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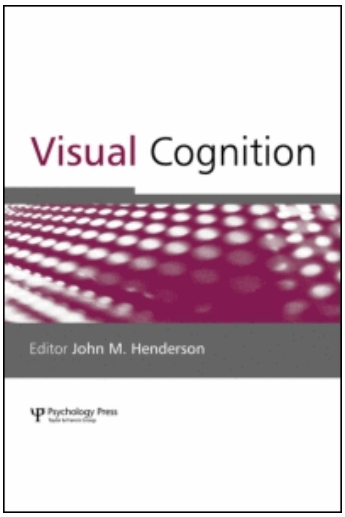

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Training attention: Interactions between central cues and reflexive attention

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Training attention: Interactions between central cues and reflexive attention

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Three experiments are reported in which we investigate whether the recently reported interactions between central cues (e.g., arrows) and reflexive attention are attributable to the overlearned spatial properties of certain central cues. In all three experiments, a nonpredictive cue with arbitrary spatial properties (a colour patch) is presented prior to a detection target in the left or right visual field. Reaction times to detect targets are compared before and after a training session in which participants are trained to associate each colour patch with left and right space, either via a target detection task in which colour predicts target location 100% of the time (Experiments 1 and 3), or via a left/right motor movement as a function of colour (Experiments 2 and 3). In the first two experiments, a small but highly significant training effect is observed. Participants are approximately 10 ms faster to detect targets at congruent locations relative to incongruent locations after training relative to before training, despite the fact that cue colour was nonpredictive during the test sessions. In Experiment 3, the length of the training session is increased and the magnitude of the training effect also increases as a result. Implications for the interaction between central cues and reflexive attention, as well as premotor theory of attention, are discussed.

Keywords: Attention; Training; Central cues; Premotor theory.

The visual attention system is critical to all of our interactions with our external world, as attention is the mechanism through which visual input is

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selected for further processing and action. Attention can be shifted either exogenously (e.g., reflexively) or endogenously (e.g., volitionally) but the end result tends to be the same: The processing of stimuli at attended locations is facilitated while the processing of stimuli at unattended locations is substantially less efficient. Generally, endogenous and exogenous shifts of attention are studied in the lab via the presentation of either central cues (e.g., a directional arrow predicting target location: Endogenous cue) or peripheral cues (e.g., a rapid onset in the periphery, which does not predict target location, but which captures attention regardless: Exogenous cue) (Posner, 1980; Yantis & Hillstrom, 1994). Behaviourally, the influence of these cues is manifest in response times (RTs): Individuals are faster to respond to stimuli presented at attended relative to unattended locations. The time course of these cueing effects differ as a result of cue type, however, with exogenous cues leading to rapid cueing effects (e.g., after 100 ms), which are replaced at later SOAs by slowed responding to targets appearing at cued locations (inhibition of return: Posner & Cohen, 1984), whereas endogenous cueing effects take longer to develop (however, see Ristic & Kingstone, 2006)—given that individuals need time to process the meaning of the cue—but lead to longer lasting cueing effects that are never replaced by inhibition at long SOAs.

Though researchers have traditionally separated shifts of attention into the aforementioned two broad classes—with central cues being used to study endogenous shifts of attention and peripheral cues being used to study exogenous shifts of attention—recent evidence has arisen to suggest that the presentation of certain central cues can interact with reflexive shifts of attention. For example, Hommel, Pratt, Colzato, and Godijn (2001; see also Pratt & Hommel, 2003) have reported that the presentation of a spatially nonpredictive arrow or directional word (e.g., "left") results in targets being detected more quickly at the location consistent with the cue's directional meaning. Moreover, Fischer, Castel, Dodd, and Pratt (2003) have demonstrated that the presentation of a nonpredictive digit at fixation influences the allocation of attention throughout the visual field as a function of digit magnitude: Participants are faster to respond to targets presented in the left visual field following the presentation of a small number (e.g., 1 or 2) relative to a large number (e.g., 8 or 9), whereas participants are faster to respond to targets presented in the right visual field following the presentation of a large number relative to a small number. This finding was attributed to the manner in which numbers are organized in the brain, in terms of a mental number line with low digits appearing at the left end of the line and high digits appearing at the right end, meaning that individuals automatically associate low numbers with left space and high numbers with right space (see also Dehaene, Bossini, & Giraux, 1993). The results of each of these studies demonstrate that the presentation of an overlearned spatial symbol at

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fixation can lead to a reflexive shift of attention to the periphery, even when the symbol does not predict target location. It is not the case, however, that all spatially organized symbols interact with attention in the same manner. For example, Dodd, van der Stigchel, Leghari, and Kingstone (in press) recently reported that, whereas the presentation of numbers at fixation does seem to influence target detection as a function of digit magnitude, the same is not true for other ordinal sequences (e.g., days, months, letters). It is unclear why certain stimuli interact with reflexive shifts of attention (e.g., numbers) and other seemingly similar stimuli (e.g., days) do not.

One possible reason for this discrepancy is that the spatial meaning of certain symbols is substantially overlearned and can not be ignored: For example, the presentation of arrows and directional words in the real world is almost always spatially predictive and meaningful (e.g., on a street sign) and, as such, require a shift of attention that is consistent with the meaning of the symbol. Although numbers would seem to have less spatial meaning than arrows and directional words on the surface, numbers are frequently used to organize lists, categories, and sequences, as well as to represent other ordinal information such as days, months, and addresses, and as such, the spatial properties of these stimuli may also be overlearned. Another possibility is that there is an overlap in the manner that the brain organizes space and the perception of certain stimuli (e.g., arrows) that does not exist for other stimuli (e.g., letters). Hubbard, Piazza, Pinel, and Dehaene (2005) have argued that numerical–spatial interactions are attributable to shared parietal pathways underlying visuospatial attention and the internal representations of numbers. It is feasible then that similar connections could exist between visuospatial attention and the internal representation of arrows/directional words, but not other ordinal stimuli. This latter possibility is difficult to test behaviourally, but it is possible to test the former possibility by training participants to associate an arbitrary symbol with spatial properties that would not otherwise exist and to then examine whether the presentation of these symbols in a target detection task lead to spatial biases in behaviour. This is the purpose of the present study. In Experiment 1, we train participants to associate the colour of a central stimulus (blue or green) with a side of space (left or right). Following training, we examine whether the learned colour–space associations influence target detection in the left and right visual fields. To preface our results, participants were faster to detect targets at *congruent* (colour of central cue associated with the same side of space that a target appears) relative to *incongruent* locations (colour of central cue associated with the side of space opposite to the target location) following training, despite the fact that our training session—in which the colour of the fixation cue always predicts the location of the upcoming target—was only 800 trials, and the colour of the cue was no longer predictive of the upcoming target location.

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In Experiment 2, we investigate whether a similar result is obtained when participants are trained to make a left/right motor movement as a function of cue colour: A task that, unlike target detection, does not necessarily require a shift of visual attention to the periphery to perform.

EXPERIMENT 1

The purpose of Experiment 1 was to determine whether participants, trained to learn arbitrary associations between stimulus features (colours) and spatial locations, would exhibit spatial biases on a peripheral target detection task when a central cue was rendered in one of the training colours. Furthermore, would the spatial biases be similar to those observed when overlearned spatial symbols are presented at fixation. That is to say, will participants be faster to detect targets that appear in a *congruent* location (cue colour with a learned spatial association that is the same as the target location) relative to a *incongruent* location (cue colour with a learned spatial association that is different from the target location) following a training session in which they are trained to associate certain colours with the left/right visual fields? To determine this, participants completed three blocks of trials: A pretest block in which a nonpredictive colour cue was presented at fixation and was then followed by a target to the left or right requiring a detection response; a training block, in which the colour cue was 100% predictive of target location; and a posttest block, which was identical to the pretest in that the colour cue was again nonpredictive. The critical question is whether target detection RTs change between the pre- and posttest blocks as a result of training.

Method

Participants

Twenty-eight undergraduate students (fifteen from the University of British Columbia, thirteen from the University of Toronto) volunteered to participate in the experiment, and received course credit for their participation. All participants had normal or corrected-to-normal vision and were naïve about the purpose of the experiment, which took place in a single 1-hour session.

Apparatus and procedure

The experiment was conducted on an AMD Athlon XP 2400 PC with a VGA monitor in a well-lit, sound-attenuated testing room. Participants were seated approximately 50 cm from the front of the computer monitor. A

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keyboard was placed directly in front of the participant, and they made responses using the spacebar on the keyboard. The experiment consisted of three blocks of trials, and all participants completed the blocks in the same order. These will be outlined in turn.

Pretest block. At the beginning of each trial, a large white circle (1° in diameter) was presented at the centre of the screen. Participants were instructed to fixate on this circle for the entire experiment. In addition to the fixation circle, an experimental display consisting of two white outline placeholder boxes (each box was 1° in diameter and the boxes were located on the horizontal meridian to the left and right of fixation) was presented on the computer monitor with a black background. Following a period of 500 ms, the colour of the fixation circle changed from white to either blue or green, and remained this colour until a response was recorded. Participants were explicitly informed that the colour of the fixation cue was not predictive of the location of the upcoming target. After a variable stimulus–onset asynchrony (SOA) of 100, 500, or 800 ms, a white target (0.25° in diameter) appeared in one of the two peripheral placeholders with equal probability. Participants were instructed to press the spacebar as soon as they detected the target, and to respond as quickly and accurately as possible. To reduce anticipatory responses, catch trials in which the target did not appear were also included and participants were told not to respond if the target did not appear. Incorrect responses on catch trials (and responses less than 100 ms and responses greater than 1000 ms) were considered errors, and a short error tone was presented if any of these occurred. The next trial began 500 ms after each response.

Training block. The training block was identical to the first with the exception that the colour of the fixation point now *did* predict the location of the target. Whenever the fixation cue turned green, the target would appear in the right peripheral box, and whenever it turned blue, it would appear in the left peripheral box. Participants were explicitly informed of this contingency. Participants were again instructed to press the spacebar as soon as they detected the target, and to respond as quickly and accurately as possible. During training, no catch trials were included.

Posttest block. The posttest block was identical to the pretest block, with the colour of the fixation cue again being independent of the location in which the target appeared. Again, participants were explicitly informed that the fixation colour did not predict the upcoming target location. Participants were instructed to press the spacebar as soon as they detected the target, and to respond as quickly and accurately as possible.

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Design

The pretest and posttest blocks each consisted of 120 trials, with 100 test trials and 20 catch trials. Short breaks were offered after every 60 trials in these test blocks. The training block consisted of 800 trials, with short breaks being offered after every 200 trials. Prior to the pretest block of trials, participants were given five practice trials to familiarize themselves with the task.

Results and discussion

Errors occurred on less than 0.5% of all trials and these trials were excluded from the analyses. Reaction times (RT), standard deviations (SD), and congruency effect (CE) scores for targets appearing at each location as a function of test type and SOA are presented in Table 1. The CE scores refer to the RT to detect a target at a congruent location minus the RT to detect a target at an incongruent location—when the fixation circle turns blue, the congruent location is the left placeholder and the incongruent location is the right placeholder; when the fixation turns green, the congruent location is the right placeholder, and the incongruent location is the left placeholder. For the purposes of these analyses, the same congruent/incongruent labels were used for the pretest block, even though these labels are arbitrary as participants had not yet learned the colour–space associations. Preliminary analyses indicated there were no differences in RT as a function of fixation colour, and given we have no reason to suspect that any differences would emerge as a function of fixation colour, all data were collapsed across this variable. Table 1 also presents the training effect (TE), which is the change in CE scores from pretest to posttest (the CE on the pretest minus the CE score on the posttest).[1] To determine whether target detection was influenced by the training session, the mean CE scores were analysed with a 2 (test type: Pretest or posttest) × 3 (SOA: 100, 500, or 800 ms) analysis of variance (ANOVA). There was a significant main effect of test type, $F(1, 27) = 9.53$, $MSE = 399.34$, $p < .01$ indicating that the congruency effect posttest (-11 ms) was larger than that observed pretest (approximately -1 ms). That is, participants were faster to respond to targets appearing at congruent locations relative to incongruent locations after

[1] Given that our primary interest is in the change in target detection performance between the pre- and posttests, we do not report the training data. To ensure that participants were being "trained", however, the training data were analysed by breaking performance down into four blocks, each representing 200 trials of the training session. As would be expected, average RTs decreased across each block, as did the average number of errors (though very few errors—less than 0.5%—were made overall). This was also the case in Experiments 2 and 3.

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TABLE 1
Experiment 1: Reaction times (in ms), standard deviations (in parentheses), the congruency effect (CE) scores, and the overall training effect (TE) score

	Pretest			*Posttest*			
	CON	*INCON*	*CE*	*CON*	*INCON*	*CE*	*TE*
100 SOA	401 (73)	399 (70)	2	361 (45)	367 (45)	−6	8
500 SOA	330 (54)	339 (57)	−9	306 (43)	321 (45)	−15	6
800 SOA	346 (53)	342 (58)	4	316 (36)	327 (46)	−11	15
Mean	359	360	−1	328	338	−11	10

training, whereas before training there was, as expected, no congruency effect. A close examination of Table 1 indicates that, overall, there was a 10 ms training effect. Thus, even though fixation colour was irrelevant to target detection during the posttest, the meaning of the fixation colour learned during training influenced the allocation of spatial attention. Though this 10 ms difference is relatively small—especially when compared to the cueing effects usually observed when arrows or directional words are presented at fixation (e.g., Hommel et al., 2001)—it was highly reliable and occurred following only 800 training trials, which took participants approximately 35 min to complete, whereas individual experience with the spatial properties of arrows/directional words is lifelong and impossible to simulate in the lab.

One potential concern in the present experiment is that the observed congruency effects do not represent a "training" effect inasmuch as a carryover effect from the training block. Perhaps participants find it difficult to break out of the mental set established in the training block and continue to treat the colour cue on the posttest as predictive early on in the posttest. Two separate analyses were conducted to rule out this possibility. First, we reanalysed the present data by eliminating the first 20 trials to make sure that our observed effect was not being driven by a large congruency effect early on in the posttest, which decreased over subsequent trials. Even with the first 20 trials eliminated, however, the observed congruency and training effect was nearly identical to that observed in our analysis of all previous data (the congruency effect was actually slightly larger with the first 20 trials eliminated). A 2 (test type: Pretest or posttest) × 3 (SOA: 100, 500, or 800 ms) ANOVA on this data elicited a significant main effect of test type, $F(1, 27) = 9.36$, $MSE = 401.89$, $p < .01$, indicating that the congruency effect posttest (-12 ms) was larger than that observed pretest (approximately -1 ms).

Second, to ensure that the magnitude of our congruency effect did not differ over the duration of the posttest, a further analysis was run in which

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performance on the posttest was broken down into two blocks of 60 trials, each to determine whether participants showed larger effects of training in the first half of the posttest relative to the second half of the posttest. There was no difference in detection RT as a function of block half, however, suggesting that the effects of training were equivalent in magnitude and sustained across the entire posttest. A 2 (block: First 60 trials or second 60 trials) $\times$ 3 (SOA: 100, 500, or 800 ms) ANOVA on detection RTs elicited no significant effects or interactions, $F(1, 27) < 1$, for the critical main effect of block.

Our result, then, supports the notion that even after relatively brief training that associates colours with spatial locations, the colour of central cues can have an immediate impact on the allocation of spatial attention. Moreover, it is unlikely that the posttraining congruency effect reflects an overlap in the manner in which the brain perceives space and colour, since no difference was apparent in target detection as a function of cue colour during the pretest. No other main effects or interactions were significant.

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EXPERIMENT 2

In Experiment 1, following the learning of arbitrary associations between colours and spatial locations, the colour of central cues produced spatial biases in a target detection task despite the fact that the colour of the cue was no longer predictive of target location. That we were able to observe spatial biases following the brief training of arbitrary associations between colours (a previously nonspatial feature) and spatial locations suggests that the similar influences of arrows, directional words, and numbers on spatial attention likely is attributable to their overlearned spatial properties. In Experiment 2, we look to extend the result obtained in Experiment 1 by determining whether a similar training effect can be obtained even when the primary task during training does not require a shift of attention to the periphery. Recall that in Experiment 1, the colour cue in the training task provided valid spatial information for the upcoming target which subjects presumably used to shift attention to the left or right visual field to facilitate detection of the target. Furthermore, the target should elicit an involuntary shift of attention to the periphery. In the present experiment, the training session consists of a motor task in which participants make left or right movements with a joystick as a function of cue colour. To complete this task, no shifts of visual attention are required. Instead, participants are learning to arbitrarily associate colours with motor movements.

Although the present training task does not require any spatial shifts of visual attention, there is substantial reason to believe that a spatial shift of attention may precede/accompany each motor movement. For example, there

has been considerable interest over the past two decades in Rizzolatti and colleagues' (Rizzolatti & Camarda, 1987; Rizzolatti, Riggio, Dascola, & Umiltà, 1987) premotor theory of attention, which posits that visuospatial attention is the result of the activation of the same circuits responsible for saccadic programming. Thus, a shift of spatial attention can simply be thought of as a planned motor programme. Though premotor theory of attention was initially framed in terms of the relationship between shifts of attention and saccadic planning, recent evidence suggests that visuospatial attention may be more generally influenced by a variety of motor programmes (e.g., grasping; Craighero, Fadiga, Rizzolatti, & Umiltà, 1999). This is relevant to the present experiment in that a joystick movement—which doesn't require a visuospatial shift of attention—may lead to an obligatory shift of attention in the same direction as the movement. Therefore, through training, subjects may learn an association between colours and motor movements as well as an association between colours and the obligatory shifts of attention that accompany the motor movements, in which case we would expect a training effect similar to that observed in Experiment 1 where a shift of spatial attention is undoubtedly used to facilitate performance on the training task.

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Method

Participants

Twenty-eight undergraduate students (fifteen from the University of British Columbia, thirteen from the University of Toronto) volunteered to participate in the experiment, and received course credit for their participation. All participants had normal or corrected-to-normal vision and were naïve about the purpose of the experiment, which took place in a single 1-hour session. None of the students had participated in the first experiment.

Apparatus, procedure, and design

The apparatus, procedure, and design were identical to Experiment 1, with two exceptions. First, during the pretest and posttest, participants made target detection responses using a Gravis Destroyer joystick, by pressing the trigger button on the top of the joystick. Second, during the training session, the task was no longer target detection and as such, the peripheral placeholders and targets did not appear. Rather, the display consisted solely of the fixation circle, which started off white and then turned blue or green following a period of 500 ms. Participants were instructed to make a directional response with the joystick: When the fixation circle turned blue, participants were to move the joystick to the left as quickly as they

could, and when the fixation circle turned green, participants were to move the joystick to the right as quickly as they could. The moment a joystick motion was made that surpassed a certain threshold (the equivalent of 100 pixels on the x-axis), the trial terminated. If participants failed to move the joystick following 1000 ms, or if they moved the joystick in the incorrect direction on the x-axis, a short error tone was presented. The next trial began 500 ms after each response.

Results and discussion

Errors occurred on less than 0.7% of all trials and these trials were excluded from the analyses. Reaction times (RT), standard deviations (SD), and congruency effect (CE) scores for targets appearing at each location as a function of test type and SOA are presented in Table 2. As in Experiment 1, the congruency effect scores refer to the RT to detect a target at a congruent location minus the RT to detect a target at an incongruent location—when the fixation point turns blue, the congruent location is the left placeholder and the incongruent location is the right placeholder; when the fixation turns green, the congruent location is the right placeholder, and the incongruent location is the left placeholder. For the purposes of these analyses, the same congruent/incongruent labels were used for the pretest block, even though these labels are arbitrary as participants had not yet learned the colour–movement associations. Preliminary analyses indicated there were no differences in RT as a function of fixation colour, and given we have no reason to suspect that any differences would emerge as a function of fixation colour, all data were collapsed across this variable. Table 2 also presents the training effect (TE), which is the change in CE scores from pretest to posttest. To determine whether target detection was influenced by the training session, the mean CE scores were analysed with a 2 (test type: Pretest or posttest) × 3 (SOA: 100, 500, or 800 ms) ANOVA. There was a significant main effect of test type, $F(1, 27) = 8.53$, $MSE = 612.28$, $p < .01$,

TABLE 2
Experiment 2: Reaction times (in ms), standard deviations (in parentheses), the congruency effect (CE) scores, and the overall training effect (TE) score

	Pretest			*Posttest*			
	CON	*INCON*	*CE*	*CON*	*INCON*	*CE*	*TE*
100 SOA	378 (75)	369 (65)	9	356 (47)	358 (48)	−2	11
500 SOA	327 (59)	324 (63)	3	304 (45)	306 (43)	−2	5
800 SOA	332 (64)	327 (57)	5	310 (44)	321 (45)	−11	16
Mean	346	340	6	323	328	−5	11

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indicating that the congruency effect was larger at posttest than it was at pretest. Specifically, participants were faster to respond to targets appearing at congruent locations relative to incongruent locations during the posttest than they were during the pretest. A close examination of Table 2 indicates that overall, there was an 11 ms training effect (e.g., participants were 11 ms faster at the congruent location during the posttest relative to pretest). Thus, it appears that the associations between colours and motor movements learned during training, and the obligatory attentional shifts elicited by these motor movements (e.g., Craighero et al., 1999), leads to learned associations between colours and spatial attention shifts. Furthermore, these colour–space associations influence spatial attention even though fixation colour was independent of target location during the posttest. Furthermore, it is interesting to note that the magnitude of the training effect was nearly identical to that in Experiment 1 (see later).

As in Experiment 1, we wanted to be sure that our results were due to a training effect and not simply a carryover effect from the training session. Consequently, we conducted the same two analyses has before. With the first 20 trials removed from the posttest, the congruency and training effects were identical to that observed in our analysis of all data. A 2 (test type: Pretest or posttest) $\times$ 3 (SOA: 100, 500, or 800 ms) ANOVA on this data elicited a significant main effect of test type, $F(1, 27) = 8.78$, $MSE = 595.79$, $p < .01$, indicating that the congruency effect posttest (-5 ms) was larger than that observed pretest (approximately 6 ms).

Our second analysis, in which we broke the posttest down into two blocks of 60 trials to compare the magnitude of the congruency effect, was also consistent with the idea that the congruency effect did not change in the first half of posttest trials relative to the second half of posttest trials. A 2 (block: First 60 trials or second 60 trials) $\times$ 3 (SOA: 100, 500, or 800 ms) ANOVA on detection RTs elicited no significant effects or interactions, $F(1, 27) < 1$, for the critical main effect of block.

Our result, then, supports the notion that even after relatively brief training that associates colours with spatial locations, the colour of central cues can have an immediate impact on the allocation of spatial attention. This finding is consistent with the premotor theory of attention, in that even though the training task did not require a visuospatial shift of attention, the act of planning and executing a spatial motor movement apparently produced a comparable movement of attention. Consequently, through training, the colours become associated not only with motor movements but also with spatial shifts of attention. No other main effects or interactions were significant.

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Comparing the two experiments

Experiments 1 and 2 were conducted separately and involved the learning of different associations: Colours with spatial locations of targets versus colours with direction of motor movement. Nonetheless, the pre- and posttest tasks were identical and, as such (with only the response apparatus—space bar vs. joystick—differing), a comparison of changes in CE scores as a function of training task is worth considering. To compare the experiments, the previously calculated training effect (TE) values were compared across experiment. To determine whether there was a difference in the training effect as a function of training type, a 2 (colour: Blue or green) $\times$ 3 (SOA: 100, 500, or 800 ms) mixed ANOVA was conducted with training type (target detection or motor movement) as a between subjects factor. There were no significant main effects or interactions (all Fs < 1), except for Colour $\times$ soa, $F(2, 108) = 1.79$, $p > .2$, indicating that the magnitude of the training effect was equivalent for both types of training. This finding is again highly consistent with the premotor theory of attention in that the planning/execution of a left/right motor movement seemingly influenced attention in a manner similar to that which occurs in a target detection task in which a shift of attention was required.

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EXPERIMENT 3

In Experiments 1 and 2, participants were faster to detect targets at cue-congruent locations which resulted from the learning of arbitrary associations between colours and spatial locations during a training session. This occurred despite the fact that the colour cue on each trial was not predictive of target location in the posttest session. Though the training effect we observed was highly significant, it was small (on the magnitude of about 10 ms) when compared to the effect of overlearned symbols (e.g., arrows) on visual attention, in which it is not uncommon to observe cueing effects upwards of 50 ms in magnitude (e.g., Hommel et al., 2001). It is important to keep in mind, however, that the training sessions we used in Experiments 1 and 2 were only 800 trials, whereas the association between arrows and space probably develops over a lifetime of experience. Consequently, it is unsurprising our effects are small as participants should not have had any preexisting associations between colour and space prior to our training session. Nonetheless, it is important to determine whether the magnitude of our cueing effects would increase if the training session is extended. This is the purpose of Experiment 3.

Method

Participants

Thirty-six undergraduate students from the University of Nebraska–Lincoln volunteered to participate in the experiment and received course credit for their participation. Eighteen participants participated in the attention training task in the present experiment (akin to Experiment 1); the other eighteen participated in the motor training task in the present experiment (akin to Experiment 2). All participants had normal or corrected-to-normal vision and were naïve about the purpose of the experiment, which took place in a single 1-hour session. None of the students had participated in the previous experiments.

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Apparatus, procedure, and design

The apparatus, procedure, and design were identical to Experiments 1 and 2, with the exception that the training session now consisted of 1200 trials as opposed to 800. In addition, gaze was monitored with a closed circuit camera system in this experiment to ensure that participants were complying with the instruction to remain fixated throughout the experiment. No eye movements were observed by the experimenter and, consequently, no data was omitted from the experiment.

Results and discussion

Attention training. Errors occurred on less than 0.6% of all trials and these trials were excluded from the analyses. Reaction times (RT), standard deviations (SD), and congruency effect (CE) scores for targets appearing at each location as a function of test type and SOA are presented in the upper portion of Table 3. As in the previous experiments, the congruency effect scores refer to the RT to detect a target at a congruent location minus the RT to detect a target at an incongruent location. For the purposes of these analyses, the same congruent/incongruent labels were used for the pretest block, even though these labels are arbitrary as participants had not yet learned the colour–movement associations. Preliminary analyses indicated there were no differences in RT as a function of fixation colour, and given we have no reason to suspect that any differences would emerge as a function of fixation colour, all data were collapsed across this variable. Table 3 also presents the training effect (TE), which is the change in CE scores from pretest to posttest. To determine whether target detection was influenced by the training session, the mean CE scores were analysed with a 2 (test type: Pretest or posttest) $\times$ 3 (SOA: 100, 500, or 800 ms) ANOVA. There was a

TABLE 3
Experiment 3: Reaction times (in ms), standard deviations (in parentheses), the congruency effect (CE) scores, and the overall training effect (TE) score

	Pretest			*Posttest*			
	CON	*INCON*	*CE*	*CON*	*INCON*	*CE*	*TE*
Attention training							
100 SOA	391 (57)	389 (52)	2	373 (37)	384 (46)	−11	13
500 SOA	340 (57)	337 (44)	3	324 (39)	348 (63)	−24	27
800 SOA	340 (47)	340 (56)	0	331 (39)	351 (52)	−20	20
Mean	357	355	2	343	364	−18	20
Motor training							
100 SOA	348 (53)	348 (57)	0	320 (37)	332 (47)	−12	12
500 SOA	306 (42)	304 (46)	2	280 (31)	299 (30)	−19	21
800 SOA	298 (38)	297 (41)	1	287 (30)	307 (34)	−20	21
Mean	316	317	1	296	313	−17	18

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significant main effect of test type, $F(1, 17) = 27.94$, $MSE = 531.51$, $p < .01$, indicating that the congruency effect was larger at posttest than it was at pretest. Specifically, participants were faster to respond to targets appearing at congruent locations relative to incongruent locations during the posttest than they were during the pretest. A close examination of Table 3 indicates that, overall, there was a 20 ms training effect, which almost doubles the training effect observed in Experiment 1. This result both replicates the earlier effect of attention training—trained associations between colours and space influence the allocation of attention on a later task, even when colour is irrelevant to target location—and also demonstrates that the magnitude of our congruency/training effect increases with an increase in the duration of the training session. No other main effects or interactions were significant.

Motor training. Errors occurred on less than 0.9% of all trials and these trials were excluded from the analyses. Reaction times (RT), standard deviations (SD), and congruency effect (CE) scores for targets appearing at each location as a function of test type and SOA are presented in the lower portion of Table 3. Preliminary analyses indicated there were no differences in RT as a function of fixation colour and, given we have no reason to suspect that any differences would emerge as a function of fixation colour, all data were collapsed across this variable. Table 3 also presents the training effect (TE), which is the change in CE scores from pretest to posttest. To determine whether target detection was influenced by the training session, the mean CE scores were analysed with a 2 (test type: Pretest or posttest) × 3 (SOA: 100, 500, or 800 ms) ANOVA. There was a significant main effect of test type, $F(1, 17) = 7.11$, $MSE = 1032.51$, $p < .01$, indicating that the

congruency effect was larger at posttest than it was at pretest. Specifically, participants were faster to respond to targets appearing at congruent locations relative to incongruent locations during the posttest than they were during the pretest. A close examination of Table 3 indicates that overall, there was a 18 ms training effect, which, again, almost doubles the training effect observed in Experiment 2. Thus, as before, the associations between colours and motor movements learned during training leads to learned associations between colours and spatial attention shifts on a later target detection task. Moreover, the influence of these associations increases as the duration of the training session increases. This finding is consistent with the premotor theory of attention, in that even though the training task did not require a visuospatial shift of attention, the act of planning and executing a spatial motor movement apparently produced a comparable movement of attention.

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Comparing attention and motor training. As before, it is worthwhile to compare the influence of attention and motor training on target detection to determine whether the magnitude of the training effect is equivalent. To do this, the previously calculated training effect (TE) values were compared via a 2 (colour: Blue or green) $\times$ 3 (SOA: 100, 500, or 800 ms) mixed ANOVA with training type (target detection or motor movement) as a between subjects factor. There were no significant main effects, indicating that the magnitude of the training effect was equivalent for both types of training. This finding is again highly consistent with the premotor theory of attention in that the planning/execution of a left/right motor movement seemingly influenced attention in a manner similar to that which occurs in a target detection task in which a shift of attention was required.

As in Experiments 1 and 2, we wanted to be sure that our results were due to a training effect and not simply a carryover effect from the training session. Consequently, we conducted the same two analyses as before, by removing the first 20 trials from analysis and by breaking up the posttest into two blocks. As before, the magnitude of the congruency effect and training effect were unchanged in these analyses in both the motor and attention training sessions.

GENERAL DISCUSSION

The purpose of the present study was twofold. First, we sought to determine whether the features of a central cue with learned spatial associations could influence the allocation of spatial attention in the same manner that arrows and directional words do. In Experiment 1, following a training period of 800 trials in which a central colour cue predicted the upcoming target

location, participants began to associate colours with spatial locations, such that congruency effects were observed on a later target detection task where colour was irrelevant. This finding provides strong behavioural evidence that learned associations between central cues and space can influence the allocation of spatial attention. Previous research has demonstrated that the presentation of various stimuli at fixation (e.g., arrows, directional words, numbers) influences reflexive attention whereas other ordinal stimuli (e.g., days, months, letters) do not. We suggested that this interaction is either attributable to the overlearned nature of certain spatial cues or because there is an overlap in the manner that the brain organizes space and the perception of certain stimuli (e.g., arrows). The present results seem more consistent with the former possibility in that we were able to generate a similar cueing effect with a previously arbitrary stimulus.

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Given that we observed a training effect in Experiment 1, the second purpose of the present study was to determine whether a similar effect would be observed if the training task did not require a visuospatial shift of attention, but rather indirectly created associations between colours and space. In Experiment 2, the training session consisted solely of the fixation circle, which required a left/right motor response as a function of colour. Though this task can be completed without removing attention from fixation, Rizzolatti and colleagues' premotor theory of attention (Rizzolatti & Camarda, 1987; Rizzolatti et al., 1987) is based on the notion that visuospatial attention is the result of the activation of the same circuits responsible for perception and motor activity and, as such, it is likely that the planning and execution of a left/right motor movement would also lead to a left/right shift of attention. Thus, Experiment 2 served as both an extension of Experiment 1, as well as a test of the premotor theory of attention. Interestingly, a nearly identical training effect was observed in Experiment 2 relative to Experiment 1: Participants were approximately 11 ms faster to respond to targets at cue-congruent relative to cue-incongruent locations following the training session, even though the cue was nonpredictive during both the pre- and posttests. This finding suggests that: (1) Obligatory shifts of attention are enacted by motor programmes even when the task at hand does not require a shift of attention, and (2) the interaction between central cues and reflexive attention probably reflects an inability to prevent processing of the cue meaning and the spatial properties associated with that cue.

Of note, in both of the first two experiments, the observed training effect was small but reliable after approximately 35 min of training. In Experiment 3 we investigated whether the magnitude of the effect would increase with a longer training session. For both attention and motor training we observed a substantial increase in the magnitude of our training effect when training time was increased. In all likelihood, this effect probably would have been

even larger and more enduring following a longer training session (e.g., spread over days) and, as such, is unlikely to be related to any sort of overlap in the neural systems that process space and colour.

The present results have important ramifications for premotor theory of attention. Originally, Rizzolatti and colleagues (Rizzolatti & Camarda, 1987; Rizzolatti et al., 1987) developed premotor theory to account for the connection between the attention and oculomotor systems. Movements of attention were simply thought to be planned, but unexecuted saccades, and it was thought that identical mechanisms controlled shifts of attention and shifts of the eyes (e.g., Rafal, Calabresi, Brennan, & Sciolto, 1989; Rizzolatti et al., 1987). Recently, however, premotor theory of attention has been extended to account for connections between attention and nonocular motor movements. For example, Craighero et al. (1999) had participants prepare, and then execute, a grasping motion towards a bar when a visual stimulus was presented. The visual stimuli that were presented, however, differed in the degree to which they shared properties of the to-be-grasped bar, allowing some of these stimuli to be defined as congruent (strong overlap in properties between the bar and visual stimulus) or incongruent (little to no overlap in properties between the bar and visual stimulus). Interestingly, participants were faster to grasp the bar following the presentation of a congruent stimulus, which was taken as a sign that the preparation of the grasp motion led to a facilitation in processing the congruent visual stimulus. Consequently, the authors argued that premotor theory may be extended beyond the orientation of attention to spatial locations to include the orientation of attention to graspable objects. The present study then, is relevant to premotor theory in two ways. First, the present results add to a growing literature suggesting that attention is influenced by a variety of motor movements, and not just oculomotor movements. Second, in the present task it was the training of a motor movement to the left or right that later influenced target detection, even though the actual target detection task itself did not require a left/right motor movement. So not only does the execution of a left/right movement influence attention, but the previous association between a stimulus and a left/right motor movement influences attention even when a left/right motor movement is not required. Moreover, the magnitude of this effect is identical to that observed when attention is trained via a predictive cue, suggesting a tight coupling between the motor and attentional systems.

One surprising aspect of the present results is that cue–target SOA did not influence the magnitude of the congruency or training effect during the posttest block. As previously outlined, exogenous cueing effects generally occur very rapidly, giving way to later inhibition (Posner, 1980; Posner & Cohen, 1984), whereas endogenous cueing effects usually occur later and never give way to inhibition. Given that our colour cues reflect an

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interaction between exogenous and endogenous attention (as nonpredictive central arrows and directional words have also been shown to reflect; Hommel et al., 2001; Pratt & Hommel, 2003), it would have been reasonable to assume that the time course of the present cueing effects would resemble those of either exogenous or endogenous cues but that does not seem to be the case. Unlike exogenous cues, the present cueing effects did not give way to inhibition at later SOAs and unlike endogenous cues, the present cueing effects emerged rapidly. It is worth noting, however, that Ristic and Kingstone (2006) have demonstrated that, contrary to popular belief, nonpredictive arrow cues can elicit cueing effects as early as 100 ms following cue presentation. This might suggest that our colour cues essentially became endogenous cues through training. A more intriguing possibility, however, is that nonpredictive arrow cues and directional words (and by extension, the current colour cues) share properties of both exogenous and endogenous attention, meaning they are fast-acting, long-lasting, and reflexive. Further research will be necessary to substantiate this claim.

In summary, the present study provides substantial evidence that the recently observed interactions between central cues and reflexive attention are attributable to the overlearned spatial associations of certain cues. We were able to replicate these interactions with participants learning an arbitrary association between colour and space following a short training session. Moreover, we provide further evidence favouring premotor theory of attention as training participants to make a left/right motor movement in response to a colour patch influenced the later allocation of attention on a target detection task. Further research is required to characterize these interactions between endogenous and exogenous attention.

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