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Does low perceptual load enable capture by colour singletons?

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There is considerable debate as to whether colour singletons can capture attention in a stimulus-driven manner. In this study, we explore one potential capture enabling condition—low perceptual load. To test this hypothesis, we manipulated perceptual load in a flanker task in which flanking letters sometimes were colour singletons. If low load enhances capture by colour singletons, then colour singletons should produce an especially large increase in overall reaction times and in flanker–target compatibility effects. Neither of these predictions was confirmed in any of the four experiments reported here, although we did replicate the classic load effects from previous studies. These experiments indicate that although perceptual load does strongly modulate overall performance, it does not facilitate capture by colour singletons. This finding contrasts sharply with findings from other types of salient stimuli (abrupt onsets and moving objects). Implications for theories of attentional capture will be discussed.

Keywords: Attentional capture; Perceptual load; Spatial attention.

Stimuli frequently capture our attention, seemingly against our will. An active debate exists as to whether these involuntary shifts of spatial attention are goal-driven or stimulus-driven. Some researchers argue that only stimuli that resemble what we are currently looking for can capture our attention (goal-driven); others argue that certain stimulus types can capture our attention regardless of our current goals (stimulus-driven).

Some research with dynamic stimuli, such as motion singletons and abrupt onsets, has suggested that low perceptual load is critical for enabling stimulus-driven capture (Cosman & Vecera, 2009, 2010). It is unclear, however, whether this finding generalises to static salient stimuli, such as colour singletons. This issue is important because much of the recent debate about capture has revolved around colour singletons (e.g., Folk & Remington, 2010; Folk, Remington, & Johnston, 1992; Theeuwes, 1994, 2010). In the current study, we investigate whether low perceptual load can also enable capture by colour singletons. If so, it might help to explain empirical discrepancies in the literature.

STIMULUS-DRIVEN AND GOAL-DRIVEN ACCOUNTS OF CAPTURE

A colour singleton is an object in a visual scene that differs in colour from a homogenously coloured background. For example, a lone red car parked amongst green cars would no doubt seem particularly salient and be readily noticed. But do they actually cause a rapid shift of visual attention, regardless of top-down goals? Some

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researchers have claimed that they do (Hickey, McDonald, & Theeuwes, 2006; Theeuwes, 1991, 1992, 1994; Theeuwes & Burger, 1998). In an influential study by Theeuwes (1992), for example, participants searched visual arrays for a target with a prespecified unique feature (e.g., shape) and reported the orientation (horizontal or vertical) of a line within this target object. On some trials, an irrelevant colour singleton distractor appeared along with the target. The presence of a colour singleton distractor elevated response time (RT), even when participants knew the target was defined only by its shape and that colour was irrelevant. Presumably, the increased RT reflected attentional capture by the colour singleton, consistently slowing the detection of the target item.

Other researchers have argued that only stimuli matching the viewer's behavioural goals can capture attention. Folk et al. (1992) systematically investigated the relationship between cue types and target types in a precueing paradigm. Critically, this study provided evidence that the only cues capable of capturing attention are those possessing the feature people are currently looking for. For example, when participants searched for a red singleton target, task-irrelevant red singleton cues captured attention while abruptly onsetting cues did not (and vice versa). The researchers therefore concluded that capture is contingent upon observers' goal-driven attentional control settings.

Bacon and Egeth (1994) further supported Folk et al.'s (1992) contingent capture hypothesis. They noted that, in many experiments claiming to demonstrate stimulus-driven capture by singletons (e.g., Theeuwes, 1992), participants were required to search for a singleton target. These researchers proposed the existence of a *singleton detection mode* (SDM)—if asked to search for one specific kind of feature singleton (e.g., a shape singleton), participants will simplify their search by merely looking for any type of feature singleton. This claim was supported by experiments that used a paradigm similar to that of Theeuwes (1992). Critically, when SDM was discouraged, the presence of a colour singleton failed to increase RTs relative to singleton-absent trials. These results favour contingent (goal-driven) capture: Irrelevant colour singletons capture attention only when participants are actively looking for feature singletons. Many other recent studies have further supported this conclusion (Folk & Remington, 1998; Folk, Remington, & Wright, 1994; Franconeri & Simons, 2003; Lien, Ruthruff, & Cornett, 2010; Yantis & Jonides, 1990).

To review, one group of researchers has consistently argued that all attentional capture by colour singletons is goal-driven (Folk & Remington, 1998, 2010; Folk et al., 1994; Lien et al., 2010), whereas another group of researchers argues that capture by colour singletons is entirely stimulus-driven (Belopolsky, Zwaan, Theeuwes, & Kramer, 2007; Theeuwes, 1992, 1994, 2010). The present experiments evaluated one promising capture enabling condition—low perceptual load. Indeed, some previous research suggests that low perceptual load, but not high perceptual load, may allow for capture by salient stimuli (Cosman & Vecera, 2009, 2010). Before explaining how we tested this hypothesis, we first review the previous literature on the flanker task and perceptual load.

PERCEPTUAL LOAD THEORY

In the widely used flanker task, participants search an array of letters for a target letter while another letter, known as the *flanker*, appears outside of this array (Eriksen & Eriksen, 1974). In a given trial, the identity of this flanking letter can either be compatible, neutral, or incompatible with respect to the target letter's identity. Therefore, if the flanker is semantically processed, responses to the target should be fastest on compatible trials, intermediate on neutral trials, and slowest on incompatible trials (Lavie, 1995). This pattern of RTs is called the flanker *compatibility effect*. Flanker studies that have manipulated perceptual load—the amount of relevant information in a search display—have revealed some curious findings that have spawned a large literature. Specifically, studies consistently demonstrate that flanker compatibility effects are greatly reduced, or even eliminated, when the search array becomes sufficiently complex (high perceptual load; e.g., Forster & Lavie, 2008; Lavie, 1995; Lavie & Cox, 1997; Lavie & Fox, 2000; Lavie & Tsal, 1994). This pattern has been obtained both when creating high load by increasing set size (e.g., Lavie, 1995) and by increasing distractor–target similarity (e.g., Lavie & Cox, 1997).

This finding can be conveniently explained by perceptual load theory of attentional selection, which posits an attentional mechanism that seeks to always work at full capacity (Lavie, 1995).

When little information *relevant* to the task at hand is available (low perceptual load), the attentional mechanism begins to also process *irrelevant* information, until filled to capacity; this results in strong compatibility effects from irrelevant flankers. However, when a large amount of information relevant to the task at hand is available (high load), the attentional mechanism is filled to capacity, leaving no spare attentional resources to process irrelevant items (Benoni & Tsal, 2010, recently proposed an alternative explanation based on dilution, which we will address within the General Discussion).

THE PRESENT STUDY

The specific question addressed here is whether capture by salient colour singletons occurs more frequently under low perceptual load than high perceptual load. Low perceptual load displays are assumed to free attentional resources, which might then be readily captured by task-irrelevant colour singletons.

Although no previous studies have provided a clear answer to our question, there are a few relevant studies. Theeuwes and Burger (1998), employing a modified flanker paradigm with low load, found compatibility effects from colour singleton flankers, which they attributed to salience-induced attentional capture by the colour singleton. Gibson and Bryant (2008), however, questioned whether these compatibility effects might instead be due to late selection resulting from the low perceptual load of the displays (see also Biggs & Gibson, 2010). They conducted a new experiment with a colour singleton inside each search array, containing either four letters (low load) or 12 letters (high load). Critically, colour singleton flankers produced compatibility effects under low load (replicating Theeuwes & Burger, 1998), but not under high load. They concluded that low perceptual load, not singleton salience, caused flanker compatibility effects.

Stated simply, Gibson and Bryant (2008) claim that low load, not salience, causes compatibility effects. A key prediction of this claim is that—under low load—compatibility effects should be just as large for nonsingleton flankers as for singleton flankers. However, they never actually included such a nonsingleton flanker condition (every flanker was a colour singleton). This leaves wide open the alternative hypothesis that the critical ingredient is low load *combined* with salience (an interaction). In other words, singleton flankers might cause larger compatibility effects than nonsingleton flankers under low load. To resolve this issue, the present study used a factorial design that allowed measurement of the effects of perceptual load, salience, and their interaction. In other words, we can tell whether capture is due simply to low load (as Gibson & Bryant assumed) or due to the combination of low load and high salience (as assumed by our main hypothesis, inspired by load theory). We are not aware of any direct tests of this alternative hypothesis using colour singletons. However, the hypothesis indirectly gains credibility from studies of other types of salient stimuli. Cosman and Vecera (2009), for example, found that abruptly onsetting flankers do in fact produce larger compatibility effects than offsetting flankers under low load (for a similar study with motion singletons, see Cosman & Vecera, 2010). Presumably, these enhanced compatibility effects resulted from salient onset flankers capturing attention on a larger proportion of trials than nonsingleton flankers. Similarly, Forster and Lavie (2008) found that salient task-irrelevant flankers (e.g., cartoon characters) interfered with search under low load, but not high load. These recent studies suggest that perceptual load might represent an extremely critical determinant of attentional capture, previously overlooked.

Although previous studies of capture by colour singletons have not manipulated perceptual load, these studies do provide tentative support for the hypothesis that load enhances capture by colour singletons. Many experiments reporting capture by colour singletons have employed displays with high distractor similarity (Hickey et al., 2006; Theeuwes, 1992, 1994). These distractors may be grouped together, effectively reducing the amount of task-relevant information (i.e., creating low perceptual load as in Lavie & Cox, 1997). Meanwhile, many studies demonstrating no capture by colour singletons have a relatively low distractor similarity (e.g., Folk & Remington, 1998; Lien et al., 2010), presumably creating relatively high perceptual load. Although this comparison is suggestive, it is premature to reach any conclusions because there are additional differences between the paradigms employed. The present experiment, therefore, is needed to systematically evaluate whether perceptual load is in fact a key difference between these paradigms.

To summarise, there is considerable disagreement regarding whether salient stimuli can capture attention against our will, and much recent debate has centred around the case of colour singletons (which are salient, yet static rather than dynamic). There are several reasons to believe that the ideal condition for observing capture by colour singletons is under low load: (1) Perceptual load theory predicts that low load frees attentional resources, which can then wander; (2) previous studies of other salient stimuli suggest that low load enhances capture; and (3) an analysis of previous colour singleton studies tentatively suggests that load matters. The present study therefore will both attempt to (1) provide a sensitive test of whether colour singletons can capture attention against our will, and also to (2) assess whether the enhancement of capture under low perceptual load is a general phenomenon.

EXPERIMENT 1

As in many previous studies of perceptual load (Cosman & Vecera, 2009, 2010; Lavie, 1995), we began by presenting an irrelevant flanking letter outside of the relevant search array (see Figure 1). The flanking letter (whose identity was either neutral, compatible, or incompatible with respect to the target) was a colour singleton on half of the trials. To eliminate the incentive to selectively attend to a specific colour, the target array colour varied randomly, trial-by-trial, and participants were informed of this fact. Perceptual load of the search arrays (high vs. low) was varied by block, via distractor similarity (as in Lavie & Cox, 1997). In high load blocks, a target was presented with five distractor letters with a nontarget identity. In low load blocks, Os were used as placeholders in the remaining five distractor locations. In principle, we could have manipulated load via set size, with the low load condition including only two items (target and flanker). However, a colour singleton amongst two items (low load) of another colour is probably not as salient as a singleton among six items (high load) of another colour (as in Gibson & Bryant, 2008). By using six letters for both low and high load conditions, we better control for the salience of the colour singleton across these conditions (in Experiment 3, we also examine the effects of load using a set size manipulation).

If low perceptual load frees attentional resources, spatial attention may be more readily captured by colour singleton flankers. If so, then compatibility effects should be especially large for colour singleton flankers, compared to nonsingleton flankers, under low perceptual load (but not under high load). Also, RTs should be longer when the flanker is a colour singleton (because the irrelevant singleton flanker always draws spatial attention away from the target). We refer to this effect as the *singleton cost*. Although this singleton cost should be substantial under low load, it should be greatly reduced under high load (where there should be little or no spare attentional resources to be captured).

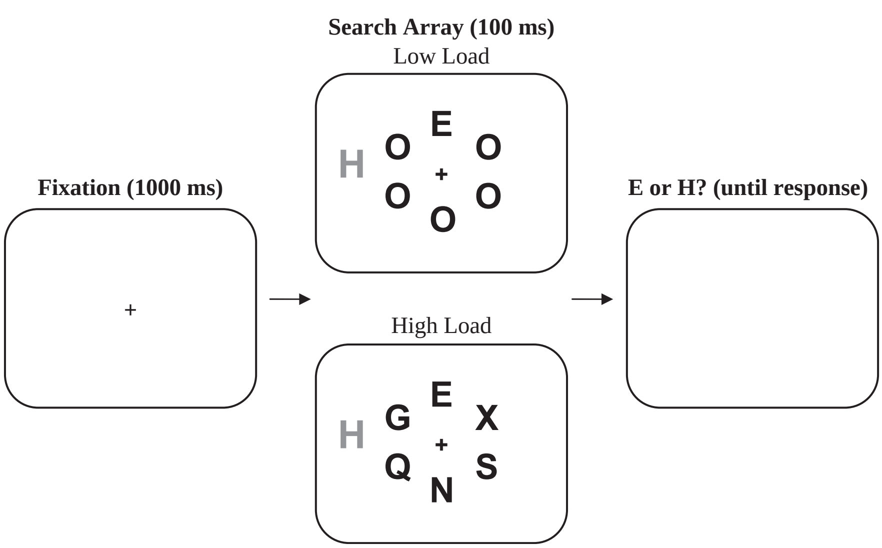

Figure 1. Example of stimulus displays used in Experiment 1. The flanker letter (grey in diagram) was a colour singleton on half of the trials. The flanker identity could be compatible, incompatible, or neutral with respect to the target identity (incompatible flanker shown in diagram).

Methods

Participants. Fifty-nine University of New Mexico students participated for class credit. All participants had normal colour vision as assessed by the Ishihara colour vision test. All participants reported normal or corrected-to-normal visual acuity.

Apparatus. Dell personal computers displayed stimuli on 19-inch CRT monitors.

Stimuli. E-prime software was used to present stimuli. The elements displayed were all the letters in the English alphabet, except M and W, in Arial font. Letters were either green (RGB values of 0,210,50), red (255,0,50), blue (0,0,200), yellow (230,200,0), or purple (145,0,110), designed to be roughly equal in luminance, on a black background. Letters inside the circular array (12.1° in diameter) were 2.1° in width and 2.5° in height, based on an average viewing distance of 43 cm. In high load blocks, the circular arrays consisted of a target letter and five distractor letters (see Figure 1). In low load blocks, the circular arrays consisted of a target letter with Os in the remaining five positions. Flanking letters were 3.4° in width and 3.8° in height. In all trials, a flanking letter appeared outside of the circular array on either the left or right side (1.9°).

Design. Each target–flanker relationship (incompatible, compatible, neutral) was equally likely (1/3). All letters inside the array were the same colour. Array and flanking letter colours were selected randomly in each trial. To minimise runs of any particular colour, we used five different array colours (blue, green, red, yellow, and purple). In half of the trials, the flanker colour was the same as the other five letters in the circular array; in the other half, the flanker was a colour singleton. When the flanker was a colour singleton, it was randomly one of four different colours than the search array. Perceptual load of the search array alternated across blocks, with the order counterbalanced across participants (e.g., high-low-high-low or low-high-low-high, etc.). Distractor letter identity (any letter, except E, H, M, and W) and target identity (E or H) were selected randomly. Each participant first performed 40 practice trials divided into two blocks. Participants then performed 480 trials divided into 12 blocks.

Procedure. Participants were asked to look for an E or H inside the circular array and respond as quickly and accurately as possible by pressing the keys labelled "E" or "H" (actual keys: "z" and "m"). Participants were told that flanker letters did not predict the target identity or location and should be ignored. Each trial began with a fixation cross for 1000 ms (see Figure 1). The circular array appeared for 100 ms and then disappeared. A blank screen remained until a participant made a response. Participants were then given immediate accuracy feedback (a low tone for incorrect responses, no sound for correct responses). Participants also received block-by-block feedback on their mean RT and accuracy.

Results and discussion

Two participants were excluded from analysis because of unusually high error rates (more than 2.5 *SD*s above the group mean). Trials with an RT greater than 1500 ms or less than 200 ms (1.3% of trials) or an incorrect response were excluded from RT analyses. These RT outliers were also excluded from error rate analyses. The resulting mean RTs are shown in Figure 2 and Table 1.

A three-way repeated measures analysis of variance (ANOVA) was conducted on mean RTs with the factors of perceptual load, flanker compatibility, and flanking-letter singleton status. In all experiments of this paper, Greenhouse-Geisser transformations were applied when the assumption of sphericity was violated. This analysis revealed much faster responses on low load trials (562 ms) than high load trials (652 ms), $F(1, 56) = 231.84$, $MSE = 5972.51$, $p < .001$, $\eta^2 = .805$, indicating that our manipulation of perceptual load was effective. In addition, incompatible trials (621 ms) were performed more slowly than compatible trials (596 ms), $F(2, 112) = 51.07$, $MSE = 775.06$, $p < .001$, $\eta^2 = .477$. The two-way interaction of perceptual load and flanking letter compatibility was also significant, with flanking letter compatibility effects (incompatible minus compatible) being smaller on high load trials (16 ms) than low load trials (36 ms), $F(2, 112) = 12.03$, $MSE = 629.96$, $p < .001$, $\eta^2 = .177$. This pattern of compatibility effects replicates the key finding of previous studies of perceptual load, used to argue that low load allows free attentional resources and

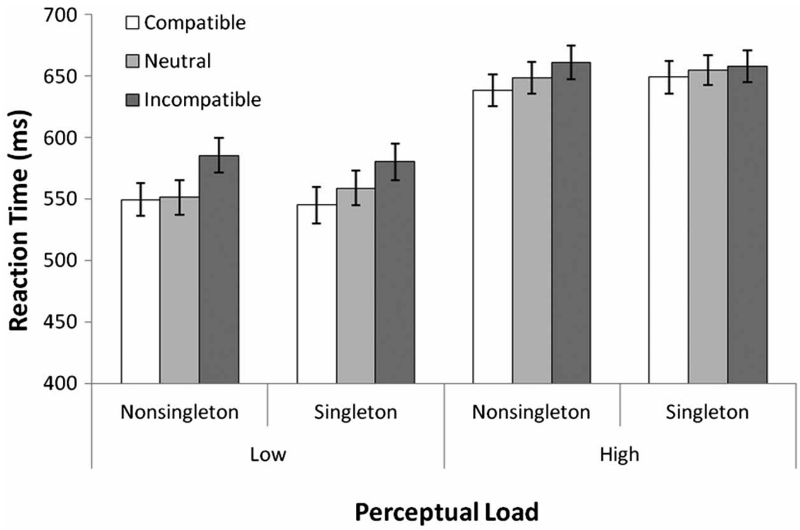

Figure 2. Mean reaction time (RT) in milliseconds in Experiment 1. The error bars are standard errors of the mean.

enables them to be applied to irrelevant display items (Lavie, 1995).

RTs were not significantly longer for singleton flankers (608 ms) than for nonsingleton flankers (606 ms), $F(1, 56) = 0.86$, $MSE = 758.40$, $p > .10$, $\eta^2 = .015$. This lack of a main effect, 95% CI (2 ± 7.3 ms), suggests that flankers did not capture spatial attention more readily when they were colour singletons. The two-way interaction of flanker compatibility by singleton status was significant, with smaller compatibility effects for singletons (22 ms) than nonsingletons (29 ms), $F(2, 112) = 3.11$, $MSE = 589.66$, $p < .05$, $\eta^2 = .053$. Note that this effect went in the opposite direction to that predicted previously by our load hypothesis. Rather than being captured by the colour singleton flankers, participants may have actually used singleton status to more effectively select against them (since singletons were always irrelevant). The interaction of perceptual load and singleton status was not significant, with singleton costs of 5 ms under low load and –1 ms under high load, $F(1, 56) = 1.81$, $MSE = 681.34$, $p > .10$, $\eta^2 = .031$. The three-way interaction of all the variables was also nonsignificant, $F(2, 112) = 1.58$, $MSE = 652.46$, $p > .10$, $\eta^2 = .027$.

The three-way repeated measures analysis of variance (ANOVA) described earlier was also applied to error rates. Participants made fewer errors in low load trials (3.7%) than high load trials (4.7%), $F(1, 56) = 8.076$, $MSE = 0.0023$, $p < .01$, $\eta^2 = .126$, further indicating the effectiveness of our load manipulation. Participants made more errors on incompatible trials (5.8%) than neutral trials (3.1%), $F(2, 112) = 23.65$, $MSE = 0.0019$, $p < .001$, $\eta^2 = .297$. All other main effects and interactions were nonsignificant ($p > .10$).

To review, we looked for evidence that attentional resources freed under low load (see Lavie, 1995) could be more easily captured by task-irrelevant colour singletons. If so, singleton

TABLE 1
Mean response times (RTs) in milliseconds and percentage of errors (PEs) as a function of perceptual load (low vs. high), singleton status (singleton vs. nonsingleton), and flanker compatibility (compatible, neutral, vs. incompatible) for Experiment 1

	Low				*High*			
	Nonsingleton		*Singleton*		*Nonsingleton*		*Singleton*	
	RT	*PE*	*RT*	*PE*	*RT*	*PE*	*RT*	*PE*
Compatible	550	3.7%	545	3.4%	639	2.2%	649	2.9%
Neutral	551	4.3%	559	4.1%	649	3.6%	655	3.4%
Incompatible	586	6.5%	580	6.5%	661	5.2%	658	4.9%
Compatibility effect	35.9	2.8%	35.3	3.1%	22.6	2.9%	9.1	1.9%

Compatibility effects were calculated as incompatible minus compatible.

costs and compatibility effects for singleton flankers would increase under low perceptual load. However, neither of these predictions was confirmed. Instead, we found that giving a flanker singleton status actually helped participants ignore it.

EXPERIMENT 2

Some researchers have suggested that only information appearing within the viewer's attentional window will capture attention (Belopolsky et al., 2007; Theeuwes, 1992, 2010). In Experiment 1, the colour singleton appeared outside the search array, in a task-irrelevant location, as in the majority of previous flanker studies. Thus, the colour singleton may have appeared outside the viewer's attentional window, discouraging capture. In Experiment 2, we therefore placed the flanker at the centre of the array, to provide an even more sensitive test for the effects of load on capture. As in Experiment 1, if freed attentional resources are readily captured by colour singleton flankers, we would expect enhanced compatibility effects and singleton costs for singleton flankers compared to nonsingleton flankers under low perceptual load.

Method

Participants. A new sample of 47 University of New Mexico students participated for class credit.

Apparatus, stimuli, and procedure. The methods were similar to those used in Experiment 1 except that the flanker now appeared at fixation. To roughly compensate for the greatly reduced eccentricity of the central flanker, it was shrunken compared to Experiment 1 (1.7° in width and height). Before the search array, a fixation display of six crosses (one at each potential target location) appeared for 500 ms to clearly mark the future location of the search array, leaving the central location empty. This fixation display (not utilised in Experiment 1) reduced the incentive to attend to the centre of the display.

Results and discussion

One participant was excluded from analysis because of an unusually high error rate (more than 2.5 *SD*s above the group mean). Trials with an RT greater than 1500 ms or less than 200 ms (1.2%) or an inaccurate response were excluded from RT analyses. These RT outliers were also excluded from the error rate analyses. Mean RTs are shown in Figure 3 and Table 2.

As in Experiment 1, a three-way repeated measures analysis of variance (ANOVA) was conducted on mean RTs with the factors of perceptual load, flanker compatibility, and flanking-letter singleton status. This analysis revealed shorter RTs on low load trials (549 ms) than high load trials (652 ms), $F(1, 45) = 214.091$, $MSE = 7858.84$, $p < .001$, $\eta^2 = .826$. Also, compatible trials (581 ms) were performed more quickly

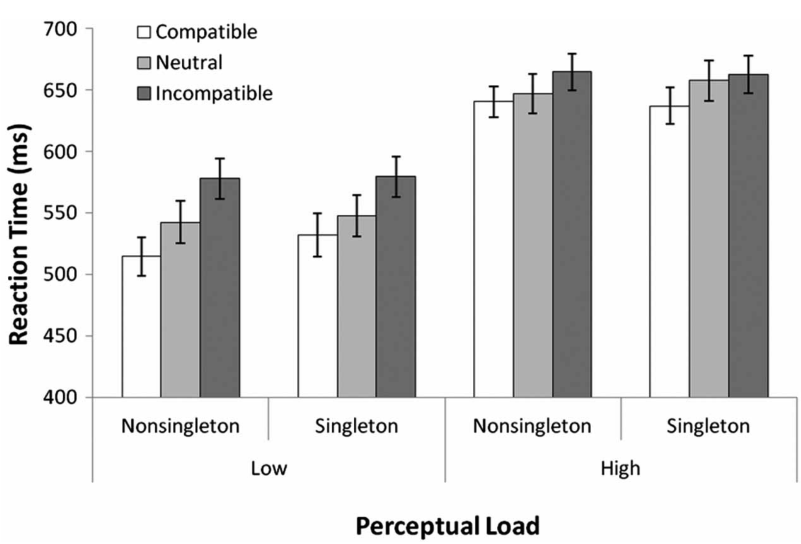

Figure 3. Mean reaction time (RT) in milliseconds in Experiment 2. The error bars are standard errors of the mean.

TABLE 2
Mean response times (RTs) in milliseconds and percentage of errors (PEs) as a function of perceptual load (low vs. high), singleton status (singleton vs. nonsingleton), and flanker compatibility (compatible, neutral, vs. incompatible) for Experiment 2

	Low				*High*			
	Nonsingleton		*Singleton*		*Nonsingleton*		*Singleton*	
	RT	*PE*	*RT*	*PE*	*RT*	*PE*	*RT*	*PE*
Compatible	515	4.1%	532	3.1%	641	6.6%	637	6.6%
Neutral	543	4.7%	548	3.9%	647	6.9%	658	7.6%
Incompatible	578	7.4%	580	7.9%	665	9.8%	663	8.3%
Compatibility effect	63.3	3.3%	47.3	4.8%	24.2	3.2%	25.4	1.7%

Compatibility effects were calculated as incompatible minus compatible.

than incompatible trials (621 ms) or neutral trials (599 ms), $F(2, 90) = 30.84$, $MSE = 2537.146$, $p < .001$, $\eta^2 = .407$. The interaction of load by compatibility was also significant, with compatibility effects (incompatible minus compatible) being higher for low load displays (55 ms) compared to high load displays (25 ms), $F(2, 90) = 6.517$, $MSE = 1508.03$, $p < .01$, $\eta^2 = .127$. Thus, our manipulation of load was successful and replicated findings from previous studies of perceptual load.

Participants produced slightly longer RTs with singleton flankers (603 ms) than nonsingleton flankers (598 ms), $F(1, 45) = 3.877$, $MSE = 1069.40$, $p < .10$, $\eta^2 = .079$. However, the two-way interaction of perceptual load and singleton status was nonsignificant, with singleton costs only slightly greater under low load (8 ms) than high load (2 ms), $F(1, 45) = .630$, $MSE = 847.25$, $p > .10$, $\eta^2 = .014$. The small overall singleton costs could be due to either capture of spatial attention or filtering costs (Becker, 2007). Because we failed to find any converging evidence of capture based on compatibility effects (to be discussed next), we suspect that the modest singleton costs primarily reflect filtering costs in this case.

Compatibility effects were not significantly greater for colour singleton flankers (36 ms) than nonsingleton flankers (44 ms), $F(2, 90) = .863$, $MSE = 947.25$, $p > .10$, $\eta^2 = .019$; in fact, the trend was opposite to the predicted direction based on our load hypothesis. The three-way interaction of all three variables was marginally significant, $F(2, 90) = 2.50$, $MSE = 973.09$, $p < .10$, $\eta^2 = .053$. Preplanned *t*-tests revealed that, under low load, the interaction of singleton status and compatibility went in the opposite direction of that predicted by our load hypothesis, with significantly smaller compatibility effects for singleton flankers (47 ms) than nonsingleton flankers (63 ms), $t(45) = 2.241$, $p < .05$. This pattern of results suggests, if anything, that participants selectively ignored singleton flankers under low perceptual load, making them less effective at interfering with the relevant task. Under high load, however, compatibility effects were not significantly greater for nonsingletons (24 ms) than singletons (25 ms), $t(45) = 0.118$, $p > .10$.

The same three-way repeated measures ANOVA was conducted on the mean error rates as well. Participants had higher error rates on high load trials (7.6%) than low load trials (5.2%), $F(1, 45) = 7.598$, $MSE = 0.011$, $p < .01$, $\eta^2 = .144$. Participants also showed higher error rates for incompatible trials than compatible trials, $F(2, 90) = 17.484$, $MSE = 0.071$, $p < .001$, $\eta^2 = .280$. These compatibility effects were greater under low than high load, $F(2, 90) = 3.233$, $MSE = 0.004$, $p < .05$, $\eta^2 = .067$. Altogether, these error rate results are consistent with the RT results, and further confirm that our manipulation of perceptual load was successful. All other main effects and interactions were nonsignificant.

In Experiment 2, we manipulated the salience of a central flanker. Capture by colour singletons should have caused increased compatibility effects (Becker, 2007; Folk & Remington, 1998). Although we found small but significant singleton costs (5 ms) overall, these costs were not significantly greater under low perceptual load (8 ms) than high perceptual load (2 ms). Furthermore, compatibility effects by singleton flankers (47 ms) were actually smaller than those for nonsingleton flankers (63 ms) under low load, suggesting that participants learned to ignore the colour singleton flankers. Thus, this experiment, like Experiment 1, suggests that low perceptual load does not allow for enhanced capture by colour singletons.

EXPERIMENT 3

In Experiments 1 and 2, we manipulated perceptual load via distractor similarity, as in many other load studies (Lavie & Cox, 1997); that is, the set size was held constant (six items), but the nontarget letters were either homogenous (all Os; low load) or heterogeneous (high load). An advantage of this approach—using the same number of display items in both load conditions—is that it holds colour singleton salience constant across load conditions. Another common approach, however, is to manipulate perceptual load via set size (Lavie, 1995). It is logically possible that a set size manipulation of load might somehow have a different impact on attention and allow for enhanced capture effects under low perceptual load. For example, perhaps the homogenous Os in our low load condition are not completely ignored, and that it is possible to achieve even lower load by removing them.

To address this issue, the present experiment manipulated perceptual load by set size. Some adjustment in design was needed, however, to create highly salient colour singleton under low perceptual load. Our solution was to include fixed placeholders in each search array location. When the search array appeared, the placeholders changed to the same colour as the search array. This effectively allowed us to present a flanker that differed in colour from a homogenously coloured background, even with a set size of one.

Method

Participants. A new sample of 47 University of New Mexico students participated for class credit.

Apparatus, stimuli, and procedure. The stimuli and procedures were nearly identical to Experiment 1 except that the low load condition now only contained the target (plus a flanker). Six square placeholders (4.2° in width and height) appeared at each target location. These placeholders were white in the fixation frame. Then, when the search array appeared, they became the same colour as the letters in the search array. When the search array disappeared, the placeholders became white again. Pilot data suggested that the placeholders caused a general decrement in accuracy, presumably due to lateral masking. In order to boost accuracy back to the levels of the previous experiments, the search array duration was increased from 100 ms to 200 ms.

Results and discussion

Trials with an RT greater than 1500 ms or less than 200 ms (0.6%) or an inaccurate response were excluded from RT analyses. These RT outliers were also excluded from the error rate analyses. Mean RTs are shown in Figure 4 and Table 3.

A three-way ANOVA was conducted on mean RTs with the factors of perceptual load, flanker compatibility, and flanking-letter singleton status. Participants generally responded more slowly under high load (620 ms) than low load (547 ms), $F(1, 46) = 153.918$, $MSE = 4773.752$, $p < .001$, $\eta^2 = .770$. Participants also responded more slowly to incompatible flankers (598 ms) than compatible flankers (568 ms) or neutral flankers (585 ms), $F(2, 92) = 66.418$, $MSE = 643.411$, $p < .001$, $\eta^2 = .591$. Participants showed greater compatibility effects under low load (43 ms) than high load (17 ms), $F(2, 92) = 15.964$, $MSE = 474.925$, $p < .001$ $\eta^2 = .258$. This classic interaction of load and compatibility suggests that our manipulation of perceptual load was successful.

Participants did not show singleton costs (singleton minus nonsingleton), responding equally quickly with singleton flankers (583 ms) and nonsingleton flankers (584 ms), $F(1, 46) = 0.087$, $MSE = 650.727$, $p > .10$, $\eta^2 = .002$. However, singleton costs were modulated by load, with participants showing 4 ms singleton cost under low load but –5 ms cost (i.e., 5 ms benefit) under high load, $F(1, 46) = 6.895$, $MSE = 379.598$, $p < .05$, $\eta^2 = .130$. Again, singleton costs alone could reflect mere filtering costs. So, singleton costs should not be interpreted as a ‘‘capture effect’’ in the absence of compatibility effects.

The key question of this study is whether capture by colour singletons is enhanced under low perceptual load. Contrary to this hypothesis, compatibility effects were smaller for singleton flankers (26 ms) than nonsingleton flankers (35 ms), $F(2, 92) = 3.623$, $MSE = 394.885$, $p < .05$, $\eta^2 = .073$. This interaction was not modulated by

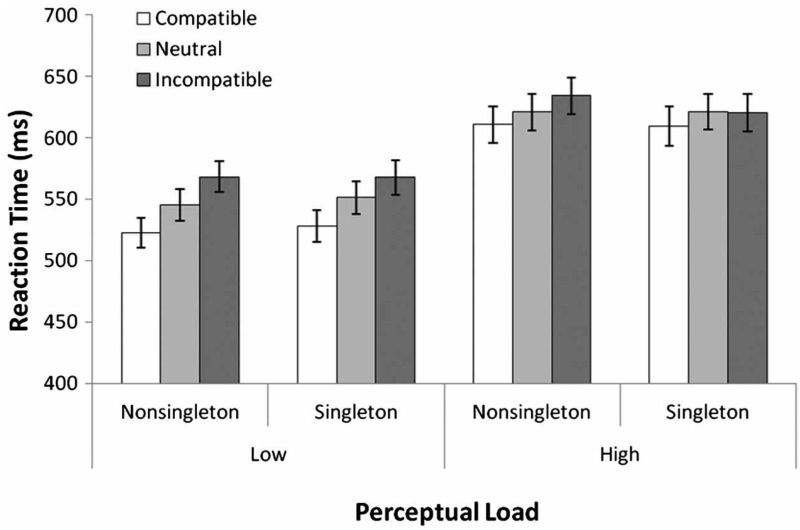

Figure 4. Mean reaction time (RT) in milliseconds in Experiment 3. The error bars are standard errors of the mean.

TABLE 3
Mean response times (RTs) in milliseconds and percentage of errors (PEs) as a function of perceptual load (low vs. high), singleton status (singleton vs. nonsingleton), and flanker compatibility (compatible, neutral, vs. incompatible) for Experiment 3

	Low				*High*			
	Nonsingleton		*Singleton*		*Nonsingleton*		*Singleton*	
	RT	*PE*	*RT*	*PE*	*RT*	*PE*	*RT*	*PE*
Compatible	523	3.0%	528	3.4%	611	6.2%	609	4.2%
Neutral	546	4.6%	552	5.3%	621	7.4%	621	5.9%
Incompatible	568	7.2%	568	8.1%	634	12.2%	621	10.3%
Compatibility effect	45.6	4.2%	39.9	4.7%	23.5	6.0%	11.2	6.1%

Compatibility effects were calculated as incompatible minus compatible.

perceptual load, $F(2, 92) = 0.425$, $MSE = 434.578$, $p > .10$, $\eta^2 = .009$.

The same ANOVA was carried out on mean error rates. Participants made more errors under high load (7.7%) than low load (5.2%), $F(1, 46) = 10.127$, $MSE = 0.084$, $p < .01$, $\eta^2 = .180$. Participants also made more errors with incompatible flankers (9.4%) than compatible flankers (4.2%) or neutral flankers (5.8%), $F(2, 92) = 73.800$, $MSE = 0.0018$, $p < .001$, $\eta^2 = .180$. Participants also made more errors for singleton flankers under low load than high load, $F(1, 46) = 20.001$, $MSE = 0.0011$, $p < .01$, $\eta^2 = .303$. All other main effects and interactions were nonsignificant.

In this experiment, we manipulated perceptual load via set size rather than distractor similarity, yet we found the same pattern of results as in Experiment 1 and 2. Participants again showed greater compatibility effects for nonsingleton flankers (35 ms) than singleton flankers (26 ms), suggesting that they were not readily captured by colour singletons. If anything, they selectively ignored them.

EXPERIMENT 4

Many previous studies demonstrating stimulus-driven capture by colour singletons have presented the singleton distractor letter at a potential target location (e.g., Theeuwes, 1994), whereas the presented Experiments 1–3 presented it in irrelevant locations, either inside or outside of the circular target array. It is logically possible that low load does enhance capture by singletons, but only for items that cannot be excluded based on location. To test this hypothesis in Experiment 4, we presented a colour singleton as a distractor in the search array, rather than as a flanker outside the search array. This colour singleton distractor (and the matched nonsingleton distractor) always had a neutral identity because compatible or incompatible distractors at potential target locations would be indistinguishable from the target. Like previous studies using distractors in the search array, capture in this experiment will be assessed using the singleton costs alone (e.g., Theeuwes, 1994). However, it is important to note that singleton costs alone may reflect mere filtering costs (Becker, 2007; Folk & Remington, 1998). Nonetheless, this issue is still a matter of debate, which is why the approach is still widely used, and one would at least expect that singleton costs are correlated with attention capture. As in Experiments 1 and 2, perceptual load was manipulated via distractor similarity to control for salience across load conditions.

Method

Participants. A new sample of 40 University of New Mexico students participated for class credit.

Apparatus, stimuli, and procedure. The methods were the same as Experiment 1 except that no flankers were presented outside the array. Rather, a special distractor letter with a neutral identity to the target (A or B) was presented inside the six-letter search array. On half of the trials, this special distractor was a colour singleton. In high load blocks, the circular arrays consisted of a target letter, a special distractor (A or B), and four unique distractor letters. In low load blocks, the circular arrays consisted of a target letter, a special distractor (A or B), and four Os.

Results and discussion

One participant was excluded from analysis because of an unusually high error rate (more than 2.5 *SD*s above the group mean). Trials with an RT greater than 1500 ms or less than 200 ms (1.2%) or an inaccurate response were excluded from RT analyses. These RT outliers were also excluded from the error rate analyses. Mean RTs are shown in Figure 5 and Table 4.

A two-way repeated measures analysis of variance (ANOVA) was conducted on mean RTs with perceptual load (high versus low) and special distractor singleton status (singleton vs. nonsingleton) as factors. The analysis revealed shorter mean RTs on low load trials (550 ms) than high load trials (615 ms), $F(1, 38) = 186.192$, $MSE = 895.596$, $p < .001$, $\eta^2 = .831$, again indicating that our load manipulation was effective. RTs were significantly longer for singleton present trials (591 ms) than singleton absent trials (575 ms), $F(1, 38) = 29.352$, $MSE = 337.82$, $p < .001$, $\eta^2 = .436$, 95% CI (16 ± 5.9 ms). Critically, the two-way interaction of perceptual load and singleton status was nonsignificant, $F(1, 38) = 0.640$, $MSE = 0.429$, $p > .10$, $\eta^2 = .017$. This finding directly suggests that colour singletons were not able to enhance attentional capture under low perceptual load.

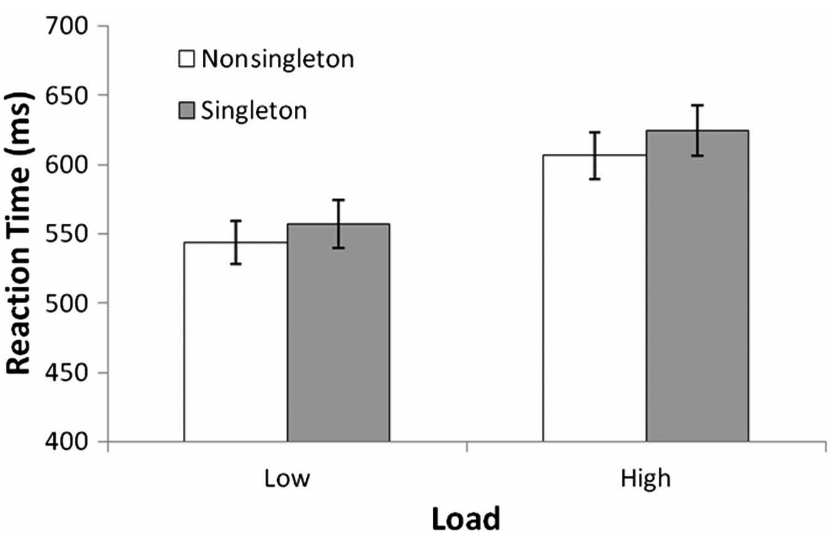

Figure 5. Mean reaction time (RT) in milliseconds in Experiment 4. The error bars are standard errors of the mean.

TABLE 4
Mean response times (RTs) in milliseconds and percentage of errors (PEs) as a function of perceptual load (low vs. high) and singleton status (singleton vs. nonsingleton) for Experiment 4

	Low		*High*	
	RT	*PE*	*RT*	*PE*
Singleton	557	4.4%	625	5.3%
Nonsingleton	543	3.4%	607	4.2%
Present–absent cost	13.9	1.0%	18.0	1.1%

Present–absent costs were calculated as singleton minus nonsingleton trials.

The same two-way repeated measures ANOVA was conducted on the mean error rates as well. Participants performed low load trials with fewer errors (3.9%) than high load trials (4.7%), $F(1, 38) = 5.288$, $MSE = 0.0005$, $p < .05$, $\eta^2 = .122$. Also, participants made more errors on singleton trials (4.8%) than nonsingleton trials (3.8%), $F(1, 38) = 8.21$, $MSE = 0.0005$, $p < .01$, $\eta^2 = .178$. The interaction of perceptual load and special distractor singleton status was nonsignificant, $F(1, 38) = 0.102$, $MSE = 0.0001$, $p > .10$, $\eta^2 = .003$.

To review, we moved the colour singleton inside the search array in Experiment 4, which significantly increased the overall singleton cost relative to Experiment 1 (16 ms vs. 2 ms), $t(74) = 3.87$, $p < .001$. If low perceptual load is critical for enabling capture by colour singletons, we would expect to see exaggerated singleton costs under low load. Contrary to this prediction, the overall singleton cost was no greater under low load (14 ms) than under high load (18 ms); in fact, the nonsignificant trend went in the wrong direction. This experiment therefore provides further evidence that perceptual load has little or no influence on the ability of colour singletons to capture attention.

GENERAL DISCUSSION

Many studies have failed to find entirely stimulus-driven capture by colour singletons (Folk & Remington, 1998; Folk et al., 1992, 1994; Franconeri & Simons, 2003; Jonides & Yantis, 1988; Lien et al., 2010), whereas other paradigms consistently produce capture by colour singletons (e.g., Belopolsky, 2007; Theeuwes, 1992, 1994). This contrast suggests that stimulus-driven capture by colour singletons, although not a general phenomenon, might nevertheless be possible under certain conditions. Perceptual load has previously been shown to strongly influence attention (Lavie, 1995; Lavie & Cox, 1997; Lavie & Fox, 2000; Lavie & Tsal, 1994). The classic explanation is that low load frees up attentional resources, which then are automatically applied to irrelevant items. Therefore, it seemed plausible that low load could enhance the capture of spatial attention by colour singletons. In fact, previous studies have demonstrated that capture by other salient features (e.g., abrupt onsets) is more likely under low perceptual load (Cosman & Vecera, 2009, 2010; Forster & Lavie, 2008). These studies indicate that load might in fact have a powerful influence on attentional capture, though the generality of this principle needs to be better established. Furthermore, low load seems to characterise many of the real-world situations in which, anecdotally, salient stimuli capture attention (e.g., a bright red stop sign on a barren desert road). In short, low load appears to be an ideal setting for a sensitive test of whether colour singletons can capture spatial attention.

We therefore conducted a series of experiments varying perceptual load, to determine whether low perceptual load frees attentional resources and therefore enables capture by task-irrelevant colour singletons. In Experiment 1, a flanker appearing outside of the search array was a colour singleton on half of the trials. If this flanker captured spare attentional resources under low perceptual load, we should have observed especially large singleton costs and compatibility effects on singleton trials relative to nonsingleton trials. We observed neither effect, suggesting that low load did not enable capture by colour singletons. In Experiment 2, we placed the flanker in the centre of the search array. We again found no evidence of enhanced singleton costs or enhanced compatibility effects for singleton flankers under low perceptual load. In Experiment 3, we manipulated perceptual load via set size rather than distractor similarity. Again, colour singletons did not enhance compatibility effects or singleton costs under low perceptual load. In fact, in the first three experiments, the pattern of compatibility effects (often thought to be a reliable indicator of attentional allocation) suggested that participants selectively ignored singleton flankers under low load, opposite to our hypothesis. In Experiment 4, we included the colour singleton as a distractor in the search array and assessed the effect of load on singleton costs alone. Although we found stronger singleton costs than previous experiments, these singleton costs were not greater under low load. To summarise, colour singletons failed to capture spatial attention, despite our concerted attempts to find the most favourable conditions. Note that we did not merely fail to find evidence of capture, but can actually rule out even a very small amount of capture. Pooling across Experiments 1–3, we find that singleton flankers (40 ms) produce smaller compatibility effects than nonsingleton flankers (47 ms), 95% CI (6.9 ± 3.3 ms).

Note that, in all of the present experiments, perceptual load produced large effects on mean RT (100 ms in Experiment 1, 103 ms in Experiment 2, 73 ms in Experiment 3, and 65 ms in Experiment 4). Perceptual load also reliably modulated compatibility effects, replicating the classic load effect. Hence, perceptual load did have a substantial overall effect in these experiments. Nevertheless, load did not specifically influence attention capture by colour singletons in any of our four experiments.

Relation to previous studies

Previous studies have demonstrated that low perceptual load, not flanker salience, accounts for compatibility effects in flanker paradigms (Biggs & Gibson, 2010; Gibson & Bryant, 2008). But because these studies had no nonsingleton control condition, they could not determine whether capture was due to a main effect, or an interaction between load and salience. According to the latter account, low load displays enhance capture by colour singleton flankers, and the extra allocation of spatial attention increase compatibility effects. Indeed, previous studies with abrupt onsets have shown such a pattern (Cosman & Vecera, 2009). The present study therefore directly addressed this issue. Although we found strong effects of perceptual load in all our experiments, low perceptual load did not allow for enhanced capture by colour singleton flankers. Thus, we support Gibson and Bryant's (2008) conclusion about colour singletons—large compatibility effects by such stimuli is indeed due to low load, not an interaction between load and salience.

Our results contrast with the finding that abrupt onsets and motion singletons capture attention more readily under low load than high load (Cosman & Vecera, 2009, 2010). From this, it appears that enhanced capture under low perceptual load is not a general principle of attentional capture. Rather, low perceptual load may selectively encourage capture by dynamic stimuli rather than static stimuli. Indeed, some research demonstrates that colour singletons cannot capture attention under conditions that dynamic stimuli do. These findings have led some researchers to conclude that static features like colour singletons are inherently less salient that dynamic features like abrupt onsets (Franconeri & Simons, 2003; Jonides & Yantis, 1988). The present results support this hypothesis by showing that capture by colour singletons does not occur under conditions that promote capture by dynamic stimuli.

Some researchers argue that colour singletons are never truly able to capture attention. Rather, only stimuli matching a viewer's attentional control settings can capture attention (Folk & Remington, 1998; Folk et al., 1992, 1994; Lien et al., 2010). Typical singleton costs observed by colour singletons may merely reflect filtering costs, instead of actual shifts of spatial attention (Becker, 2007; Folk & Remington, 1998). Our data fit such goal-driven theories remarkably well. In Experiments 1, 2, and 3, nonsingleton flankers produced larger compatibility effects than singleton flankers, which presumably mismatched the viewers attentional set. In other words, only stimuli matching the viewer's attentional control settings caused the typical compatibility effects in the flanker paradigm. In Experiment 4, where we were unable to assess compatibility effects, strong singleton costs were observed across load conditions. Given the general discrepancy with all previous experiments, these singleton costs were likely mere filtering costs. This data highlights the importance of using compatibility effects and cue validity effects, which reflect true shifts of spatial attention, rather than singleton costs, which are more ambiguous.

Slippage vs. leakage under low perceptual load

As already noted, we propose that compatibility effects indicate (at least in part) the allocation of spatial attention to the flanker (i.e., "slippage" of the attention, in the case of an irrelevant item). However, some researchers have argued that the compatibility effects do not indicate attentional capture (Gibson & Bryant, 2008). According to this account, flanker compatibility effects under low perceptual load are a result of semantic processing of flankers without spatial attention (i.e., ''leakage'' of semantic processing through the attentional filter, as in late selection theory).

There is reason to doubt that leakage is the only, or even the primary, cause of the flanker compatibility effects. Although many assume that flankers are truly unattended, this assumption has been sharply criticised. Lachter, Forster, and Ruthruff (2004) provide evidence that, unless several strict precautions are taken, it is easy for spatial attention to slip to the flankers. For instance, attention might be partially allocated to the flanker location before the stimuli appear, or might move there after the stimuli appear. Slippage of attention to the flanker might be even more likely under low perceptual load; when there is a low amount of task-relevant information, because there are fewer possible stimuli for attention to shift to. In fact, Johnson, McGrath, and McNeil (2002) directly supported the conclusion that the typical perceptual load effects reflect slippage not leakage. Using a 100% valid precue of the target location to deter slippage to the flanker location, flanker-compatibility effects were nearly eliminated, even under low perceptual load.

Even if load effects do reflect, in part, semantic processing without spatial attention (i.e., leakage), capture by the flanker should still further enhance compatibility effects (Becker, 2007; Remington, Folk, & McLean, 2001; Yantis & Johnston, 1990). It is difficult to imagine how leakage would be *increased* for a salient item, without presuming some sort of attentional slippage; indeed, this is essentially the definition of an attentional effect, though one could debate precisely which kind of attentional resource was allocated to the flanker. Because the present Experiments 1, 2, and 3 used a factorial design, we were able to assess whether flanker salience enhanced compatibility effects. We found no evidence of enhanced compatibility effects by singleton flankers. However, in Experiments 2 and 3, we did find smaller compatibility effects for singleton flankers than nonsingleton flankers under low perceptual load, suggesting that participants learned to selectively ignore colour singletons. This interaction highlights the importance of using a factorial design that allows for the interaction of salience, perceptual load, and flanker compatibility.

Perceptual load and dilution

Perceptual load is usually varied by manipulating the relevant set size or distractor similarity. The classic finding of reduced compatibility effects in high load displays is assumed to reflect an exhaustion of attentional resources, leaving no spare resources to process the task-irrelevant flanker. However, Benoni and Tsal (2010) have recently argued that the lack of compatibility effects with larger set sizes might instead reflect weaker representations of distractor items in memory, also known as *dilution*. The current results are consistent with the dilution interpretation, in that we also find no effect of load on attentional processes (i.e., on capture). Because the dilution account does not assume any spillover of spare attentional capacity onto distractors, it would seem to predict no extra capture by salient colour singletons under low load. That is, the dilution account correctly predicts the present results. However, the present experiments were not specifically designed to test between explanations of load effects, so further research is needed to clarify the relationship between perceptual load and dilution.

CONCLUDING REMARKS

There is a considerable debate as to whether colour singletons can capture attention in a purely stimulus-driven manner. We pointed out that low load might provide the most sensitive condition for observing such capture, because it is thought to free attentional resources, which are then automatically applied to other stimuli. We found no evidence for capture by colour singletons, despite using low load, and despite conducting four different experiments in search of the ideal conditions to enable capture. Pooled across the present experiments, our data are sufficiently precise to rule out even a tiny increase in compatibility effects under low load. If anything, we found evidence that participants selectively ignored these task-irrelevant singletons, indirectly supporting goal-driven theories of attentional capture. These findings also resolve a recent debate regarding whether salience or low load is responsible for compatible effects by colour singleton flankers (see Gibson & Bryant, 2008, and Theeuwes & Burger, 1998); the present data unequivocally indicate that the culprit was low load, not salience. Note that there are recent reports that load does enhance capture by abrupt onsets and moving targets (Cosman & Vecera, 2009, 2010). Consequently, this research provides new support for the claim that colour singletons are processed in a fundamentally different manner than dynamic stimuli such as abrupt onsets.

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REFERENCES

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

Becker, S. I. (2007). Irrelevant singletons in pop-out search: Attentional capture or filtering costs? *Journal of Experimental Psychology: Human Perception and Performance*, *33*, 764–787.

Belopolsky, A. V., Zwaan, L., Theeuwes, J., & Kramer, A. F. (2007). The size of an attentional window modulates attentional capture by color singletons. *Psychonomic Bulletin and Review*, *14*, 934–938.

Benoni, H., & Tsal, Y. (2010). Where have we gone wrong? Perceptual load does not affect selective attention. *Vision Research*, *50*, 1292–1298.

Biggs, A., & Gibson, B. (2010). Competition between color salience and perceptual load during visual selection can be biased by top-down set. *Attention, Perception and Psychophysics*, *72*, 53–64.

Cosman, J. D., & Vecera, S. P. (2009). Perceptual load modulates attentional capture by abrupt onsets. *Psychonomic Bulletin and Review*, *14*, 934–938.

Cosman, J. D., & Vecera, S. P. (2010). Attentional capture by motion onsets is modulated by perceptual load. *Attention, Perception, and Psychophysics*, *72*, 2096–2105.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception and Psychophysics*, *16*, 143–149.

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

Folk, C. L., & Remington, R. W. (2010). A critical evaluation of the disengagement hypothesis. *Acta Psychologica*, *135*, 103–105.

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

Folk, C. L., Remington, R. W., & Wright, J. H. (1994). The structure of attentional control: Contingent attentional capture by apparent motion, abrupt onset, and color. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 317–329.

Forster, S., & Lavie, N. (2008). Failures to ignore entirely irrelevant distractors: The role of load. *Journal of Experimental Psychology: Applied*, *14*, 73–83.

Franconeri, S. L., & Simons, D. J. (2003). Moving and looming stimuli capture attention. *Perception and Psychophysics*, *65*, 999–1010.

Gibson, B., & Bryant, T. (2008). The identity intrusion effect: Attentional capture or perceptual load. *Visual Cognition*, *16*, 182–199.

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

Johnson, D. N., McGrath, A., & McNeil, C. (2002). Cuing interacts with perceptual load in visual search. *Psychological Science*, *13*, 284–287.

Jonides, J., & Yantis, S. (1988). Uniqueness of abrupt visual onset in capturing attention. *Perception and Psychophysics*, *43*, 346–354.

Lachter, J., Forster, K. I., & Ruthruff, E. (2004). Forty-five years after Broadbent (1958): Still no identification without attention. *Psychological Review*, *111*, 880–913.

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human Perception and Performance*, *21*, 451–468.

Lavie, N., & Cox, S. (1997). On the efficiency of visual selective attention: Efficient visual search leads to inefficient distractor rejection. *Psychological Science*, *8*, 395–398.

Lavie, N., & Fox, E. (2000). The role of perceptual load in negative priming. *Journal of Experimental Psychology: Human Perception and Performance*, *26*, 1038–1052.

Lavie, N., & Tsal, Y. (1994). Perceptual load as a major determinant of the locus of selection in visual attention. *Perception and Psychophysics*, *56*, 183–197.

Lien, M., Ruthruff, E., & Cornett, L. (2010). Attentional capture by singletons is contingent on top-down control settings: Evidence from electrophysiological measures. *Visual Cognition*, *18*, 682–727.

Remington, R. W., Folk, C. L., & McLean, J. P. (2001). Contingent attentional capture or delayed allocation of attention? *Perception and Psychophysics*, *63*, 298–307.

Theeuwes, J. (1991). Exogenous and endogenous control of attention: The effect of visual onsets and offsets. *Perception and Psychophysics*, *49*, 83–90.

Theeuwes, J. (1992). Perceptual selectivity for color and form. *Perception and Psychophysics*, *51*, 599–606.

Theeuwes, J. (1994). Stimulus-driven capture and attentional set: Selective search for color and visual abrupt onsets. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 799–806.

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

Theeuwes, J., & Burger, R. (1998). Attentional control during visual search: The effect of irrelevant singletons. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 1342–1353.
Yantis, S., & Johnston, J. C. (1990). On the locus of visual selection: Evidence from focused attention tasks. *Journal of Experimental Psychology: Human Perception and Performance*, *16*, 135–149.
Yantis, S., & Jonides, J. (1990). Abrupt visual onsets and selective attention: Voluntary versus automatic allocation. *Journal of Experimental Psychology: Human Perception and Performance*, *16*, 121–134.