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Modulation of non-spatial attention and the global/local processing bias

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ABSTRACT

Amelioration of the rightward spatial attention bias in patients with hemispatial neglect following manipulations of non-spatial attention suggests that spatial attention and mechanisms related to the regulation of attention are interrelated. Studies in normal, healthy subjects have shown similar modulation in spatial bias following tonic and phasic changes in attention suggesting that this interaction is a general mechanism of attention rather than a curiosity of the neglect disorder. The current study examined this attentional interaction to determine if perceptual processes favoring one hemisphere over the other are affected by this relationship. Participants first made rapid discriminations of Navon figures presented at central fixation. As expected, when participants attended to either the local or global dimension, incongruence in the orthogonal dimension resulted in longer reaction times for accurate discrimination compared to congruent trials. However, following a brief (16-min) continuous performance task designed to elicit behaviors associated with greater tonic and phasic alertness, participants showed significantly less local interference when attending the global dimension and more global interference when attending the local dimension on the Navon discrimination task compared to a control task condition. The results indicate that exercising tonic and phasic alertness produces a global processing bias.

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1. Introduction

Co-occurring deficits in spatial and non-spatially lateralized attention (e.g., selective attention, sustained attention and alertness) in patients with hemispatial neglect has led to the notion that non-spatial attention mechanisms modulate spatial attention (see review Husain & Rorden, 2003). Support for this idea comes from studies that show a reduction, and in some cases elimination, of patients' spatial neglect when presented with unpredictable alerting tones (Robertson, Mattingley, et al., 1998; Van Vleet & Robertson, 2006) or when they are able to achieve a more ready and focused attentional state as a result of behavioral training (DeGutis & VanVleet, 2010; Robertson, Tegner, et al., 1995; Thimm, Fink, et al., 2006). Modulations in non-spatial attention can be conceptualized as tonic or phasic in nature (see review Aston-Jones & Cohen, 2005). Tonic modulations of attention refer to fluctuations in intrinsic readiness on the order of minutes to hours that provides the cognitive tone for more complex functions such as working memory and executive control (Posner, 2008; Sturm, de Simone, et al., 1999). This system is supported by a noradrenergic network comprised of the locus coeruleus and predominantly right inferior frontal, inferior parietal, and anterior cingulate regions (Robinson & Coyle, 1980; Robinson, 1985; Singh-Curry & Husain, 2009; Sturm & Willmes, 2001; Thiel, Zilles, et al., 2004). Patients with neglect commonly have lesions that involve this network and often demonstrate marked deficits in sustaining attention (Hjaltason, Tegner, et al., 1996; Robertson, Manly, et al., 1997) and a significant decrement in vigilance with prolonged time on task (Malhotra, Coulthard, & Husain, 2009). Further, reducing tonic alertness in patients that have recovered from neglect via administration of a sedative produces a re-emergence of patients' rightward bias (Lazar, Fitzsimmons, et al., 2002).

In contrast to tonic changes in attention, *phasic* modulations of attention occur on the order of seconds and are typically associated with brief external events, such as the presentation of salient stimuli. Phasic modulations of attention supports cognitive operations such as orienting and selective attention (Husain & Rorden, 2003; Posner, 2008), both of which are often compromised in patients with neglect. For example, when detecting two targets embedded in a rapid serial presentation of characters at fixation (attentional blink), a task that requires the efficient updating of visual working memory (Roth, Serences, et al., 2006), rapid engagement and disengagement of attention (Kranczioch, Debener, et al., 2005) and has been associated with locus coeruleus phasic responses (Nieuwenhuis et al., 2005), Husain and colleagues (1997) found that patients with neglect required a 1400 ms interval between

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targets to consistently identify the second target whereas unimpaired controls required only 400 ms.

Corbetta and Shulman (2002) argue that a right-lateralized ventral fronto-parietal network is especially sensitive to detecting and processing brief salient events often associated with phasic modulation of attention. Studies comparing the neural mechanisms supporting tonic and phasic attention show that these systems are highly overlapping, with phasic attention also incorporating left frontal and parietal regions (Coull, Nobre, et al., 2001; Sturm & Willmes, 2001). Modulating attention phasically has been shown to improve spatial and non-spatially lateralized deficits common in patients with neglect, albeit transiently. For example, unexpected auditory tones have been shown to induce improvements in visuospatial detection (Robertson et al., 1998) and speeded selective attention (attentional blink task; Van Vleet & Robertson, 2006) lasting on the order of seconds. Evidence also suggests that attention modulated phasically from the 'topdown', as when waiting for the appearance of a target image in a stream of similar distractors, can produce sustained improvements in selective attention and spatial attention in patients with neglect (DeGutis & VanVleet, 2010). This state of focused attention to a pre-determined target presented among similar distractors has been associated with large transient bursts of activity in the locus coeruleus to target (but not non-target) stimuli and correspondingly has been referred to as the phasic mode of attention (Aston-Jones & Cohen, 2005). This phasic mode of attention requires the active maintenance of a goal (i.e., responding to all non-targets and withholding a response to a predetermined target stimulus) and is associated with a high level of task engagement (see also Singh-Curry & Husain, 2009). Finally, electrophysiological studies show that bottom-up and top-down phasic modulations of attention may engage similar mechanisms (Singh-Curry & Husain, 2009), though bottom-up modulations (e.g., when presented with an oddball stimulus) typically elicit a P300a component that may have a frontal source, whereas top-down modulations (e.g., when presented with a pre-determined target) typically elicit a slightly later P300b component that may have a parietal source.

Modulation in spatial bias following tonic and phasic changes in attention has also been shown in healthy controls (Bellgrove, Dockree, et al., 2004; Manly, Dobler, Dodds, & George, 2005), suggesting that this interaction is a general mechanism of attention rather than a curiosity specific to the neglect disorder. A recent study by Manly et al. (2005) showed that under low levels of alertness (i.e., sleep deprivation) or over prolonged periods of time (i.e., fatigue), healthy individuals exhibit a rightward shift in attention that is much smaller but in the same direction of patients with left neglect due to right hemisphere damage. Similarly, Bellgrove et al. (2004) showed that healthy individuals who performed poorly on a test of sustained attention showed a similar pattern (i.e., greater rightward or reduced leftward/normal spatial bias) compared to those with good sustained attention capacity. Finally, Dodds et al. (2008) showed that the modulatory influence of non-spatial attention on spatial attention is present even under conditions of restricted eye-movement and brief stimulus presentation. While increasing task difficulty negatively affected performance, spatial bias was only affected by time-on-task (i.e., fatigue; Dodds et al., 2008).

Although the interaction between non-spatial attention and spatial attention is compelling, the mechanism(s) of this relationship is unclear. Because non-spatial attention is thought to engage predominantly right hemisphere mechanisms (Robinson & Coyle, 1980; Robinson, 1985; Sturm & Willmes, 2001; Thiel et al., 2004), in the current study we examined whether this may influence hierarchical perceptual processing. To examine this,

we utilized a well known technique for probing the influence of attention on perceptual processing, whereby healthy subjects made speeded discriminations of hierarchical stimuli presented at central fixation (nested letter identification task). This task was chosen due to the compelling evidence that the right hemisphere is biased towards global processing and the left towards local processing as shown in a number of prior studies: neuropsychological (e.g., Delis, Robertson, & Efron, 1986; Robertson, Lamb, & Knight, 1988), electrophysiological (e.g., Evans, Shedden, Hevenor, & Hahn, 2000; Malinowski, Hübner, Keil, & Gruber, 2002; Volberg & Hübner, 2004), psychological (e.g., Flevaris, Bentin, & Robertson, 2010; Van Kleeck, 1989), and functional imaging studies all provide evidence of hemispheric processing differences (e.g., Fink et al., 1996; Heinze, Hinrichs, Scholz, Burchert, & Mangun, 1998; Martinez et al., 1997; Weissman & Woldorff, 2005).

In the current study, in separate blocks, subjects identified the global or local level of hierarchical stimuli (Navon, 1977) in which large letters or numbers were formed out of small letters or numbers. The stimuli could be congruent (e.g., a large letter built of small letters) or incongruent (e.g., a large number built of small letters). This nested letter identification task allows measurement of the extent to which participants are able to ignore the information at one level (e.g., local) while directing their attention to the other (e.g., global). Difficulty ignoring information at one level (local or global) while processing information at another is manifested as slower response times to stimuli that contain incongruent information compared to stimuli that have congruent information (i.e., interference).

To modulate attention both tonically and phasically, we utilized a novel continuous performance task (CPT) recently shown to improve performance on a resource demanding attention task (attentional blink) and eliminate rightward bias on search and landmark tasks in patients with unilateral neglect following limited training (36 min/day, 9 days total; DeGutis & VanVleet, 2010; discussed above). Similarly, participants in the current study were asked to respond via button press to frequent and centrally presented images on a computer screen while trying to inhibit their response to an infrequent and randomly presented target image, similar to a go/no-go task (Logan, 1994). Continual engagement with the task required sustained attention (i.e. tonic modulation of attention), and the inhibitory aspect of the task made the target image particularly salient (i.e., producing a strong phasic modulation in attention), informing participants to inhibit the execution of a pre-potent motor response (see review Aston-Jones & Cohen, 2005; DeGutis & VanVleet, 2010).

In the current study, by administering a hierarchical figures task before and after training in the same session, we compared the influence of the CPT that targets task with a categorization control task (CCT) that was less focused on tonic and phasic modulations of non-spatial attention. Specifically, prior to and immediately following 16-min of engagement with the CPT or CCT, subjects made speeded global and local discriminations on hierarchical stimuli presented at central fixation. We evaluated global and local interference pre and post 16-min of engagement with the CPT vs. the CCT. We predicted that engagement with the CPT task compared to the control task would produce a global processing bias associated with the right hemisphere, thereby reducing local interference in the globally directed task and increasing global interference in the locally directed tasks. We also predicted that this effect would fade over a relatively short period of time given the limited time spent on the CPT (16 min). Finally, to examine the potential contribution of differences in general, physiological arousal elicited in each task, we conducted a respiration analysis of two groups performing either the CPT task or the control task.



Fig. 1. The nested letters/numbers identification task required participants to rapidly categorize either the local or the global form (separate blocks, counter balanced). Participants indicated their choice (letter or number) by pressing one of two buttons on a button pad with the index and middle fingers of their right hand. The identity of the local and global forms could be categorically identical (congruent) or different (incongruent). The stimulus remained on the screen for a fixed duration of 750 ms and participants were instructed to respond as quickly and accurately as possible; the next trial began 500 ms following response.

2. Method

2.1. Participants

Sixty-four students from the University of California, Berkeley (continuous performance task, CPT group: 12 males, mean age 21.3 years-old, 2 left-handed; categorization control task, CCT group: 14 males, mean age 20.8 years-old, 1 left-handed) participated in the experiment for course credit. All had normal or corrected-to-normal vision. The experiment was approved by the University of California, Berkeley, Committee for Protection of Human Subjects, and all participants gave informed consent before participating (Figs. 1 and 2).

2.2. Stimuli and procedure

Subjects completed the following sequence of tasks: (1) nested letter identification task (2) 16-min of the CPT or CCT task (3) nested letter identification task (see Fig. 3). The nested letter identification task was designed based on results of a pilot study with 16 students in which the size of the stimuli were adjusted to produce reliable interference from the unattended dimension across both conditions: attend local/attend global.

Because of known alterations in spatial attention following a similar behavioral manipulation as used in the current study (i.e., greater awareness of the left side of space and objects; DeGutis & VanVleet, 2010), we chose to equate the size



Fig. 2. The continuous performance task (CPT) consisted of sequentially presented images in the center of the screen, separated in time by a fixation cross. Subjects were required to respond via a button press when the picture was a random object (distractor objects) and withhold responding when the picture was a tea pot (target picture; 8 versions of tea pots were shown in random order). The task lasted approximately 16-min and contained 360 trials: 36 target objects (10% of trials) and 324 distractor objects (90% of trials) randomly ordered. Objects were presented for a fixed duration of 500 ms and between trials a fixation cross was presented at 3 different SOAs (600 ms, 1800 ms or 3000 ms).



Fig. 3. Design: all participants completed the nested letter/number identification task before engaging in either 16-min of the CPT task (n=32) or 16-min of the CCT task (n=32). Immediately following these tasks, half the participants (n=16) in each group (CPT or CCT) completed the 'globally-directed' identification block of the nested letter/number identification task followed by the 'locally-directed' block. The other half (n=16) completed the nested letter/number identification tasks in the reverse order.

of the Navon figures for both conditions (attend local/attend global). This way, we could be assured that any change in the allocation of attention between conditions would not be attributed to differences in the area subtended on the retina. Central presentation was important as a number of studies have shown that hemispheric lateralization in global/local processing is stronger at (and sometimes limited to) central stimulus position in the visual field. For example, fMRI and ERP studies have shown that activity over the occipito-temporal areas show hemispheric asymmetry in global/local processing when compound letters are presented in the center of the visual field (Han, He, Yund, & Woods, 2001; Heinze, Münte, Johannes, & Mangun, 1994) whereas no such asymmetry is observed under the condition of unilateral presentation (Han, Fan, Chen, & Zhuo, 1999; Han et al., 2002). Stimuli were presented on a computer screen positioned 50 cm from the participant's eyes. Thirty two participants identified the global level of hierarchical stimuli first ('globally-directed' task) and Thirty two participants identified the local level first ('locally-directed' task) pre-CPT or CCT task, with 36 practice trials provided prior to each task. Each group identified the orthogonal level in a second block of trials pre-CPT or CCT. For each condition, the trial began with a $0.5^{\circ} \times 0.5^{\circ}$ central fixation cross. Participants were instructed to look at the cross throughout the entire trial. After 500 ms, the fixation cross was replaced by a hierarchical stimulus. The stimuli consisted of 16 small letters or numbers (the local forms) arranged to form a large letter or number (the global form). In the globally directed task, local forms were $.25^{\circ}$ wide $\times 25^{\circ}$ high and global form was 2° wide $\times 2^{\circ}$ high. In the locally directed task, local forms were $.15^{\circ}$ wide $\times .15^{\circ}$ high and global form was 1.5° wide $\times 1.5^{\circ}$ high. The possible set of letters and numbers was {A, E, F, H, L, P, 2, 3, 4, 6, 7, 9}. The sets of global letters and numbers were the same as the sets of local letters and numbers. The identity of the local and global forms could be categorically identical (congruent) or different (incongruent), resulting in 24 stimuli (note: stimuli with the same global and local form were not used, i.e. global E made of local E's). There were 15 repetitions of each of the 24 stimuli resulting in a total of 360 trials for each global and local task. In the local task the participants categorized the local form. In the global task the participants categorized the global form. Participants indicated their choice (letter or number) by pressing one of two buttons on a button pad with the index and middle fingers of their right hand. Participants practiced the response mapping prior to the commencement of the experiment during a practice session (40 trials). The stimulus remained on the screen for a fixed duration of 750 ms and participants were instructed to respond as quickly and as accurately as possible; the next trial began 500 ms following response.

Participants in the CPT group engaged in 16-min of a continuous performance task in which subjects' ability to inhibit inappropriate responses was challenged (see DeGutis & VanVleet, 2010). Images of objects were acquired from the Caltech-256 Object Category dataset (Griffin, Holub, & Perona, 2007) due to their diverse set of natural and artificial objects in various settings. Images were sequentially presented one at a time in the center of the screen, separated in time by a fixation cross. Subjects were required to execute a speeded response via button press when the picture was a random object (distractor picture) and withhold responding when the picture was a tea pot (target picture: 8 pictures of different tea pots were used and the order of presentation was randomized). The task lasted approximately 16-min and contained 360 trials: 36 target objects (10% of trials) and 324 distractor objects (90% of trials) randomly ordered. Each object subtended a visual angle of 4 degrees $(vertical) \times 6$ degrees (horizontal). On each trial, objects were randomly presented for a fixed duration of 500 ms. In between trials, a fixation cross was presented at 3 different SOAs (600 ms, 1800 ms or 3000 ms). After completing this task, participants were tested on the same nested letter identification task as described above; 16 subjects completed the local discrimination condition followed by global discrimination while the remaining 16 subjects completed the tasks in reverse order.

Participants in the CCT group engaged in 16-min of a serial categorization task in which they were required to judge the spatial orientation (upright or inverted) of the same objects used in the CPT task. Images of objects were presented sequentially at central fixation and participants were required to execute a non-speeded response indicating whether objects were upright or inverted using a 2-button response pad with their dominant, right hand (index finger="upright"; middle finger="inverted"). Objects were randomly presented for 500 ms duration and presentation was jittered across 3 SOAs (600 ms, 1800 ms or 3000 ms) for 360 trials: 180 upright, 180 inverted.

2.3. Physiological examination of arousal

Respiratory parameters have been widely used in psychophysiology to index the effects of psychological arousal (Grossman, 1983; Wientjes, 1992). Increased psychological arousal generally leads to increases in respiration rate and minute volume, and a shift from abdominal to thoracic breathing. Recent and more detailed analyses of arousal and sustained attention have examined the relationship between respiration and vagal control over the heart; this direct cardiorespiratory interaction is reflected in a phenomenon known as the respiratory sinus arrhythmia (RSA; see Pattyn, Neyt, Henderickx, & Soetens, 2008). For our present purposes, we simply examined the respiration rate and volume (inspiration and expiration time. described below) to quantify the stability of thoracic breathing in 14 volunteers from the community (12 males, mean age 28.4 years-old). Participants were monitored for a 5-min baseline period while they simply listened to task instructions and also while they engaged in either the CPT or control (CCT) task. Respiration parameters were collected via strain-gauge or 'stretch resistor' (hollow silastic tube) strapped around the waist and positioned 1 cm above the navel to capture maximal thoracic distention. Changes in respiration (thoracic impedance) were relayed to a PC, real time via wireless connection and sampled at 4 Hz.

The respiration signal was transformed to obtain total expiration time (TTE) and total inspiration time (TTI) on a breath to breath basis (in ms; see de Geus, Willemsenb, Klaver, & van Doornen, 1995). TTI (and TTE) were comprised of inspiration (expiration for TTE) time and the intervening pause. TTI began from the first point on the uphill slope of the original respiration signal, to the start of the downhill slope where the first derivative again reached a minimal threshold. This later point was considered to be the end of the inspiratory pause and the start of the TTE. The expiratory pause was considered to begin when the changes in downhill slope were lower than the minimal trend and to end with the start of the next inspiration. The minimal trend was computed as 80% of the square root of the first derivative maximum reached in the uphill or downhill slope that followed. Finally, the 'total cycle time' or interval between the start of the current and the start of the next breath was recorded as the average respiration rate (RR) in cycles per minute. All breaths in a condition (CPT vs. CCT) were averaged to yield the mean TTI, TTE and RR for that condition.

3. Results

Participants had no difficulty performing the global/local task (92% accuracy); mean reaction time (RT) was 568 ms (STE = 8 ms) and 518ms (STE = 11) for the global and local task, respectively. Similarly, performance on the CPT task across participants was consistent, mean RT for nontarget objects = 462 ms (STE = 11 ms); target accuracy (correct response omission; NoGo) was 77% with



Fig. 4. Average performance on the CPT task.

a 2% error rate on Go trials (i.e., misses; see Fig. 4). Performance on the CCT was comparable: mean RT upright images = 562 ms (STE = 15 ms), inverted images = 556 ms (STE = 15 ms); accuracy for upright images = 84%, inverted = 87% (Fig. 5).

Post 16-min of CPT, RTs dropped to 530 ms (STE = 7 ms) and 492 ms (STE = 9 ms) for the global and local task, respectively for all participants. A 2×2 repeated measures ANOVA (pre/post RT × global/local condition) showed that participants were significantly faster post-CPT compared to pre-CPT (F(28) = 6.796, p < 0.05), and that the speed increase occurred irrespective of condition (i.e., non-significant interaction, F(28) = 0.401, p = 0.532). For both the global and local task, the amount of local/global interference, respectively, was calculated as the difference in RTs between incongruent trials and congruent trials. For example, the reaction time disadvantage in discriminating a stimulus with a global form made of local forms of a different category compared to the same category (incongruent RT – congruent RT) reflects the level of interference. The important finding for the purposes of this study, was a significant 3-way interaction between Session (pre/post) × interference (global/local) × order (global first/local first) on interference (F(56) = 8.417, p < 0.01), indicating that global and local interference changed immediately after CPT.

A priori t-tests were used to examine global and local interference before and after CPT. Prior to CPT there was significant local interference in the globally-directed task, with RTs 35 ms faster for congruent stimuli (t(28) = -2.82, p < 0.01). There was also significant global interference on responses in the locally-directed task, with RTs 4 ms faster for congruent stimuli than incongruent stimuli (t(28)=2.13, p<0.05). This pattern changed sharply following 16min of the alertness task. Immediately following CPT, on the first of two blocks of trials (1 block per condition: global or local discrimination), the pre-training 35 ms local interference effect decreased to 25 ms (t(14) = 3.14, p < 0.01). In comparison, the pre-training 4 ms global interference effect reliably increased to 10 ms(t(14) = -3.01), p < 0.01). However, when participants completed a second block of trials comprised of the alternate condition, the interference returned to pre-CPT levels (i.e., participants' level of interference was no different from pre-CPT levels, ps > 0.05; see Table 1). For example, when participants who completed the local discrimination task in block 1, completed the global discrimination task in the second block, the local interference effects were not different from pre-CPT levels (pre = 29 ms vs. post = 32 ms(t(14) = 0.58, p = 0.57)).



Fig. 5. Average performance on the nested letter/number identification task pre and post 16-min of CPT by group (globally directed task first followed by locally directed task post 16-min of CPT in top panel, n = 16; vice versa in bottom panel, n = 16). The results show a global biasing effect on the first block of trials post CPT, as evidenced by significantly less local interference on the globally directed task and significantly greater global interference on the locally directed task compared to pre CPT performance. The global biasing effect faded before the second block of trials in each group (i.e., no significant difference from pre CPT levels of interference).

For the CCT group, A 2 × 2 repeated measures ANOVA (pre/post RT × global/local condition) showed that participants were significantly faster post-CCT compared to pre-CCT (F(29)=23.08, p < 0.001), and that the speed increase occurred irrespective of condition (i.e., non-significant interaction, F(29)=1.31, p=0.26; see Table 1). However, unlike the CPT group, for both the global and local task, the amount of local/global interference was unchanged following the CCT task, as a Session (pre/post) × Interference type (global/local) × order (global first/local first) only showed a main effect of Interference type (F(59)=30.41, p < 0.001), indicating that global and local interference did not change following the CCT.

3.1. Arousal

A priori *t*-tests were used to examine the following respiratory time intervals to determine if the CPT or CCT differentially

Table 1

(a) and (b) Mean reaction time (RT) per condition pre and post 16-min of either CPT or CCT, per group (Glob=globally directed task; Local=locally directed task; C=congruent; I=incongruent).

(a)				
	1ST block post-CPT		2ND block Post-CPT	
	Glob-C	Glob-I	Local-C	Local-I
Pre	565	600	525	532
Post	533	557	495	502
	Local-C	Local-I	Glob-C	Glob-I
Pre	533	537	577	607
Post	507	516	538	570
(b)				
	1ST block post-CCT		2ND block post-CCT	
	Glob-C	Glob-I	Local-C	Local-I
Pre	557	595	518	526
Post	525	556	502	509
	Local-C	Local-I	Glob-C	Glob-I
Pre	551	592	518	523
Post	534	572	498	507

affected physiological arousal: total time inspiration (TTI), total time expiration (TTE) and respiration rate (RR; cycles per minute). No differences were found in TTE (CCT: 2289 ms vs. CPT: 2275 ms; t(12) = 0.212, p = 0.83), TTI (CCT: 1012 ms vs. CPT: 993 ms; t(12) = 0.093, p = 0.92) or RR (CCT: 11.5/min vs. CPT: 12.75/min; t(12) = -0.814, p = 0.43) between tasks.

4. Discussion

The results of the current study indicate that 16-min of engagement in a behavioral task designed to modulate tonic and phasic alertness (DeGutis & VanVleet, 2010; also see review Aston-Jones & Cohen, 2005) was sufficient to induce a global perceptual bias. Immediately following this continuous performance task (CPT), participants exhibited greater global interference on a local discrimination task and less local interference on a global discrimination task compared to pre-CPT performance on the same tasks. Equivalent time spent on a categorization control task (CCT) that showed a similar amount of physiological arousal as the experimental task failed to influence global/local processing (i.e., amount of interference was unchanged from pre-CCT levels). A recent study using a similarly challenging CPT demonstrated significant improvements in performance on a resource demanding attention task (attentional blink) and reduced rightward bias on search and landmark tasks in patients with neglect following limited CPT training (36 min/day for 9 days; DeGutis & VanVleet, 2010).

Presentation of all stimuli at central fixation in the current study insured that any change in bias was attributable to an unbalanced change in activation, likely between hemispheres post-CPT. Findings from a number of prior studies suggest that this change resulted in a right hemisphere advantage (e.g., Delis et al., 1986; Martin, 1979; Martinez et al., 1997; Robertson & Delis, 1986; Robertson et al., 1988; Robertson, Egly, Lamb, & Kerth, 1993; Weissman & Woldorff, 2005; also see meta-analysis Van Kleek, 1989). A possible account for this effect is that the right hemisphere was recruited more than the left during the CPT, as shown in prior studies demonstrating increased activation of the right inferior frontal cortex (rIFC) in similar Go/NoGo tasks (Aron, Robbins, & Poldrack, 2004; Aston-Jones & Cohen, 2005; Chambers et al., 2006; Ray, Huang, Constable, & Sinha, 2006). Prior studies have also shown preferential involvement of rIFC, as well as inferior parietal, and anterior cingulate regions when engaged in tasks of tonic alertness or sustained attention (Robinson & Coyle, 1980; Robinson, 1985; Sturm & Willmes, 2001; Thiel et al., 2004) and selective attention as in the current study (Coull et al., 2001; Sturm & Willmes, 2001). A recent study by Flevaris et al. (2010) also demonstrates the malleability of the global/local processing bias following hemispheric activation. The authors demonstrate that low spatial frequency primes preferentially processed by the right hemisphere modulate global processing of a hierarchical probe presented in the left visual field (projected directly to the right hemisphere) in neurologically healthy participants.

While engaging right-lateralized frontally-mediated attention mechanisms may account for alterations in perceptual bias, this notion must be reconciled with evidence from neuropsychology and neuroimaging studies that support an important role of right temporoparietal regions in global processing. For example, when Delis et al. (1986) asked patients with unilateral lesions to copy hierarchical stimuli, patients with right hemisphere lesions often drew many of the local elements in a disorganized arrangement, failing to reproduce the global structure. Conversely, patients with left hemisphere lesions drew the global form without local elements or with local shapes drawn incorrectly. A subsequent study showed that patients with lesions that overlapped in the right temporoparietal area exhibited longer RTs when identifying global compared to local shapes, while those with left temporoparietal lesions had longer RTs for local shapes (Robertson et al., 1988). Ivry and Robertson (1998) have made the case that this functional difference generalizes to other types of hierarchical stimuli and holds across modalities (see Justus & List, 2005). Also, behavioral, ERP and functional neuroimaging studies have provided converging support for this difference in processing between hemispheres (Fink, Marshall, Halligan, Frith, & Frackowiak, 1997; Kimchi & Merhav, 1991; Martinez et al., 1997; Proverbio, Mimritic, & Zani, 1998; Weissman & Banich, 1999). Given the dense interconnections between right temporoparietal and frontal regions, CPT stimulated frontal activation likely influenced a large-scale cortical network consisting of posterior areas involved in global/local processing (Corbetta & Shulman, 2002; Mesulam, 1981; Posner & Petersen, 1990).

The results of the current study suggest that the CPT-mediated global biasing effect reflects accelerated visual stimulus extraction and encoding of properties at the global level, rather than an enhancement of response preparation and/or execution, as participants in both groups demonstrated faster RTs for both conditions (attend local, attend global) following the CPT or CCT task (Matthias et al., 2010). A recent study by Bultitude, Rafal, and List (2009) showed a similar influence on global/local processing as the current study following a manipulation of visual perception (prismadaptation) in patients with neglect. Following prism adaptation, patients exhibited a global processing bias or failed to show the local processing bias common in these patients (Bultitude et al., 2009). The authors argue that changes in relative hemispheric activity following adaptation to rightward-shifting prisms could improve both leftward inattention and the local processing bias by restoring the activation balance of the two hemispheres (see also Luauté et al., 2006b; Pisella, Rode, Farne, Tilikete, & Rossetti, 2006).

In the current study, it was found that the global biasing effect persisted throughout the first block of trials immediately following CPT (approximately 16-min) and faded by the second block of trials (i.e. interference as a result of incongruence at global/local levels was not different than pre-CPT interference). This temporary effect argues against an interpretation that a new strategy developed as a result of the intervening CPT task and is consistent with recent findings from DeGutis and VanVleet (2010). In this study, 12 patients with hemispatial neglect completed 9-days (36 min/day) of training on a CPT task similar to the one used in the current study. As a group, patients failed to exhibit a lateralized attention bias on conjunction search and landmark tasks 24-h post training compared to a *wait-list* control group. Participants also showed significant improvements in a non-spatially lateralized measure of selective attention (attentional blink task). The persistent effects of CPT engagement in this study are consistent with repeated neural stimulation protocols (e.g., transcranial magnetic stimulation) in which beneficial effects last for days following the stimulation (Boggio, Nunes, et al., 2007; Brighina, Bisiach, et al., 2003; Naeser, Martin, et al., 2005). However, because improvements in focused attention, sustained attention and response inhibition on the CPT were significantly correlated with improvements on the outcome measures, the authors contend that it is also likely that these cognitive skills were recruited beyond the training session and generalized to performance on untrained, resource demanding attention tasks. Thus, the temporary effects seen in the current study may simply reflect a stimulation effect, whereas prolonged engagement with the CPT may enable greater skill acquisition.

Finally, a study by Peers, Cusack, and Duncan (2006) examining visual detection in patients with left or right parietal lesions and controls, show that increased cognitive demand (i.e., dual-task vs. single-task) induced a general rightward shift in spatial bias. A potential explanation of this effect is that under conditions of high cognitive load, right hemisphere attentional resources are being utilized and are unavailable for other processes, which could create a situation where the left hemisphere out-competes the right hemisphere for control of spatial attention (Ballard, 1996; Paus, Zatorre, Hofle, & Caramanos, 1997; Smit, Eling, & Coenen, 2004a, 2004b, also see review Warm, Parasuraman, & Matthews, 2008). Alternatively, this rightward bias may be due to attending to a concurrent task and may decrease alertness (Peers et al., 2006). Thus, it may be that either low alertness or high cognitive load can deplete attentional resources specific to the right hemisphere. The latter account and the results following engagement with the CPT employed in the current study as well as the DeGutis and VanVleet study (2010), suggest that a boost in right hemisphere function may support improvements in attentional state (Tang & Posner, 2009) leading to greater cognitive efficiency (e.g., improvements in perceptual discrimination and sustained attention; MacLean et al., 2010).

The respiration results indicate that the effects of CPT on global/local attention compared to the control condition were not a product of differences in physiological arousal (e.g., respiration rate and volume; see de Geus et al., 1995; Pattyn et al., 2008). This suggests that, rather than simply providing phasic boosts in alertness (Robertson et al., 1998; Van Vleet & Robertson, 2006) which is often associated with boosts in physiological arousal, the CPT is engaging a state of attention that is more conducive to focusing and sustaining attention, similar to what has been referred to as the phasic mode of attention (Aston-Jones & Cohen, 2005; Singh-Curry & Husain, 2009).

In summary, the current study is consistent with the induction of a right hemisphere perceptual processing bias following brief exposure to a task requiring sustained attention punctuated by short periods in which participants had to inhibit a pre-potent motor response (phasic alertness). Despite the central location of all stimuli, participants exhibited a global processing bias immediately following the CPT compared to the CCT that persisted for approximately 16-min. The current results are consistent with a brief activation or biasing of the right hemisphere and may represent a rather simple mechanism for stimulating the damaged hemisphere in patients with hemispatial neglect (DeGutis & VanVleet, 2010).

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