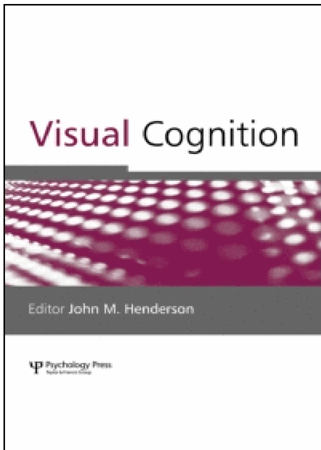

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Transfer of information into working memory during attentional capture

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Previous research has shown that task-irrelevant onsets can capture spatial attention even when attending to the onset is inconsistent with our intentions. The present study investigated whether information acquired during attentional capture is transferred into working memory. To measure whether this is the case, 25% of visual search trials were followed by a distractor recognition task. The results showed that the onset letter was recognized more often than a non-onset letter. In addition, the magnitude of attentional capture was positively correlated with the onset letter recognition advantage. The results suggest that attentional capture results in transfer of information into working memory.

Selective attention is necessary to reduce the large amount of information available to the visual system. Effective attentional selection involves prioritizing relevant information, while ignoring irrelevant information. The relevance of information is determined by the goals of the observer, resulting in a top-down control over visual selection. However, the process of visual selection can also be controlled by the properties of the visual input, in a bottom-up way, allowing salient and potentially important events in the environment to be noticed. The intricate interplay of these two selection mechanisms is what determines the resulting visual experience.

Although subjectively it may appear that we are able to exert full control over visual selection, previous research has showed that this is not the case.

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Especially in early vision, the allocation of spatial attention is strongly affected by cross-dimensional (e.g., colour, shape, size, luminance, etc.) salience of objects in the visual field (Cave & Wolfe, 1990; Nothdurft, 1993; Theeuwes, 1992, 1994; Wolfe, Cave, & Franzel, 1989).

While there is still a great deal of controversy regarding features and conditions that are capable of capturing attention in a bottom-up fashion (Bacon & Egeth, 1994; Belopolsky, Zwaan, Theewes, & Kramer, 2007; Folk, Remington, & Johnston, 1992; Franconeri, Hollingworth, & Simons, 2005; Jonides & Yantis, 1988; Theeuwes, 1992, 1994; Yantis & Jonides, 1984), most researchers agree that objects presented with an abrupt onset capture attention in an exogenous way. This special status often granted to the abrupt onsets has to do either with the fact that they constitute perceptually new objects (Yantis & Jonides, 1996) or that they simply are a subclass of luminance transients (e.g., offsets, motion, brightening, dimming), all of which are capable of capturing spatial attention (Franconeri et al., 2005; Miller, 1989).

Recently, it has been demonstrated that bottom-up factors also influence transfer of information into working memory. For example, it was shown that change blindness was attenuated for the exogenously cued onset or colour items in the flicker paradigm (Scholl, 2000). In another study, Schmidt, Vogel, Woodman, and Luck (2002) asked participants to memorize an array of objects. Memory was later tested by means of a probe object presented at one of the memorized locations. On each trial, one of the to-be-memorized objects was presented with an abrupt onset, while other objects were revealed by changing colours of the existing placeholders. Importantly, there was no incentive to attend to the onset, since it was equally likely to appear at the probed location than at any other location (Yantis & Jonides, 1984). The authors showed that memory performance for the object presented with an irrelevant abrupt onset was higher than for other objects. These results suggest that bottom-up attention facilitates transfer of perceptual information into working memory (see also Woodman, Vecera, & Luck, 2003).

However, it is possible that this bottom-up influence on the transfer of information into working memory is restricted to tasks in which memorization of visual input is the primary objective. The question that remains is whether bottom-up factors also influence transfer into working memory when memorization is not the primary task and when attending to the attentionally salient information is counterproductive to performance of the primary task.

The goal of the present study was to extend the previous findings by examining whether attentional capture during visual search results in transfer of information into working memory. We used a modified version of the irrelevant singleton paradigm (Theeuwes, 1994) to investigate this issue. Participants searched for a grey letter (C or a reversed C) among red distractor letters (Figure 1). We chose the target letter to be a singleton to maximize attentional capture by the abrupt onset (and the probability of its transfer into working memory). It has been shown that attentional capture by an irrelevant singleton is greater during parallel than during serial search (Belopolsky Zwaan et al., 2007). On 50% of the trials one of the distractor letters was presented with an abrupt onset. Presentation of an abrupt onset distractor typically results in an increase in reaction times (RTs) to the target by 20–30 ms, which is taken as the evidence that spatial attention was captured. But what is the fate of the information selected during attentional capture? Since attention dwells on the irrelevant onset distractor only briefly, it is reasonable to assume that the information it contains is either not encoded or is quickly discarded. However, if bottom-up factors facilitate transfer of information into working memory, one might expect that information contained by the onset will also be retained.

To examine this issue, 25% of the search trials were unpredictably followed by two-alternative forced choice recognition task of the red letter

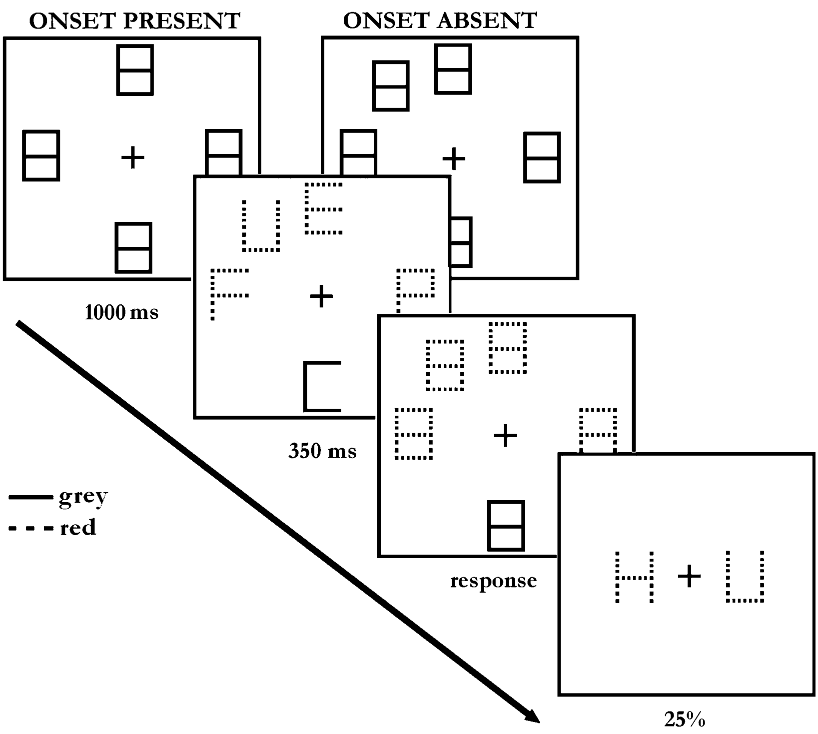

Figure 1. Examples of the displays used in the experiment.

distractors. It was emphasized that the visual search task was the primary task, and on 75% of trials it was the only task that participants had to perform. To make the strategy of memorizing the distractors even more inefficient, all letters were revealed for only 350 ms and then masked. If attentional capture results in transfer of information into working memory, we should find better recognition of the distractor letters that were presented with an abrupt onset. To further establish a link between attentional capture and working memory, we correlated the magnitude of attention capture in RT to the recognition performance across participants. We hypothesized that greater attentional capture should correspond to better recognition of the onset letter.

METHOD

Participants

Nineteen volunteers from the University of Illinois were paid to participate in a 1 hour session. Their ages varied between 18 and 25, with a mean age of 20 (14 females). They all had normal or corrected-to-normal visual acuity and normal colour vision.

Stimuli

Custom software was used to create and present stimuli. Display elements were figure-of-eight premasks and letters constructed out of their segments (1.3° in height, 0.7° in width). During the search task, elements were positioned on an imaginary circle (3.6° radius) around the fixation point (0.2° × 0.2°). Four of the elements always appeared at the end points of the horizontal (left, right) and vertical (top and bottom) midlines. An onset or an extra premask could appear at one out of four possible intervening locations (see Figure 1). The grey and red colours were matched for luminance (21 cd/m^2). All stimuli were presented on a black background and the viewing distance from the screen was approximately 70 cm.

Design

Two main conditions, the onset present and onset absent condition, were varied within-subjects and mixed within blocks of trials (see Figure 1). On 75% of all trials participants had to carry out only a visual search task. Display size was always five elements and the target was either a C or reversed C. The distractors were randomly (without replacement) picked from the letters A, E, *F*, H, O, P, S, and U. On randomly chosen 25% of trials, the visual search task was followed by a two-alternative forced choice recognition task, in which participants needed to indicate which distractor letter they thought was present in the preceding visual search display. One letter was always the letter that was present in the visual search display and the other one was randomly picked from the remaining distractor letters. All four distractors in the search display were probed with equal probability (25%), and the target was never probed. In total there were 896 trials divided into 14 blocks of 64 trials each.

Procedure

The trial started with a fixation cross, which stayed on the screen for 2000 ms, followed by a display of grey premasks. In the onset present condition, the display contained four premasks, while in the onset absent condition one extra premask was added. After 1000 ms, the premasks changed into the letters and at the same time all of them, except for one changed their colour to equiluminant red. The participants' task was to search for the single grey letter and determine whether it was a C or a reversed C by pressing, respectively, the "/" or the "z" key. Participants were encouraged to be as fast and as accurate as possible. The letters were masked after 350 ms by the figure-of-eight masks of the same colour, which stayed on the screen until the response. Masking was done to make active memorization of the distractor letters after completing the visual search task difficult. Participants received a beep if they made an error in the search task.

Unpredictably, 25% of the search trials were followed by a display of two red letters. The participants were asked to indicate which red letter had occurred in the immediately preceding search display. Since sometimes the subjective experience of the participants was that no letters were remembered, they were encouraged to guess. No feedback was given for the recognition task and a speeded response was not required. Before the start of the experiment, participants received 10 practice search trials. It was emphasized that they should maintain their fixation in the centre of the screen throughout the trial.

RESULTS

One participant was replaced due to a high error rate ($> 10\%$) in the search task. Trials with errors in the search task were excluded from the analysis. Reaction times less than 100 ms and greater than 1500 ms were discarded. This led to the loss of 1.5% of trials.

TABLE 1
Mean performance in the onset present and onset absent conditions

Onset present			*Onset absent*		
	Distractor recognition (% correct)			*Distractor recognition (% correct)*	
Target RT (ms)	*Extra onset*	*Other*	*Target RT (ms)*	*Extra nononset*	*Other*
593	63	54	574	52	54

The reaction times for correct onset present and onset absent conditions are presented in Table 1. There was a main effect of condition, $t(18) = 5.56$, $p < .001$, with participants responding 19 ms slower when the onset was present. Participants made 4.7% of errors in the onset present trials and 4.3% of errors on the onset absent trials, $t(18) = 1.15$, $p = .26$.

Percentages of correctly reported distractor letters in the onset present and onset absent conditions are presented in Table 1. A repeated measures two-way ANOVA with condition (onset present and onset absent) and probe location (extra location or fixed location) as factors showed a main effect of condition, $F(1, 18) = 5.80$, $p < .05$, but not of the probe location, $F(1, 18) = 2.49$, $p = .13$. This suggests that participants were better at recognizing the letters in the onset present condition than in the onset absent condition. There was also a significant interaction between the two factors, $F(1, 18) = 6.78$, $p < .05$, suggesting that the onset letter was recognized correctly more frequently than any other letter.

Planned comparisons showed that the onset letter was recognized better than non-onset letters in the onset present condition (63% vs. 54%), $t(18) = 2.87$, $p < .05$. Importantly, the onset letter was recognized correctly more frequently than the extra non-onset letter presented at the same spatial positions in the onset absent condition (52%), $t(18) = 2.90$, $p < .05$. There was no difference in recognition of the non-onset letters between the onset present and onset absent conditions, $t(18) < 0.2$.

The recognition of the extra non-onset letter in the onset absent condition was not significantly different from the 50% chance level, $t(18) = 0.77$, $p = .45$, suggesting that participants were guessing about its identity. However, recognition of other letters was slightly above chance in both onset present, $t(18) = 2.47$, $p < .05$, and onset absent, $t(18) = 2.23$, $p < .05$, conditions. Allocation of attention on a particular trial could have been influenced by the position of the target on the previous trial. To test this, we excluded the trials on which the probed nononset letter was preceded by the search target at the same location. Recognition of other non-onset letters dropped to

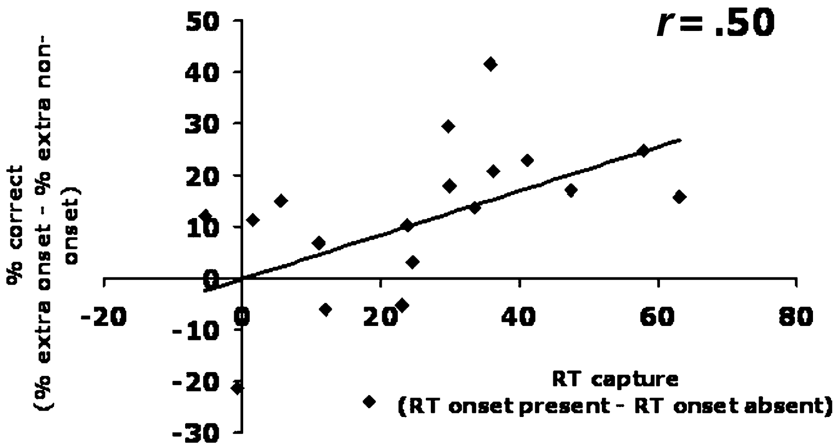

Figure 2. X-axis: Attentional capture measured by a difference in RT between onset present and onset absent conditions on the trials followed by a recognition task. Y-axis: Recognition advantage for the extra onset letter relative to the extra non-onset letter.

52.8% in the onset present and to 53.0% in the onset absent condition, which was not significantly different from chance, $t(18) = 1.76$, $p = .1$, and $t(18) = 1.54$, $p = .14$, respectively. This suggests that the slight increase in memory performance could be due to expectation of the target location.

To establish a link between attentional capture and memory transfer, we computed a Pearson correlation coefficient between the size of attentional capture as evidenced in the reaction times (RT(onset present) – RT(onset absent)) and the difference in the extra letter recognition of performance (% correct(onset present) $-$% correct (onset absent) for each participant). As shown in Figure 2, there was a significant correlation, $r = .50$, $p < .05$, between the two measures across participants, suggesting that the stronger the attentional capture, the better was the transfer of the attended information into the working memory.

DISCUSSION

The findings reported here suggest that attentional capture by an abrupt onset results in transfer of information into working memory. In our experiment, we replicated previous results showing that presentation of an irrelevant abrupt onset captured spatial attention (Table 1). Distraction caused by the abrupt onset was about 19 ms, an estimate that is similar to previous findings (Theeuwes, 1994).

In addition, the onset letter was recognized correctly more frequently than other letters in the display (Table 1), suggesting that the information it contained was transferred into working memory. Importantly, the non-onset letter presented at the same location as the onset letter was recognized at a chance level. The recognition performance for other non-onset letters (54%) was only slightly above chance. Although participants probably tried to actively memorize the distractors (since they were all equally relevant for the memory task), the low recognition rates for the non-onset letters suggest that short exposure time combined with performing the visual search task made this process very inefficient. In comparison, in the memory task used by Schmidt et al. (2002), the recognition performance for the chance-level onset was around 67%. Further analysis showed that in our experiment, this slight increase for the non-onset letters could also be due to expectation of the target location based on the previous trial.

Current results provide converging evidence that presentation of an irrelevant salient distractor triggers a shift of spatial attention to its location (Theeuwes, 1996). This argues against the notion of a "filtering cost", according to which response slowing is caused by increased difficulty of shifting attention to the target, and therefore, postulates no prioritized processing of the onset distractor (Folk & Remington, 1998). Instead, it appears that attention was first shifted to the onset distractor and the information it contained was encoded into working memory.

Supporting this idea of serial shifting of an attentional spotlight is the fact that the magnitude of attentional capture was also correlated with the onset letter recognition advantage. In our singleton search task, attentional dwell time on the onset distractor was sufficient to encode the information into working memory. We propose that on average, the longer attention dwelled on the onset distractor, the greater was the chance that information was transferred into working memory. Such a conclusion can be drawn, since the task design and the pattern of the recognition data suggested that active memorization of the distractors while performing the visual search task was inefficient. This finding indicates a direct link between allocation of spatial attention engendered by bottom-up factors and working memory.

A similar idea relating attentional dwell time and the amount of acquired information has been suggested in studies of overt attentional capture. For example, it was shown that an increase in eye fixation duration on the onset distractor increases the chance that participants become aware of the onset presence (Belopolsky, Kramer, & Theeuwes, 2007; Godijn & Theeuwes, 2002). Our results suggest that the longer attention is allocated to the irrelevant onset, the greater is the amount of acquired information and the greater is the chance that it is transferred into working memory.

Interestingly, when asked at the end of the experiment, most participants did not report noticing an onset letter added to the display. Failure to notice abrupt onsets while they reliably capture visual attention was noted in several previous studies (Kramer, Hahn, Irwin, & Theeuwes, 2000;

Theeuwes, Kramer, Hahn, Irwin, & Zelinsky, 1999; Yantis & Jonides, 1984). This suggests that not only the shift of attention but also the transfer of information into working memory might have occurred without awareness.

Many previous studies showed that top-down directed attention influences transfer of information into working memory (Irwin & Gordon, 1998; Sperling, 1960). However, relatively few studies so far have demonstrated a similar effect for the bottom-up factors (Schmidt et al., 2002; Scholl, 2000; Woodman et al., 2003). The present results extend the previous findings by showing that bottom-up factors influence transfer of information into working memory in the context of a visual search task, in which transfer into working memory is incidental. Although the abrupt onset was irrelevant to the search goal, it captured spatial attention and information it contained was transferred into working memory. We speculate that such capture and transfer occurred without awareness, but critically depended on the amount of attentional resources available (Cowan, 1995). Although participants might be unaware of the transfer of information into working memory during capture, they could be aware of working memory contents. Alternatively, information could have been encoded in implicit memory (Schacter, 1987) and not in working memory. While further research is needed to distinguish between these two alternatives, the encoded information most likely provides feedback that attentional capture occurred and is used to guide future search behaviour more efficiently.

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