account, since our sudden onsets, as in many other experiments (but see Rauschenberger & Yantis, 2001) are accompanied by large luminance changes. It appears to be the sudden "point of appearance" of the object itself that is necessary for attentional capture. If that point of appearance is masked (Franconeri et al., 2005), or perhaps unnoticed because attention is deployed to a second task (e.g., Theeuwes, 1991), then sudden onsets lose their ability to capture attention. Furthermore, the current evidence suggests that if these changes occur in the absence of competing changes, by being "temporally unique" they may be enhanced in terms of salience, and take longer to filter out, but this may not be sufficient to cause a shift in spatial attention. Unique temporal change may increase some aspect of the salience of a stimulus, but on the basis of the current evidence it does not appear to be the feature that accounts for bottom-up attentional capture.

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