Effects of Bilateral Colour Cues on Visual Orienting: Revisiting William James' 'Derived Attention'

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William James' proposal that the propensity of environmental objects to capture attention can be influenced by learning and experience was tested in a spatial cueing experiment. Participants made a simple detection response to targets that were preceded by bilateral colour change cues. During two training blocks of trials the location of the target was predicted by the nature of the peripheral colour change, but participants were not informed of this contingency. The effects of peripheral colour changes on attention were then assessed during a test block of trials in which there was no relationship between target location and the colour cues. Results showed that participants who remained unaware of the cue-target relationship nevertheless oriented attention rapidly towards the colour that had been associated with the target during the training phase. Implications of this finding for views of spatial attention are discussed, and it is concluded that William James' concept of 'derived attention' deserves renewed consideration.

Research on visual orienting has suggested that this can occur in two ways: either reflexively or under voluntary control (e.g. Jonides, 1981; Muller & Rabbit, 1989; Cheal, Lyon & Gottlob, 1994). The reflexive-voluntary distinction accords well with everyday intuitions concerning attention. For example, as I write these words, my attention is oriented, under voluntary control, to appropriate locations on the computer screen and keyboard. However, from time to time my attention may be captured involuntarily (reflexively) by salient events elsewhere in the visual field, as when a sparrow alights on the windowsill.

The distinction between reflexive and voluntary orienting also receives support from a substantial body of laboratory research. In an influential study, Jonides (1981) presented participants with two kinds of spatial cue. In one condition the cues were arrows presented in the centre of a visual display, indicating the likely location of an impending target object. In a second condition, participants were also presented with arrow cues, but in this case the cues were presented at a peripheral location, adjacent to the likely location of the target. In both cases Jonides compared response times for *valid* trials (where the target appeared at the cued location) with response times for *invalid* trials (where the target appeared at an uncued location). The difference between valid and invalid trials can be seen as an index of the extent to which participants had oriented their attention to the likely location of the target, in response to the information provided by the cue. Jonides observed different patterns of performance in the two conditions. Consistent with the idea that peripheral cues operate in a relatively automatic and reflexive manner, Jonides found that in the peripheral cueing condition, orienting effects were observed even when participants were instructed to ignore the cue; whereas participants did not orient in response to central cues when instructed to ignore them.

Speed of operation is another property which has been studied in investigations of the distinction between automatic-reflexive and voluntary processes. In general, automatic processes are thought to occur relatively rapidly, while voluntary processes have a slower time-course. In the context of visual attention, the time-course of orienting has been studied by varying the interval between onset of the cue and onset of the target object (the term stimulus onset asynchrony (SOA) is used to denote this delay). For example, Cheal and Lyon (1991) found that participants oriented very rapidly in response to peripheral cues. That is, clear differences between valid and invalid trials were observed with very brief (100ms) delays between cue and target. In contrast, orienting in response to central cues appeared to develop more slowly: valid-invalid differences reached a maximum with a delay of 300ms between cue and target onset. Hence, laboratory research is consistent with the notion that central and peripheral attentional cues elicit different forms of visual orienting. Orienting in response to peripheral cues appears to involve a relatively rapid and automatic process, whereas orienting in response to central cues appears to involve a relatively time consuming voluntary process.

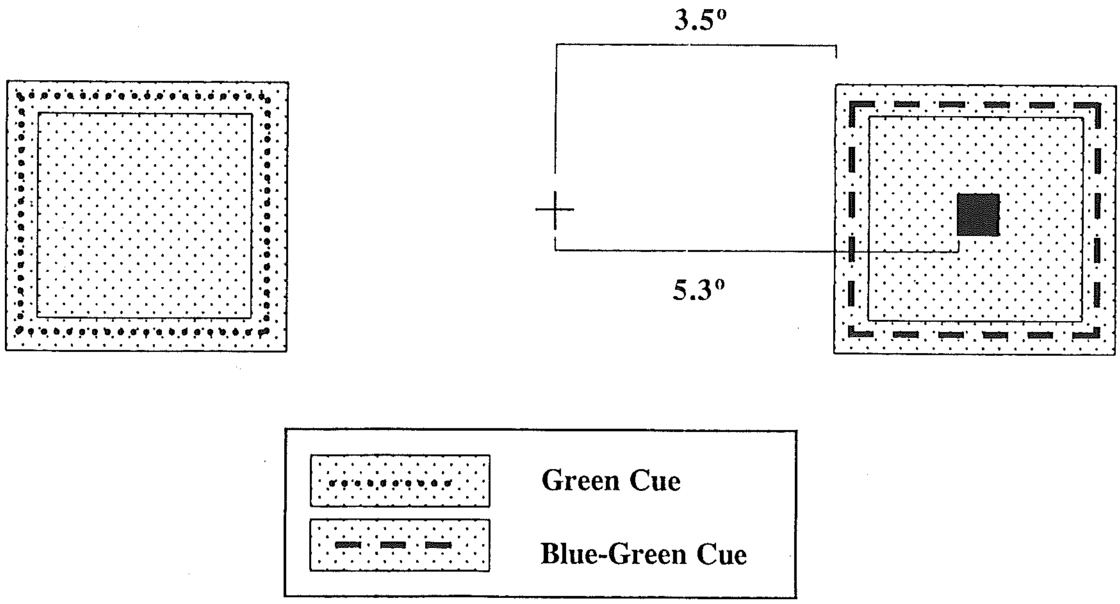
The reflexive-voluntary distinction was clearly recognized by William James. In his celebrated text, James (1890/1983) proposed that attention could either be "Passive, reflex, non-voluntary, effortless; or Active and voluntary" (p.384). However, William James also drew a further distinction which is not strongly represented in modern studies of attention. For James, attention could also be either "Immediate; or ...Derived; immediate, when the topic or stimulus is interesting in itself, without relation to anything else; derived when it owes its interest to association with some other immediately interesting thing" (p.393). James proposed that voluntary attention is always derived, but reflex attention could be either immediate or derived.

Modern conceptions of reflexive orienting correspond quite directly to James' idea of *passive, immediate attention*, where attention is captured by a sense impression with a "directly exciting quality" (p.394). An especially popular procedure has been to assess the attentional effects of peripheral cue stimuli consisting of transient luminance changes (e.g. Posner & Cohen, 1984; Muller & Rabbitt, 1989). However, very few studies have been concerned with James' concept of 'derived attention'. This is perhaps surprising, since everyday beliefs concerning attention are certainly consistent with the notion that learning and experience can influence the degree to which objects in the environment capture our attention. (but see Lambert & Sumich, 1996; Lambert, Naikar, McLachlan & Aitken, 1999). For example, many parents feel that the sight or sound of their own child tends to capture attention, even when these stimuli are competing against many others in a noisy or visually complex environment.

The experiment reported below was an empirical test of the Jamesian hypothesis of derived attention. This was done by associating coloured peripheral cue stimuli with the location of target stimuli in a spatial attention task. After a training period in which participants were exposed to a cue-target association, we then examined effects of the location associated cue stimuli on spatial attention. Participants made a simple detection response to targets that could appear on the left or right of a visual display. Grey frames were present on either side of the display, and prior to each target *both* frames underwent a transient colour change (see Figure 1). On every trial, part of one frame became green for 66ms, while the corresponding region of the other frame became blue-green. Two groups of participants were tested. For the Green Group targets always appeared on the same side as the green colour cue during the training phase. For the Blue-Green Group targets always appeared on the same side as the blue-green cue during the training phase. During the test phase, target location and the location of the green / blue-green colour changes were unrelated. According to the derived peripheral cueing hypothesis, participants should orient towards the colour that had been associated with the target during the training phase of the experiment.

The green and blue-green hues were deliberately chosen to be subjectively similar. This was done because we wanted to test for the presence of 'derived' peripheral cueing effects for participants who failed to notice the link between target location and the nature of the colour changes. During pilot research (see Roser, 1998) we discovered that when there was a salient distinction between the two peripheral colours (e.g. red vs. green) the vast majority of participants became consciously aware of the cue-target relationship during the experiment. This made it possible, and perhaps more parsimonious, to explain the results with reference to voluntary orienting, rather than in terms of non-voluntary attentional capture due to derived peripheral cueing. However, previous work from our laboratory has demonstrated derived cueing effects for peripheral cue

Figure 1. Cue and target stimuli used in the experiment.



stimuli differing in visual form (Lambert et al., 1999) and semantic category (Lambert & Sumich, 1996), and has shown that these effects occur even for participants who remain unaware of decidedly obscure cue-target relationships. In view of this, we proposed (Lambert & Sumich, 1996; Lambert et al., 1999) that the associative learning that underlies derived peripheral cueing proceeds at an *implicit* level (see also Berry, 1994). Thus, in order to establish this point in relation to coloured stimuli it was necessary to ensure that the distinction between the cues and their relationship with target location was *non-salient* (c.f. Berry, 1994). As in our earlier work (Lambert et al., 1999; Lambert & Sumich, 1996) a post-experiment questionnaire was used to assess the extent to which participants became aware of the relationship between target location and cue colour during the experiment.

Prior to the experiment, flicker photometry was used to equate the subjective luminance of the green, blue-green and grey components of the peripheral frame stimuli. The aim of this was to equate the relative salience of the two colour cues. If one of the cues produced a clear luminance change, while the other produced a weak or absent luminance contrast, then cueing effects would likely be dominated by conventional reflexive orienting (immediate, reflex attention, in James' terminology) towards the more salient cue (see Posner & Cohen, 1984; Posner, Cohen & Rafal, 1982).

Method

Participants: 30 adult volunteers from the University of Auckland population took part. None of the participants reported any difficulties with colour vision.

Apparatus: The experiment was run with an IBM compatible 386 PC and VGA monitor. Software for display presentation and timing was written in Turbo Pascal v.6. Graphics resolution was 640x350 pixels. The testing was carried out in a dimly illuminated room. A chinrest was used to control viewing distance at 57cms.

Display and stimuli: The fixation display, cue stimuli and target stimuli are illustrated in Figure 1. The fixation display comprised a central cross subtending approximately 0.6° x 0.6°, flanked by two grey frames subtending 4.2° x 4.2°. The inner edge of each frame was 3.5° from the central cross. The horizontal components of each frame were approximately 0.5° thick (equivalent to 9 pixels); the vertical components of each frame were 0.35° thick (equivalent to 9 pixels). Cue stimuli were transient colour changes within the box outline. The central region of each frame, formed by a line 3 pixels in width, changed colour from grey to green (or blue-green) then back to grey. The duration of this colour change was 66ms. Hence, the cues involved the brief appearance of a thin coloured frame within each of the grey frames, as illustrated in Figure 1. The target stimulus was a grey filled square subtending 0.3° x 0.3° presented in the centre of either the left or right frame. The inner edge of each target was approximately 5.3° from the central cross. The physical luminance of the grey colour used for the frames, fixation cross, and target stimuli was 6.8 Cd/m^2. The luminance of the 'black' background, due to ambient illumination in the room was 1.2 Cd/m^2.

Flicker photometry: Prior to commencing the experiment flicker photometry was used to adjust the energy of the green and blue-green cues to be approximately isoluminant with the grey frames. Four observers viewed the display shown in Figure 1, and fixated the central cross. The green (or blue-green) colour cue was presented on both sides of the display for 300ms, switched off for 300ms, switched on again for 300ms, and so on. The observers' task was to adjust the intensity of the colour cue until it appeared isoluminant with the grey frame. At this point, there was no apparent brightening, or dimming of the coloured area inside the frame, as the cue stimuli were switched on and off. Four observers performed this procedure twice, once for the green cue, and once for the blue-green cue. The intensity of the colour stimuli was adjusted using the '>' and '<' keys on the keyboard. The green cue was a pure green; the blue-green cue was made up of a small amount of blue, mixed with green. In both cases, observers adjusted the intensity of the green signal (i.e. the amount of blue light in the blue-green cue was held constant). The software and hardware used for the experiment enabled the intensity of the red, green and blue (RGB) components of any colour to be varied from zero to 63 units. Thus, any colour was defined in terms of three co-ordinates, each of which could vary from 0 to 63. The RGB co-ordinates of the grey used for the two frames was Red:25, Green:25, Blue 25. The intensity of the pure green judged to be isoluminant with this grey was set at Green:27. (Red & Blue values were zero for this hue. The green values for the four observers were 26,27,27,28.) The Blue-Green hue was Red: zero, Blue:24, together with a green value adjusted to render the blue-green subjectively isoluminant with the grey frame. The intensity of this green value was set at 27. The green values for the four observers were 26,27,27,28). Thus, the blue component of the blue-green cue made no measurable contribution to subjective luminance under these conditions.

Procedure: Participants were instructed to fixate the central cross at the beginning of each trial. One second before the cues were presented the central cross disappeared for 100ms (i.e. the central cross blinked at the beginning of every trial). The aim of this was to draw participants' attention to the fixation cross, and to remind them of the requirement to fixate centrally on every trial. The bilateral colour cues were then presented for 66ms. Either 100ms or 600ms after cue onset, a target was presented inside either the left or right frame. Hence, there were two stimulus onset asynchrony (SOA) conditions, 100ms and 600ms. Participants were instructed that when the target appeared they were to press the spacebar as quickly as a possible. The target disappeared as soon as the spacebar was pressed. After an interval that varied randomly from 500ms to 1000ms the central cross blinked to signal the beginning of the next trial. Participants were warned about the occurrence of 'catch trials', on which a peripheral colour change, but no target, was presented. They were instructed to avoid responding on these trials, and informed that pressing the space bar would result in the following message 'Warning: Catch Trial Error" being displayed in the lower part of the screen. Participants were also requested to avoid making anticipatory responses, and were informed that pressing the space bar before the target appeared would result in the following message, "Warning: Anticipation Error" being displayed in the lower part of the screen.

Participants were presented with 10 practice trials to familiarize them with the task. The structure of the practice trials was the same as the training trials (see below). They then performed two blocks of 88 training trials, followed by the test block of 88 trials.

Post-Experiment Questionnaire: Participants completed this immediately after the final block of trials. The questionnaire comprised three items, which are shown below. Items 2 and 3 were not shown to the subject until after they had responded to Item 1.

1. Did you notice any relationship between the colour of the boxes and the subsequent location of the target square? If so please describe it below.
2. Please indicate with a tick which of the statements below you think is correct
   A. Most of the time the target was on the same side as the pure green square.
   B. Most of the time the target was on the same side as the bluish-green square.
3. Please indicate with a tick how confident you feel in your response to Question 2.
   A pure guess
   Mainly guesswork
   Possibly correct
   Probably correct
   Very likely correct
   Almost certainly correct

Design: All participants completed 3 blocks of 88 trials. Within each block there were:

- 44 trials on which the colour cues were green on the left and blue-green on the right, and 44 trials with the reverse arrangement;
- 80 trials on which a bilateral colour cue was followed by a target, and 8 catch trials in which participants were presented with a colour cue that was not followed by a target stimulus;
- 40 trials with a target presented to the left visual field (LVF) and 40 trials with a right visual field (RVF) target;
- 40 trials with the short SOA (100ms) and 40 trials with the long SOA (600ms).

The first two blocks of trials were Training Blocks, in which there was a consistent relationship between target location and the peripheral colour cues. For the 15 participants in the Green Condition, targets *always* appeared on the same side as the green cue, during the two training blocks. For the 15 participants in the Blue-Green condition, targets always appeared on the same side as the blue-green cue during the training blocks. The third block of trials was the Test Block. In this block, target location was unrelated to the colour of the peripheral cues (i.e. there were 40 trials on which the target appeared on the same side as the green cue, and 40 trials on which the target appeared on the same side as the blue-green cue). Aside from the constraints just described, trial type varied pseudorandomly within each of the three blocks.

Result

Participants' response latencies during the Test Phase of the experiment were analysed. Responses less than 100ms in latency were classified as anticipations and were discarded from analysis. This accounted for 1.4% of participants responses. Long outliers, more than three standard deviations greater than the mean response latency for the testing phase were also discarded from analysis. This accounted for 0.5% of the data. The average rate of catch trial errors in the experiment was 1.7%.

Response latency results for the experiment are shown in Figure 2. Initial analysis of the data revealed no significant differences between participants who were assigned to the Green Group and those who were assigned to the Blue-Green group. The 30 participants who took part in the experiment were then divided into three groups on the basis of their responses to the post-experiment questionnaire. The 'Aware Group' (N=7) comprised participants who indicated awareness of a possible link between target location and the peripheral colour changes in response to the free recall item of the post-experiment questionnaire (Item 1, see Method). The confidence of participants in their response to Item 2, which involved a two alternative forced choice (2AFC) concerning the cue-target relationship, was calculated by assigning 1 for 'Pure guess', 2 for 'Mainly guesswork', and so on, through to 6 for 'Almost certainly correct'. Mean confidence for the Aware Group was 4.4 (S.D.=0.98). The Semi-Aware Group (N=11) comprised participants who were unable to make any response to the free recall item of the questionnaire, but who chose the correct alternative in response to the forced choice item, *and* indicated that confidence in this choice better than 'a pure guess' (i.e. participants' confidence was >= 'Mainly guesswork'). The average confidence of the Semi-Aware Group in their response to the 2AFC item of the questionnaire was 3.9 (S.D.=1.30). The 'Guessing Group (N=12) comprised participants who were unable to make any response to the free recall item of the questionnaire, and who either chose the *wrong alternative* from the forced choice item, *or* who indicated that their choice was a *pure guess*. The average confidence of the Guessing Group in their response to the 2AFC questionnaire item was 1.5 (S.D.=1.00). Mean response times were then entered into a split-plot analysis of variance with one independent groups factor, Awareness Group (Guessing vs. Semi-Aware vs. Aware), and three within groups factors, Location Cueing (Valid Location vs. Invalid Location (i.e. target on the same side as the colour associated with the target during the training phase vs. target not on the same side as the colour associated with the target during the training phase), SOA (100ms vs. 600ms) and Target Visual Field (Left Visual Field - LVF vs. Right Visual Field – RVF). There was a significant main effect of SOA, $F(1,27)=24.14$, $p<.001$, which showed that overall, response times were quicker in the SOA 600ms condition relative to SOA 100ms (359ms vs. 388ms). There was also a main effect of Location Cueing, $F(1,27)=20.77$, $p<.001$, showing that overall, response latencies were quicker when targets appeared at the Valid location (i.e. on the same side as the colour that had been associated with the target during the training phase of the experiment) compared to the Invalid Location (368ms vs. 380ms; see Figure 2).

In addition, there were two significant interactions. SOA interacted with Awareness Group, $F(2,27)=3.45$, $p<.05$. This interaction is illustrated in Figure 2. As this figure shows, the interaction reflects the presence of a larger difference between the two SOA conditions for the Aware Group (56ms - SOA 600ms = 351ms; SOA 100ms=407ms), than for the Semi-Aware Group (23ms - SOA 600ms=352ms; SOA 100ms=375ms) or the Guessing Group (19ms - SOA 600ms=371ms; SOA 100ms=390ms).

Awareness Group also interacted with Location Cueing, $F(2,27)=8.12$, $p<.005$. Since we were particularly interested in the contrast between valid and invalid trials for the Guessing Group, this interaction was broken down further by analysing data from each of the three Awareness Groups separately. This enabled the significance of Location Cueing effects to be evaluated separately for each Awareness Group.

Guessing Group: Response latency results for the Guessing Group are shown in the left hand panel of Figure 2. In addition to a significant main effect of SOA, $F(1,11)=12.01$, $p<.01$, these participants showed a significant latency advantage for Valid (374ms) compared to Invalid (388ms) trials, $F(1,11)=9.26$, $p<.025$.

Semi-Aware Group: Results for this group are shown in the centre panel of Figure 2. There was a significant main effect of SOA, $F(1,10)=8.26$, $p<.025$. However, neither the main effect of Location Cueing, $F<1$, nor any of its interactions with SOA or Target Visual Field approached significance.

Aware Group: Results for this group are shown in the right hand panel of Figure 2. There was a significant main effect of SOA, $F(1,6)=7.73$, $p<.05$, and a significant advantage for Valid (366ms) compared to Invalid (392ms) trials, $F(1,6)=22.47$, $p<.005$.

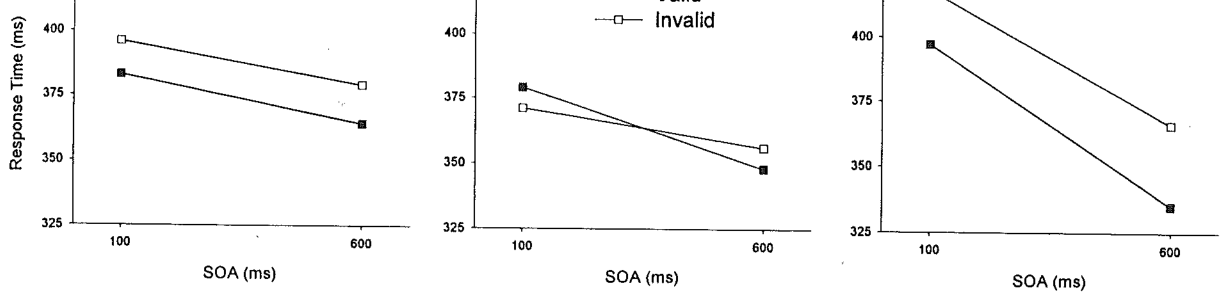
Discussion

Results from the experiment were in agreement with the derived peripheral cueing hypothesis. After a relatively brief practice period, participants' orienting behaviour was influenced by the colour of peripheral stimulus events that had been associated with the spatial location of a target stimulus. The latency advantage for valid over invalid trials cannot be explained in terms of reflexive orienting, as currently conceived, since the effect was driven by the *nature* of the peripheral stimulus event, rather than by the location of a gross visual change. Voluntary orienting cannot furnish an adequate explanation of the results either, since a clear advantage for the valid location was shown by participants in the Guessing Group. These individuals displayed no conscious awareness of the relationship between target location and the colour of the peripheral cue stimuli. This result supplements the findings reported by Lambert et al. (1999) concerning the effects of bilateral form cues on attention, and support the contention that visual orienting processes are subject to associative learning, and that this learning can proceed independently of conscious awareness.

Although the effect is clearly distinct from reflexive orienting as currently conceived, the results also show that, like reflexive orienting, the time-course of colour based derived peripheral cues is very rapid. As Figure 2 shows, the advantage for valid over invalid trials is clearly present 100ms after onset of the colour changes[1].

Interestingly, the advantage for valid over invalid trials was present for participants in the Guessing Group, and participants in the Aware group, but not for participants in the Semi-Aware Group. Lambert et al. (1999) reported

Figure 2. Mean response latency for valid and invalid trials, as a function of SOA. Results for the Guessing Group (see text) are shown in the left panel, for the Semi-Aware Group in the centre panel, and for the Aware Group in the right hand panel.



that visual orienting was influenced by an association between target location and the visual form of peripheral cue stimuli. As in the present study, effects were observed for participants who displayed no conscious awareness of the link between cues and targets, and occurred even when this relationship was rendered obscure. In view of this, it was proposed that participants' ability to make use of the cue-target relationship involved a form of implicit learning (see Berry & Dienes, 1993). The observation in the present study that participants in the Guessing Group responded more rapidly to targets at the valid location also suggests that associative learning of cue-target relationships can proceed implicitly. Why then, should the effect be *absent* for participants in the Semi-Aware Group? The fact that these participants were unable to make an appropriate response to the free recall item of the questionnaire suggests that the cue-target relationship was not fully or clearly represented in conscious awareness. However, it is reasonable to suppose that, unlike participants in the Guessing Group, these individuals had formed explicit hypotheses concerning the cue-target relationship in the course of the experiment. These participants chose the correct alternative from the 2AFC item of the questionnaire, and also indicated some confidence in this choice.

Previous research in the area of implicit learning has shown that explicit attempts to learn non-obvious structural relationships can be *detrimental* to performance, relative to an implicit condition where participants make no voluntary attempt to discern the structural relationships embedded in a task (Reber, 1976; Reber, Kassin, Lewis & Cantor, 1980). For example, in a study of artificial grammar learning Reber (1976) found that the accuracy of grammaticality judgements was *worse* for participants who were explicitly instructed to search for structure in sequences of letters generated by a finite state grammar, compared to participants who were given a neutral instructional set. Berry and Broadbent (1988) observed a similar pattern in a condition where structural aspects of the task were non-salient. When the structure of the task was non-salient, a performance advantage was observed for participants performing under implicit conditions compared to a group given explicit instructions. In the present context, it is easy to see how explicit, but partial knowledge of the relationship between cue colour and target location could impair performance. If participants suspect that the colour of the peripheral boxes may be related to target location, they are likely to engage in voluntary orienting on the basis of hypotheses concerning the possible relationship between cues and targets. However, if knowledge is incomplete, on a significant number of trials participants will orient to the *invalid* location, on the basis of an inappropriate hypothesis. An alternative, but related interpretation, is that participants in this group attained relatively complete explicit knowledge of the cue-target relationship during the training blocks of trials, but then noticed that during the test block, the previously reliable cue-target relation was often violated. Again, this could lead to the formation of alternative hypotheses concerning the cue-target relationship, producing voluntary orienting to the invalid location on a significant number of trials.

Like participants in the Guessing Group, participants in the Aware Group also displayed a significant latency advantage for valid over invalid trials. The cue-target relationship was clearly represented in conscious awareness for these participants, enabling them to freely recall the link between cue colour and target location. In this case, voluntary orienting on the basis of this explicit knowledge would act in concert with non-voluntary effects arising from associative learning during the training phase.

Participants in the Aware Group also showed a significantly larger difference in latency between the SOA 600ms and SOA 100ms conditions. An overall advantage for the SOA 600ms condition would be expected in this situation, since in addition to acting as a spatial cue the peripheral colour changes provide a general warning signal that a target stimulus is about to appear (see also Posner & Cohen, 1984; Lambert, Spencer & Hockey, 1991). Consistent with previous research, increasing foreperiod (i.e. SOA) was associated with shorter response latencies (Niemi & Naataanen, 1981). The presence of a larger foreperiod effect for the Aware participants suggests that they may have allocated more resources to processing the cue stimuli, enabling them both to gain explicit awareness of the cue-target relation, and also to prepare more effectively for target presentation.

Conclusion

The results of this experiment provide empirical support for William James' proposal that the propensity of objects to capture attention in a passive, non-voluntary manner can be influenced by learning and experience. After a relatively brief practice period, participants oriented towards a colour change that was associated with target presentation. This effect had a rapid time course, and occurred for participants who remained unaware of the contingent relation between target location and peripheral colour changes. Following James (1890/1983), and more recently Lambert et al. (1999) we propose that in addition to voluntary and reflexive processes, modern theories of attention need to acknowledge a further component, whereby visual orienting behaviour is subject to associative learning. The present results and earlier findings (Lambert et al., 1999; Lambert & Sumich, 1996) show that this learned component of orienting, can be acquired via implicit processes. Current theory suggests that non-voluntary orienting involves a rather limited and inflexible process, whereby attention is drawn reflexively to the location of a gross peripheral visual event. This account appears to be incomplete, and does not do justice to the flexibility and sophistication of visual processing. It is easy to appreciate the improved ecological utility of a system that can orient rapidly towards events of interest, not only in response to the location of gross visual changes, but also in response to the *nature* of peripheral objects. The ability to capitalize on predictive contingencies operating between task components, so that attention is deployed in a dynamically efficient way, may be an important component of skilled performance in many visuospatial tasks, such as driving, playing ball games, or even walking unscathed across a crowded restaurant floor.

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Note:

1 Since the Green and Blue-Green cues were rendered approximately equiluminant with the grey frames of the fixation display, it might be thought that the results are also germane to the issue of whether equiluminant peripheral stimuli capture attention (see Theeuwes, 1995; Yantis & Hillstrom, 1994). However, we feel it would be premature to recruit the present findings as clear support for the view that equiluminant visual onsets can capture attention (Yantis & Hillstrom, 1994). Our primary objective was to test the derived peripheral cueing hypothesis with coloured stimuli; the aim of the pre-experimental flicker photometry was to ensure that any effects would not be swamped by reflexive orienting towards the subjectively 'brighter' colour change. Accordingly, the intensity of the colour stimuli were set pre-experimentally on the basis of judgements by four observers, rather than requiring each individual subject to adjust the stimuli for equiluminance. In view of this, it is appropriate to describe the cue stimuli as approximately equiluminant with the grey background frames. The question of whether derived peripheral cueing effects can occur with fully equiluminant peripheral colour stimuli will require further research, in which the stimuli are adjusted for equiluminance by each individual subject (see Cavanagh, MacLeod & Anstis, 1988).

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