

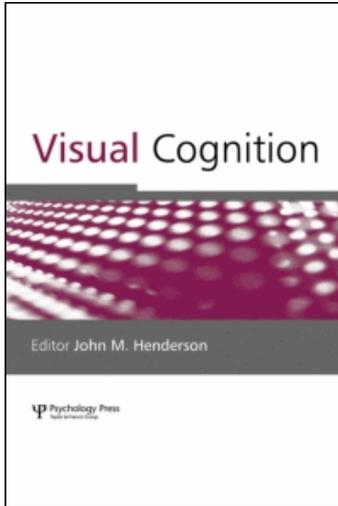
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You can't stop new motion: Attentional capture despite a control set for colour

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You can't stop new motion: Attentional capture despite a control set for colour

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When a stationary object begins to move, visual spatial attention is reflexively deployed to the location of that object. We tested whether this capture of attention by *new motion* is entirely stimulus driven, or whether it is contingent on an observer's goals. Participants monitored a visual display for a colour change, inducing an attentional control set (ACS) for colour. Across the three performed experiments, irrelevant new-motion cues always captured visual spatial attention, despite the ACS for colour. This persistence of the attentional cueing effect demonstrates that ACSs, in particular an ACS for colour, cannot prevent new motion from capturing attention. Unlike other stimulus types, such as luminance changes, colour singletons, and new objects, new motion may always capture attention regardless of an observer's goals. This conclusion entails that new motion is an important determinant of when, and to where, visual spatial attention is deployed.

Keywords: Attention capture; Attention control; Attentional control settings; Motion onset; New motion.

When a stationary object begins to move, visual spatial attention is reflexively deployed to the location of that object (Abrams & Christ, 2003, 2005a, 2005b, 2006; von Mühlénen & Lleras, 2007), allowing responses to visual stimuli presented at that location to be made more quickly. This form of attentional capture, referred to as capture by new motion (or the onset of motion), is particularly powerful. For example, an object that begins to move will dominate the allocation of reflexive attention even when presented concurrently with other salient stimuli, such as ones that are continuously moving, stationary, or cease to move (Abrams & Christ, 2003); although not ones that suddenly appear (i.e., new objects or object onsets; Christ &

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Abrams, 2008). Further, it has been argued that capture by new motion may be purely stimulus driven (Abrams & Christ, 2003; von Mühlenen & Lleras, 2007). That is, capture by new motion may not be contingent on an observer's goals but, rather, strictly automatic (Jonides, Naveh-Benjamin, & Palmer, 1985; Kahneman & Treisman, 1984). This conclusion would imply that new motion provides one of the most important determinants of the deployment of attention, as capture by other stimulus types, including luminance transients, singletons, moving objects, and new objects, is not automatic (e.g., Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994). For this reason, in the present study we directly test whether capture by new motion is stimulus driven, or whether it is contingent on an observer's goals.

ASSESSING ATTENTIONAL CAPTURE

The constraints for demonstrating that a stimulus captures attention counter to an observer's goals have been outlined in the attentional control setting (ACS) literature. According to the contingent involuntary orienting hypothesis (Folk et al., 1992, 1994), as an observer's task changes, he or she will adopt control settings that reflect the attentional demands of the new task. For example, if the task is to find a red stimulus among other nonred stimuli, then the observer will adopt an ACS for the colour red.¹ Once this particular ACS has been established, a stimulus will only capture attention if coloured in red. Other-coloured stimuli, regardless of whether they are singletons, appear suddenly, or are moving, will not capture attention, because these stimuli do not match the ACS, and are therefore irrelevant to the observer's goals (Atchley, Kramer, & Hillstrom, 2000; Bacon & Egeth, 1994; Chen & Mordkoff, 2007; Folk & Remington, 1998, 1999; Folk et al., 1992, 1994; Gibson & Amelio, 2000; Gibson & Kelsey, 1998; Lien, Ruthruff, Goodin, & Remington, 2008; Yantis & Egeth, 1999; although see Hickey, McDonald, & Theeuwes, 2006; Schreij, Owens, & Theeuwes, 2008; Theeuwes, 1991, 1992, 1994, 2004; Theeuwes, Atchley, & Kramer, 2000; for recent reviews, see Burnham, 2007; Ruz & Lupiañez, 2002). As such, ACSs allow the types of stimulus features that will capture attention to be specified in a top-down manner. Consequently, in order to demonstrate that a stimulus captures attention independently of an observer's goals, it must be demonstrated that this stimulus captures attention even when it is incompatible with the observer's ACSs.

¹ Unless the red target is always the only uniquely coloured stimulus, in which case the observer will adopt an ACS for singletons (Bacon & Egeth, 1994).

One ACS paradigm that has been effectively and repeatedly used to test for stimulus-driven attentional capture was developed by Folk et al. (1992). This paradigm employs a cueing task (Posner, 1980) in which the type of cue and the type of target are systematically manipulated. Participants are instructed to locate a visual target that will appear in one of multiple locations, and the target is presented in such a way that it can only be identified by a single stimulus feature, thus establishing an ACS for that feature. Just prior to the appearance of each target, a cue is presented at one of the possible target locations. If the cue captures attention, then it should cause the typical cueing effect, where participants' reaction times (RTs) are faster on valid-cue trials (i.e., when cue and target appear at the same location) than invalid-cue trials (i.e., when cue and target appear at different locations). Importantly, the test of whether capture by a particular feature is purely stimulus driven comes by incorporating that feature into the cue, and manipulating whether the target is defined, or not defined, by that feature. As an example, capture by new objects has been frequently assessed by having participants look for either a new-object target or a colour target. Using this type of cueing task, it has been demonstrated many times that new-object cues capture attention when participants are looking for a new-object target, but not when they are looking for a colour target (Ansorge & Heumann, 2003; Chen & Mordkoff, 2007; Folk & Remington, 1998; Folk et al., 1992, 1994; Lien et al., 2008; Pratt & McAuliffe, 2002), leading to the conclusion that attentional capture by new objects is not purely stimulus driven. Given its past success, this experimental paradigm provides a useful framework for assessing whether other stimulus types can capture attention counter to an observer's goals.

ATTENTIONAL CAPTURE BY NEW MOTION

In the present research, we will use this paradigm to gauge attentional capture by the onset of motion. The onset of motion, or new motion, refers to the moment when a visible but motionless object begins to move. Based on the argument that new motion may be an effective indicator of animacy (Dittrich & Lea, 1994; Tremoulet & Feldman, 2000), the saliency of motion onsets has recently become a topic of interest (Abrams & Christ, 2003, 2005a, 2005b, 2006; Christ & Abrams, 2008; Christ, Castel, & Abrams, 2008; von Mühlénen & Lleras, 2007). To test the assertion that new motion is especially salient, Abrams and Christ (2003) compared participants' performance on a visual search task when the target was a motion onset to when the target incorporated a different type of motion (i.e., was in motion continuously throughout the trial, or was a motion offset) or was static. When the target incorporated new motion, and the onset of motion

occurred as the visual search began, search times were independent of search set size, and were faster than for all other target types. Equivalently, when the onset of motion preceded the beginning of the visual search by 900 ms, search times were slower for motion onset targets than other target types, as would be expected if the onset of motion captured attention and generated inhibition of return. It has since been shown that the attentional priority for motion onsets can be achieved using the coherent motion of random dot patterns that are completely segregated from the target (von Mühlenen & Lleras, 2007), that it can be observed for the onset of translating, looming, and receding motion (although binocular-disparity depth cues may be necessary for capture by the onset of receding motion; Abrams & Christ, 2005a; Franconeri & Simons, 2005), and that it persists even in older adults, for whom stimulus-driven capture is thought to be intact, but top-down attentional systems degraded (Christ et al., 2008). Therefore, the capture of attention by new motion appears to be a particularly robust form of stimulus-driven attentional capture, and for this reason we investigate whether this capture is purely stimulus driven, or whether it can be controlled through ACSs.

There are reasons to both expect, and to not expect, that the onset of motion can capture attention counter to an observer's goals. On the one hand, it can be inferred that in a number of previous demonstrations of new-motion capture, capture occurred counter to observers' goals, supporting the possibility that the capture was purely stimulus driven. In most demonstrations of new-motion capture, attending to new motion cannot be used to improve task performance, and participants are explicitly instructed that the onset of motion is task irrelevant. These facts led both Abrams and Christ (2003) and von Mühlenen and Lleras (2007) to argue that there was no reason for the onset of motion to be part of their subjects' ACSs, and, therefore, that the observed capture was purely stimulus driven. The tasks used by both Abrams and Christ, and von Mühlenen and Lleras, however, are quite different from the typical tasks used to study ACSs. In particular, as the tasks in both studies were not designed to test ACSs, it is difficult to establish the precise control settings that participants had adopted, and, as has been shown before, the control settings that participants choose to adopt are often unclear until direct tests have been used to evaluate them (e.g., Bacon & Egeth, 1994; Gibson & Kelsey, 1998). Therefore, although prior demonstrations of capture by motion onsets suggest that the capture may be purely stimulus driven, a direct test of ACSs is needed before any conclusions can be made.

On the other hand, there are also a number of reasons to believe that ACSs can eliminate attentional capture by motion onsets. In one of the first demonstrations of ACSs, Folk et al. (1994) had participants search for a target in the presence of irrelevant motion cues. When the target was defined

by motion (which is different than the onset of motion), motion cues captured attention, but when the target was defined by colour, motion cues did not capture attention. Thus, a colour ACS prevented capture by motion. Interestingly, it is possible that the stimuli used by Folk et al. as motion cues may have produced motion onsets. To create apparent motion, cues were presented for three consecutive 40-ms frames, with slight changes in orientation across each frame. All subjects reported perceiving rotational motion, but it is unclear whether they perceived one continuous motion (i.e., a motion cue only) or two abrupt movements (i.e., a motion onset(s) cue). It is even less clear how the subjects' attentional systems will have perceived this stimulus. Certainly, Folk et al. have demonstrated that an ACS can prevent capture by motion cues. It is possible, however, that they have already demonstrated that an ACS can also prevent capture by motion onsets.

A recent investigation by Christ and Abrams (2008) provides further evidence that ACSs may be able to prevent new-motion capture. In this study, Christ and Abrams first demonstrated that the onset of a new object may have a greater impact on the allocation of attention than new motion, which is suggestive, as it has been repeatedly demonstrated that ACSs can prevent new objects from capturing attention. More importantly, these authors also provided evidence that new objects can suppress the attentional effects of new motion, possibly indicating that capture by new motion is not strictly automatic. Thus, this study, and that by Folk et al. (1994), provide circumstantial evidence that new-motion capture can be controlled by ACSs, although a direct test of ACSs is clearly necessary before any conclusions can be made.

In the present study, we directly test whether ACSs can eliminate attentional capture by new motion. In particular, building off past research that has demonstrated that an ACS for colour can eliminate capture by new objects, we test whether the same ACS for colour can eliminate capture for new motion. To preview the results, throughout the three reported experiments, irrelevant new motion always captured attention, even when capture by other irrelevant stimuli was suppressed by an ACS for colour.

EXPERIMENT 1

The purpose of Experiment 1 was to provide an initial assessment of whether an ACS for colour can prevent attentional capture by new motion. Participants monitored two white triangles, which were presented inside white square placeholders, until one triangle changed colour to red (see Figure 1 for a depiction of a sample trial sequence). Participants had to report which triangle turned red, inducing them to adopt an ACS for the

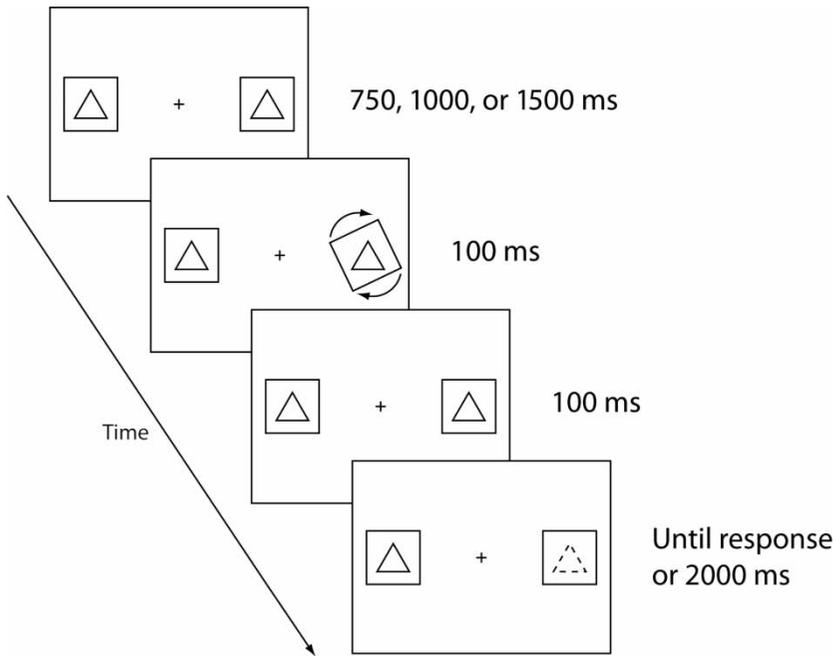


Figure 1. A sample trial sequence from Experiment 1. Following a fixation display, one of the two rectangular placeholders either began to rotate clockwise, or changed colour from white to red. After 100 ms, the fixation display reappeared and remained present until the target appeared 100 ms later. As a target, one triangle changed colour. In the depicted trial, the cue is a new-motion cue (red is depicted as a dashed line). Black and white are reversed in the figure.

target colour. Shortly before the target appeared, a cue was presented; either one of the placeholders began to move (i.e., rotate), or one of the placeholders changed colour to red. If attentional capture by new motion is contingent on ACSs, then new-motion cues should be effectively ignored and should not affect participants RTs to report the target's location. If, on the other hand, capture by new motion is purely stimulus driven, then new-motion cues should not be ignored and RTs should be shorter following valid new-motion cues than invalid new-motion cues.

As noted earlier, the main purpose of this experiment was to provide an initial assessment of whether or not new-motion capture is contingent on ACSs. This initial assessment will then provide the direction for the subsequent experiments in the present study. On the one hand, if no new-motion cueing effects are found, there is initial evidence that new motion is contingent on ACS, and subsequent experiments will confirm that our new motion cues can indeed capture attention when they are task relevant (i.e., when participants are looking for a new-motion target). On the other hand,

if new-motion cueing effects are found, there is initial evidence that new-motion capture is not contingent on ACSs, and subsequent experiments will confirm the integrity of the colour-based ACS. Thus, the results of Experiment 1 will guide which of these two directions is required to assess the automaticity of new-motion attentional capture.

Method

Participants. Nine undergraduate students at the University of Toronto received partial credit towards an introductory psychology course as compensation for their participation. All participants reported having normal, or corrected to normal, vision.

Apparatus and procedure. The experiment was conducted on a PC computer with a VGA monitor and a head/chinrest, and responses were made on a standard keyboard. Displays were presented at a resolution of 1024×768 pixels, using a refresh rate of 85 Hz. Animation frames for new-motion cues were generated in real time at more than 60 frames per second, producing a smooth continuous movement.

The experimental session consisted of three blocks of 72 trials each.² Each trial began with the presentation of a fixation point, two placeholder boxes, and two target triangles (see Figure 1). The fixation point was a white (RGB: 255, 255, 255) cross in the centre of the display and subtended 0.8° of visual angle horizontally and vertically. The two placeholder boxes were white outlines of squares located 7° to the left and right of fixation (all reported distances are from the centres of stimuli). The sizes of the squares were such that they could be inscribed within an invisible circle 6° in diameter. The two target objects were white outlines of equilateral triangles, each centred within a placeholder, and inscribed in an invisible circle 3° in diameter. All stimuli were drawn using line widths of 0.1° . Following a random delay of 750, 1000, or 1500 ms, one placeholder was randomly cued using either a colour cue or a new-motion cue. For colour cues, the placeholder became red (RGB: 255, 0, 0) for 100 ms. For new-motion cues, the placeholder rotated 90° clockwise over 100 ms. One of the target triangles, determined randomly, then changed colour from white to red 200 ms after the onset of the cue, and remained present until a response was made or 2,000 ms had elapsed. Participants

² In addition to the blocks of trials where subjects looked for colour targets, participants in Experiments 1 and 2 also completed blocks of new-motion target trials (target type alternated on blocks in Experiment 1, and was switched half-way through the session in Experiment 2). New-motion target trials were not included in Experiment 3. The results of these blocks of new-motion target trials are not reported because they test a different question than the one being addressed in the present study, namely: Can an ACS for new motion be adopted? For completeness, the results from these trials are presented in the Appendix.

reported the location of the target (Z-key for left, and /-key for right), and response times (RTs) and accuracy were recorded. Cue location was not predictive of target location. This procedure resulted in a two-factor experimental design, with all factors being completely crossed within subjects: Cue type (colour cue vs. new-motion cue), and cue validity (valid vs. invalid). Before the experiment began, participants completed a separate set of 32 trials for practice, and responses were not recorded.

Results and discussion

Trials during which an error was made (1.7% of trials), or the RT did not fall within 2.5 *SDs* of the participants mean RT (1.4%), were excluded from the analyses that follow.

Reaction times were analysed using a 2 (cue type) \times 2 (cue validity) within-subjects ANOVA in order to assess whether only colour cues would capture attention, or whether both colour and new-motion cues would capture attention. This analysis revealed a significant effect of cue validity, $F(1, 8) = 21.47$, $MSE = 421.58$, $p = .002$. The effect of cue type was not significant, $F(1, 8) = 4.14$, $MSE = 244.30$, $p = .076$, nor was the two-way interaction, $F < 1$. The main effect of cue validity (and the absence of a two-way interaction) demonstrates that both colour cues and new-motion cues caused significant attentional capture. These cueing effects (invalid RTs minus valid RTs) are plotted in the white bars of Figure 2, and the simple effects of cue validity were confirmed using paired samples *t*-tests (Table 1). Although new motion was irrelevant to the participants' task, and should have been incompatible with their ACSs, new-motion cues nevertheless captured attention.

In Experiment 1, we observed that even though participants were searching for the colour red, new-motion cues presented in white captured attention. This result provides initial evidence that the effect of new motion on visual spatial attention is stimulus driven and operates independently of ACSs. It is worth noting that the new-motion cues in Experiment 1 incorporated new motion, (old) motion, and motion offset signals. As a result, the observed attentional capture could be attributed to any of these signals. Given prior demonstrations that capture by new motion can override capture by both motion and motion offset (e.g., Abrams & Christ, 2003), and further that ACSs prevent motion and motion offsets from capturing attention (Folk et al., 1994), we attribute the observed capture specifically to new motion.

One important limitation of Experiment 1 is that it provides no evidence that participants had established the expected ACSs. That is, capture was observed in every condition, and so it is unclear what types of features were

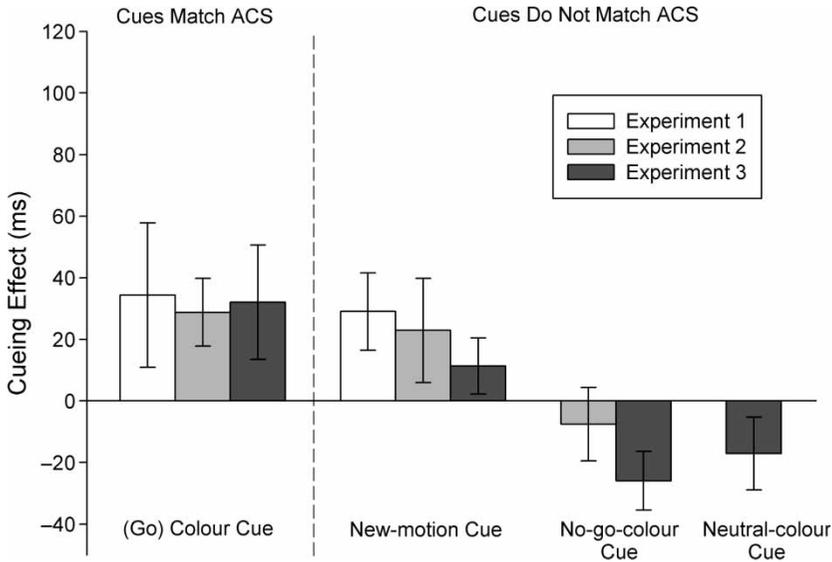


Figure 2. Mean cueing effects (invalid minus valid reaction times) of Experiments 1, 2, and 3. Go-colour cues, which were presented in the go-target colour, facilitated responses to targets at the cued location relative to the uncued location; no-go colour cues did not, demonstrating that participants had adopted an attentional control set (ACS) for colour. Despite this control set, new-motion cues produced facilitation at cued locations in all three experiments, suggesting that an ACS for colour cannot prevent attentional capture by new motion. Error bars are 95% confidence intervals on the cueing effects.

excluded from participants' control sets. Further, although participants were instructed to attend for a specific feature (the colour red), the task itself did not preclude them from implementing more broadly defined sets. For example, participants could have performed the task by identifying the target triangle based on a visual property shared between the colour and new-motion stimuli, such as local changes in luminance. Given the resulting ACS for luminance transients, it is possible that this could account for the observed capture by new-motion cues in Experiment 1. Similarly, it could be argued that participants entered into a singleton search mode (finding the target based on its status as the only singleton on target displays), rather than the instructed feature search mode (Bacon & Egeth, 1994). Experiment 2 was designed to replicate the results of Experiment 1, and to evaluate these alternate accounts of the observed persistence of new-motion capture.

A second limitation of Experiment 1 is that, because participants were required to report the location of the target, the observed cueing effects may be attributable to a response activation bias rather than attentional capture. For example, cues on the left side of the monitor may have preactivated the

TABLE 1
Cueing effects by cue type

<i>Cue</i>	<i>Exp.</i>	<i>Valid RT (SD)</i>	<i>Invalid RT (SD)</i>	<i>T</i>	<i>df</i>	<i>p</i>
Go-colour	1	326 (44)	360 (54)	3.39	8	.010
	2	398 (59)	424 (56)	5.37	12	<.001
	3	343 (46)	375 (34)	3.77	12	.003
New-motion	1	318 (37)	347 (43)	5.34	8	<.001
	2	414 (48)	435 (60)	2.76	12	.017
	3	354 (40)	365 (39)	2.71	12	.019
No-go-colour	2	448 (70)	443 (68)	-0.86	12	.407
	3	376 (34)	350 (38)	-5.90	12	<.001
Neutral-colour	3	369 (34)	353 (40)	-3.15	12	.008

t-values are from two-tailed paired samples *t*-tests comparing mean valid to mean invalid RTs for each condition.

response for targets on the left side of the monitor, speeding responses to these targets independently of attentional capture. To avoid this response activation bias, in Experiment 2 participants were required to discriminate the colour of the target, rather than its location.

EXPERIMENT 2

In Experiment 2, the procedure from Experiment 1 was modified to directly test whether participants adopted the expected ACS or not. Rather than requiring participants to discriminate the location of a target that appeared on every trial, a go/no-go task was employed so that, on no-go trials, a nontarget was presented that forced participants to adopt very specific ACSs. Specifically, the no-go target differed from the go target by only a single feature, and, therefore, participants had to attend to this specific feature of the target to perform the task optimally. In this experiment, some participants were told to respond to the appearance of red triangles, but not green triangles (for the remaining participants, the colours were reversed), preventing them from using noncolour visual properties, such as luminance, to identify the target. Importantly, an additional cue type was included to more thoroughly assess the status of participants ACSs. In particular, colour cues were presented on some trials in the no-go colour. As such, this cue/target configuration provides one condition where, if the paradigm successfully generates an ACS for a specific colour, capture should be eliminated. Therefore, if participants adopt the intended colour ACS (rather than, for example, an ACS for luminance transients) go-coloured cues should capture attention, but no-go-coloured cues should not.

Method

Participants. Thirteen undergraduate students at the University of Toronto received partial credit towards an introductory psychology course as compensation for their participation. All participants reported having normal, or corrected to normal, vision.

Apparatus and procedure. The apparatus was the same as that used in Experiment 1, as were the stimuli and display layouts (Figure 1). The procedure, however, was modified in the following ways. Participants completed six blocks of 60 trials, for a total of 360 trials. Participants were required to press the spacebar when one of the target triangles turned a specified colour, either red (RGB: 255, 0, 0) or green (RGB: 0, 255, 0) as counterbalanced across subjects, and withhold responding for 2 s if the alternate colour appeared. The target colour and the alternate colour were equally likely to occur on any trial, and each trial was equally likely to require a keypress response or a withholding of response. Prior to the appearance of the target feature, four possible feature changes could occur to one of the placeholders as a cue: The colours red or green could appear, or clockwise or counterclockwise motion could begin. This allowed us to use three cue types; relative to the target colour, cues could be presented with the go colour, the no-go colour, or new motion. Each of the four features were equally likely to appear as a cue, and, as with Experiment 1, cues were not predictive of the target locations. This procedure resulted in a three-factor experimental design, with all factors being completely crossed within subjects: Colour counterbalancing (red go colour and green no-go colour, and vice versa), cue type (go-colour cue vs. no-go-colour cue vs. new-motion cue), and cue validity (valid vs. invalid).

Results and discussion

Trials during which an error was made (0.5% of trials), or the RT did not fall within 2.5 *SDs* of the participants mean RT (1.4%), were excluded from the analyses that follow. Because the effect of colour counterbalancing did not interact with any other experimental factors, analyses were collapsed across this factor.

A 3 (cue type) \times 2 (cue validity) within subjects ANOVA was performed on the RTs in the colour-target condition, and revealed significant effects of cue type, $F(2, 24)$, $MSE = 651.43$, $p < .001$, and cue validity, $F(1, 12) = 20.12$, $MSE = 209.65$, $p = .001$. These main effects were qualified by a significant two-way interaction, $F(2, 24) = 9.07$, $MSE = 272.52$, $p = .001$, which reflects the significant cueing effects of go-coloured cues and new-motion cues, but

not no-go-coloured cues, as can be seen in the light-grey bars of Figure 2, and as confirmed by paired samples *t*-tests of the simple effects of cue validity (Table 1). Therefore, when participants looked for a colour target, they established an ACS that appropriately allowed go-coloured cues to capture attention, but prevented no-go-coloured cues from capturing attention. Despite this ACS for colour, new-motion cues continued to capture attention.

The results of Experiment 2 replicate those of Experiment 1. Despite an ACS for colour, the onset of motion once again captured attention. Importantly, Experiment 2 extends the results of Experiment 1 by providing an indication of the actual state of participants ACSs. Namely, no-go colour cues did not capture attention, revealing that participants had established an ACS that was specific to the target colour. Therefore, the persistence of capture by new-motion cues cannot be attributed to participants having adopted either an ACS for a noncolour feature, such as luminance, nor the singleton-search mode. Instead, these results again point to the conclusion that capture by new motion is stimulus driven.

There is, however, one potential confound in Experiment 2 that limits the strength of this conclusion. Because, participants were required to inhibit responses to no-go coloured targets, the absence of a cueing effect for no-go coloured cues may reflect response inhibition at the cued location, generated by the presence of the no-go target colour. That is, no-go colour cues may have captured attention, speeding responses on valid cue trials, but this benefit was offset by response inhibition. The purpose of Experiment 3 was to assess whether the absence of the no-go coloured cueing effect can be attributed to an ACS specific for the target colour (as concluded previously), or whether it is attributable to response inhibition.

EXPERIMENT 3

Experiment 3 replicates Experiment 2, and extends it by adding one cue type. In addition to the go-colour, no-go-colour, and new-motion cues, a fourth neutral-colour cue was included. This neutral-colour cue was equivalent to the new-motion cue in that it never appeared as either the go-target feature or the no-go target feature. Thus, if the absence of the cueing effect for no-go colour cues in Experiment 2 is attributable to the inhibition of the no-go target feature, then the neutral-colour cue should capture attention. If, however, participants did indeed adopt an ACS in Experiment 2 that prevented no-go-colour cues from capturing attention, then this neutral-colour cue should also fail to capture attention. Such a result would again point to the conclusion that a colour ACS does not prevent new motion from capturing attention.

Method

Participants. Twelve undergraduate students at the University of Toronto received partial credit towards an introductory psychology course as compensation for their participation. All participants reported having normal, or corrected to normal, vision.

Apparatus and procedure. Experiment 3 was similar to Experiment 2, but differed in that one cue type was added to the task: The neutral-colour cue. The target feature was a colour change to either red (RGB: 255, 0, 0) or blue (RGB: 0, 64, 255); colour was counterbalanced across subjects. The colour of the no-go target, which appeared simultaneously with the target, was always green (RGB: 0, 255, 0). There were four cue types: Go colour (the target colour), no-go colour (a green cue), neutral colour (blue for red targets, and red for blue targets), and new motion (clockwise rotational motion). Each cue condition was equally likely to appear, and was not predictive of the target location (producing balanced numbers of valid and invalid trials). Subjects performed six blocks of 80 trials each. All other aspects of the experiment, such as the timings of stimuli and the response scheme, were the same as in Experiment 2.

Results and discussion

Trials during which an error was made (2.7% of trials), or the RT did not fall within 2.5 *SDs* of the participants mean RT (2.7%), were excluded from the analyses that follow. Because the effect of colour counterbalancing did not interact with any other factors, all analyses were collapsed across this factor. The mean cueing effect for each condition is presented in Figure 2 using dark grey, and differences between these effects were assessed through a 4 (cue type) \times 2 (cue validity) within-subjects ANOVA on RT. Both main effects were not significant, $F_s < 1$. An interaction, however, was found, $F(3, 36) = 20.35$, $MSE = 225.77$, $p < .001$, indicating that the cueing effect varied for the four cue types. As revealed by individual paired-samples *t*-tests, this interaction resulted from significant cueing effects for both go-colour cues and new-motion cues, but reversed cueing effects for both no-go-colour cues and neutral-colour cues (Table 1).

As with Experiments 1 and 2, new-motion cues in Experiment 3 captured attention despite being task irrelevant. Importantly, Experiment 3 also resolves the potential confound of Experiment 2. Specifically, as the colour of the neutral-colour cue was never presented as a feature of the no-go target, the absence of a cueing effect for this cue cannot be attributed to response inhibition. Rather, this result supports the conclusion that capture

was prevented by an ACS for the target colour. Therefore, we have a clear demonstration that new motion captures attention despite an ACS for colour.

GENERAL DISCUSSION

The purpose of the present research was to evaluate if ACSs can eliminate attentional capture by new motion. Specifically, we asked whether subjects who are set to respond to a colour change can successfully ignore irrelevant new motion. Although it has been repeatedly demonstrated that a colour ACS will prevent nonmatching stimuli from capturing attention, in the three experiments reported in the present paper, new motion always captured attention regardless of participants ACSs. In Experiment 1, we demonstrated that when looking for a colour change, irrelevant new motion nevertheless caused a cueing effect, speeding RTs for valid cues relative to invalid cues. In Experiment 2, we demonstrated that the persistence of the new-motion cueing effect cannot be attributed to participants having adopted a very general ACS that included both colour and new motion, as their ACSs were sufficiently specific to eliminate capture by a colour change to the no-go target colour. Finally, in Experiment 3, we confirmed that the elimination of capture by nonmatching colour changes occurs for changes to multiple colours, not just to the colour of the no-go target. These results converge on the conclusion that an ACS for colour does not prevent new-motion cues from capturing attention.

Before accepting this conclusion, there are two alternate explanations for the persistence of new-motion capture in the present study that are worth considering. First, cues and targets in all experiments were always separated by a delay 100 ms, and this fixed timing may have encouraged participants to use the cues to predict the timing of the upcoming target. Further, although coloured stimuli can be localized preattentively (e.g., Treisman & Gelade, 1980), attention may be necessary to localize moving stimuli (e.g., Kerzel, 2003). Therefore, if participants adopted a strategy of using cue onsets to predict the timing of targets, this may have resulted in the allocation of attention to new-motion stimuli, thus accounting for the persistence of new-motion capture despite the elimination of colour capture. This account is possible, but it is unlikely because, although perception of motion may require attention, the employed new-motion cues also produced local luminance transients which, like colour, could be perceived preattentively. Therefore, attention to new-motion cues was no more necessary than attention to colour cues in order to predict the timing of upcoming targets.

The second alternate account of the persistence of new-motion capture despite an ACS for colour comes from the possibility that the employed

new-motion cues, which were drawn as white square outlines rotating on a black background, may have induced the perception of colour. This type of illusory perception of colour has been demonstrated previously for rotating black and white stimuli, and is typically referred to as pattern induced flicker colours (PIFCs), the colours of Benham's top, or Benham-Fechner colours (Benham, 1894; von Campenhausen & Schramme, 1995). If it was the case that new-motion cues produced an illusory perception of colour, then it is possible that they captured attention because the cues did in fact match the colour ACS. There are two reasons, however, why this possibility is unlikely. First the stimuli used to generate PFICs are quite different than that of the employed new-motion cues. Benham tops are typically a disc composed of a light and a dark hemisphere, with dark arcs drawn on the lighter hemisphere. The dark hemisphere and arcs are noticeably missing from the employed new-motion cues. Second, the speed of rotation at which PFICs are observed (about 8 Hz; Jarvis, 1977) are triple the speed of rotation used for our new-motion cues (2.5 Hz). Thus, it is unlikely that PFICs can account for the persistence of new-motion capture. Instead, it can be concluded that an ACS for colour cannot prevent new-motion from capturing attention.

Much of the focus of the attentional capture literature has been to determine whether new objects or luminance transients (Enns, Austen, Di Lollo, Rauschenberger, & Yantis, 2001; Folk & Annett, 1994; Franconeri, Hollingworth, & Simons, 2005; Jonides & Yantis, 1988; Theeuwes, 1990; von Mühlenen, Rempel, & Enns, 2005; Yantis & Hillstrom, 1994) provide the larger determinant of attentional capture. As such, in light of past research that has demonstrated that a colour ACS will prevent irrelevant new objects and luminance transients from capturing attention, it is particularly interesting that a colour ACS cannot prevent capture by new motion. We do not take this as evidence that new motion produces a stronger form of attentional capture than new objects or luminance transients. Indeed, as demonstrated by Christ and Abrams (2008), when both new motion and new objects are task relevant, the allocation of attention appears to be preferentially determined by new objects. Unlike new objects and luminance transients, however, new motion may always capture attention independently of an observer's goals. This possibility fits nicely with the notion that new motion is salient because it provides an indication of animacy. Given the importance placed on detecting animate objects (e.g., Gelman, 1990; Thorpe, Fize, & Marlot, 1996), it may be that new motion always captures attention to some extent, but that new objects dominate capture when they are task relevant.

In addition to the demonstration that a colour ACS does not prevent new motion from capturing attention, we also observed an interesting finding, relating to the effect of nonmatching colour cues in Experiment 3. The effect of ACSs is to prevent irrelevant cues from speeding responses to targets

appearing at cued locations. Typically, the result is that irrelevant cues are prevented from having any spatial effect on RTs. In Experiment 3, however, rather than simply eliminate the RT facilitation at the cued location, the ACS manipulation actually reversed the effect, hindering responses at the cued location. It is unclear as to what this reversal of the cueing effect should be attributed. One possibility is that when people are faced with many salient, but irrelevant, stimuli their visual systems begin to actively inhibit these stimuli to prevent them from reaching later stages of cognitive processing. In support of this possibility, it is interesting to note that there was a trend across the cue conditions of Experiments 1 to 3, that as the number of irrelevant cue types increased, cues that did not match the ACS produced decreasing cueing effects (the new-motion cueing effect decreased from 29 to 11 ms, and the nonmatching colour cueing effect decreased from -8 to -26 ms). Thus, it may be that including irrelevant new-motion cues caused distractors to be sufficiently salient that irrelevant cues were inhibited to the point of slowing responses at the cued location. Although it is an interesting possibility that increasing the amount, and saliency, of irrelevant distractors can cause irrelevant information to be inhibited, future work is clearly required to validate this possibility.

Implications for new motion

Beyond our primary question of interest, whether or not an ACS for colour can prevent new-motion capture, the present results also add to our understanding of how new motion influences the human attentional system. In an early test of motion, Hillstrom and Yantis (1994; see also Yantis & Egeth, 1999) observed that irrelevant motion (i.e., a stimulus that appears in motion) does not capture attention, but that when one member of a perceptual group of static stimuli begins to move, that stimulus does capture attention. To account for this finding, the authors argued that the onset of motion captured attention because it caused the moving stimulus to be segregated from the perceptual group and, therefore, required the creation of a new object file (Kahneman & Treisman, 1984; Kahneman, Treisman, & Gibbs, 1992). That is, new motion is salient because new-motion stimuli are perceived as new objects by the attentional system. The results of the present study, however, suggest otherwise. To be specific, although the segregation of one item from a set of new objects may capture attention because it requires the creation of a new object file, this effect occurs independently of the onset of motion (Christ & Abrams, 2006). Were it the case that new motion captures attention because it signals the appearance of a new object, then an ACS for colour should eliminate capture by new motion, because it has previously been demonstrated that an ACS for colour can eliminate capture

by new objects (Ansorge & Heumann, 2003; Chen & Mordkoff, 2007; Folk & Remington, 1998; Folk et al., 1992, 1994; Lien et al., 2008; Pratt & McAuliffe, 2002). We have demonstrated, however, that an ACS for colour does not eliminate capture by new motion, suggesting that the saliency of new motion is not derived from the saliency of new objects.

Our results also add to the debate surrounding the saliency of receding motion. In a test of their behavioural urgency hypothesis, Franconeri and Simons (2003) observed that receding motion does not capture attention. Specifically, they observed that when receding motion is simulated by having a visual stimulus begin to shrink, the stimulus does not capture attention (see also, von Mühlenen & Lleras, 2007). As noted by Abrams and Christ (2005b), this shrinking stimulus did not capture attention despite producing a motion onset signal. In response to this potential demonstration that new motion does not always capture attention, Abrams and Christ (2005b) have shown that the onset of receding motion does capture attention when it is presented using stereoscopic depth cues. From this, they argued that the receding motion used by Franconeri and Simons was perceived to be shrinking rather than motion. Abrams and Christ (2005b, 2006) further clarified this point by arguing that the retinal motion induced by changes in luminance-defined contours are insufficient to generate the new-motion signal that will capture attention; instead, new-motion capture results from the perceived movement of an internally represented object. Thus, a change in an object's shape or size, such as the shrinking used by Franconeri and Simons, is insufficient to capture attention.

In accordance with this account of the effects of receding motion on the capture of attention, it has been repeatedly demonstrated that the onset of translational motion causes new-motion capture, presumably because the internal representation of the object's location must be updated (Abrams & Christ, 2003, 2005a, 2005b; Christ & Abrams, 2008). The rotational-motion stimuli used in the present study, however, are in some ways more similar to the receding motion used by Franconeri and Simons (2003) than to translational motion. In particular, the rotation of cues in the present study did not require any change to the internal representation of the cue's location. Nevertheless, we observed robust capture by these cues, suggesting that their motion was perceived as new motion. This finding can be accounted for by the demonstration that neurons in the dorsal division of the (macaque) medial superior temporal cortex (MSTd) are sensitive to changes in orientation (Orban, 2008; Sugihara, Murakami, Shenoy, Andersen, & Komatsu, 2002; Tanaka & Saito, 1989; Zeki, 1974). Thus, our results accord with the conclusion of Abrams and Christ (2005b, 2006) that the saliency of new motion results from the processing of higher order motion, for which MST is largely responsible, rather than the low-level retinal motion generated by changes in an object's contour. Further, our

results add to the types of stimulus changes that can produce new-motion capture. New-motion capture does not occur when an object starts to change size (i.e., shrink; Abrams & Christ, 2005b), but will occur when the object starts to change location or, as demonstrated in the present study, when it starts to change orientation.

Implications for attentional control settings

Our results suggest one of two, equally interesting, consequences for ACSs. On the one hand, our results may suggest that ACSs are incapable of preventing new-motion capture. This conclusion may seem surprising, especially given that ACSs can prevent capture by new objects, luminance transients, colour transients, singletons, and (old) motion, but this is the result posited by Abrams and Christ (2003) and by von Mühlenen and Lleras (2007). Further, this conclusion coheres with past demonstrations that motion can be used to segregate the processing of visual stimuli (Gibson & Carmichael, 1966; Regan & Beverley, 1984; Rogers & Graham, 1979; Southall, 1962). In particular, it has been proposed that the visual system possesses a “movement filter” that allows moving stimuli to be attended and represented separately from stationary stimuli (McLeod, Driver, Dienes, & Crisp, 1991). In addition, based on the observation that new motion induces an event-related-potential evoked-visual-response in which early sensory components (i.e., the N170) are sensitive to attention to motion, it has been argued that this motion filter must segregate stationary from moving elements at early stages of visual processing (Lopez, Rodriguez, & Valdes-Sosa, 2004). Thus, it may be the case that attentional capture by new motion cannot be prevented by ACSs, because new motion triggers the instantiation of the motion filter in a stimulus-driven fashion, which then necessitates attention to the newly created moving representation. Under this possibility, capture by new motion is purely stimulus driven.

On the other hand, it may not be that ACSs cannot prevent new-motion capture, but rather that ACSs are always attuned to new motion, because new motion is behaviourally relevant. This possibility is compatible with a recent account of demonstrations that a colour ACS does not prevent new objects from capturing attention when they are only presented infrequently (Folk & Remington, 2007; Neo & Chua, 2006). Drawing from the work of Sokolov (1963; see also, Friston, Kilner, & Harrison, 2006) on the orienting response, Folk and Remington have suggested a habituation account of these findings. One task of the central nervous system is to develop predictions, or expectations, of the states of its sensory world, and when sensory events are discordant with these predictions an orienting response is elicited. Accordingly, when new objects are presented frequently as irrelevant distractors, these

onsets can be predicted and, therefore, cease to capture attention. In contrast, when new objects are presented only infrequently, no such predictions are made, and capture by new objects persists. This framework provides one potential account of the present results. Namely, new motion may always capture attention independently of an observer's goals, because the central nervous system does not include new motion in its sensory predictions. That is, ACSs are always attuned to new motion, because new motion always presents an unpredicted stimulus event that should be attended.

CONCLUSIONS

In the present study we observed that task-irrelevant new motion always captured attention. In particular, when a participant's goal was to search for a specific colour, the resulting colour ACS did not prevent visual spatial attention from being allocated to irrelevant new-motion cues. This observation may indicate that capture by new motion is not contingent on ACSs, and rather that new motion causes a form of attentional capture that is entirely stimulus driven. Alternatively, it may indicate that ACSs are always attuned to new motion because, as an indicator of animacy, new motion is always goal relevant. Whichever is the case, these results demonstrate that new motion provides a particularly important determinant of the deployment of visual spatial attention. Specifically, it would appear that ACSs do not prevent new motion capture and, therefore, whatever tasks an observer is performing, new motion may always capture attention.

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APPENDIX

Results from new-motion target trials according to cue type

Cue	Exp.	Valid RT (SD)	Invalid RT (SD)	<i>t</i>	<i>df</i>	<i>p</i>
Go new-motion	1	333 (45)	394 (67)	6.61	8	<.001
	2	468 (86)	540 (95)	6.48	12	<.001
Colour	1	353 (43)	389 (57)	5.44	8	<.001
	2	499 (83)	548 (96)	4.44	12	<.001
No-go new-motion	2	533 (79)	563 (101)	3.32	12	.006

t-values are from two-tailed paired samples *t*-tests comparing mean valid to mean invalid RTs for each condition. For some participants, go and no-go new-motion were presented as clockwise and counterclockwise rotational motion, respectively; for the remaining participants, direction of motion was reversed.