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Brief article

Phasic alertness can modulate executive control by enhancing global processing of visual stimuli

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ABSTRACT

Researchers have suggested that the attention system is composed of several networks that have different functions. One of these networks is responsible for achieving and maintaining an alert state (alerting system), and another for selection and conflict resolution (executive control). There is growing interest in how these attentional networks interact. The current study aims to unravel a mechanism by which the alerting system can interact with executive control. Participants were presented with a large arrow (global level) made of small arrows (local level). The arrows were pointing to the right or left so that the global and local levels could be congruent or incongruent. In separate blocks, participants were asked to attend to the global or local level. An auditory alerting cue preceded the arrow target in half of the trials. In the local task, the congruency effect was larger with the alerting cue than without it. In contrast, alerting did not modulate the congruency effect in the global task. We suggest that alerting creates a bias toward global processing and in turn, increases attention to sensory stimuli in the environment. This process can disrupt conflict resolution by allocating attention to irrelevant competing stimuli that surround the target.

1. Introduction

Attention is often subdivided into different systems that carry diverse functional demands (Posner & Petersen, 1990). One of these systems is the alerting system, a low-level system dominated by distribution of noradrenaline from the locus coeruleus in the brain stem (Aston-Jones & Cohen, 2005). Alertness is commonly divided into two modes of function: tonic and phasic alertness. Tonic alertness, which is also known as "intrinsic alertness", designates the internal control of wakefulness or arousal in the absence of an external cue (Sturm et al., 1999; Sturm & Willmes, 2001). Phasic alertness, on the other hand, represents the ability to increase response readiness for a very short period of time, following an external warning event (Posner, 1978; Sturm & Willmes, 2001).

Another attentional system is the executive control network, which deals with higher cognitive functions such as resolving conflicts and inhibiting prepotent responses. The executive network is associated with frontal brain regions (Botvinick, Cohen, & Carter, 2004). There is a question concerning the relationship between executive control and the alerting systems of attention. Cumulative evidence from the last decade revealed that these two systems interact under certain conditions. Specifically, alertness has been argued to inhibit cognitive control processes (see Callejas, Lupiáñez, Funes, & Tudela, 2005; Callejas, Lupiáñez, & Tudela, 2004). This effect was revealed through a comprehensive test of attention designed to measure several attentional systems in parallel (the attentional network test—ANT; Fan, McCandliss, Sommer, Raz, & Posner, 2002). One of the conditions of the ANT and its variants (ANTI—attentional network test interaction, Callejas et al., 2004; ANT-R—attentional network test revised, Fan et al., 2009) involves introducing an alerting warning cue to induce phasic alertness prior to an arrow-flanker task. In this task, subjects indicate the direction of a central arrow that is embedded among

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distracting arrows (i.e., flankers). The direction of the flanking arrows can be congruent (→→→→→) or incongruent (→→←→→) with respect to the central arrow. Executive control is measured by the congruency effect (mean reaction time (RT) in incongruent trials minus mean RT in congruent trials). The congruency effect represents the cost in RTs due to the conflicting incongruent condition. It has been demonstrated that the congruency effect is significantly larger when an alerting warning signal precedes the target. This effect has been replicated in many studies using different versions of the ANT (see MacLeod et al., 2010). Although the mechanisms that underlie this effect are still unclear, it was speculated that alertness might inhibit activity in the anterior cingulate cortex (ACC, Callejas et al., 2005), an area that is highly associated with executive control (Botvinick et al., 2004). However, recent data from our lab (Weinbach & Henik, in preparation) demonstrates that the influence of alertness on executive control does not extend to other executive tasks, such as the color-word Stroop task (Stroop, 1935) that is also associated with executive control and ACC activation (Pardo, Pardo, Janer, & Raichle, 1990). These findings make it difficult to claim that alertness directly shuts down control activity. It seems that alertness might modulate the congruency effect in the flanker task by increasing the influence of visually-presented distractors. A possible indication for this comes from studies that show how alertness, a non-spatial component of attention, interacts with allocation of spatial attention (DeGutis & Van Vleet, 2010; Manly, Dobler, Dodds, & George, 2005; Matthias et al., 2010; Robertson, Mattingley, Rorden, & Driver, 1998; Thimm, Fink, Küst, Karbe, & Sturm, 2006). Recently, Van Vleet, Hoang-duc, DeGutis, and Robertson (2010) reported that alertness can interact with global and local processing of visual information. Global and local processing are usually studied using the Navon task (Navon, 1977). In the classic task, subjects are presented with a large letter made up of smaller letters. In the global processing task, participants are requested to indicate what the large letter is and ignore the small letters. In the local processing task, they are requested to relate to the smaller letters and ignore the large letter. RTs for the global processing task are usually faster and less subjected to interference by the local level. Local processing, on the other hand, takes longer and is more subjected to interference by the global letter. In other words, participants find it harder to ignore the global figure. Van Vleet et al. (2010) had subjects perform a 16-min training session in a sustained attention task. This task involved both phasic and tonic components of alertness. Pre-training and post-training performance on global and local processing tasks were compared. The results revealed a global processing bias immediately after the training session. This manifested in greater global level interference when performing a local processing task.

If alertness enhances global processing, it could explain how alerting cues modulate the congruency effect in the flanker task. The flanker task requires extracting the identity of a target that is embedded among distractors. Filtering out distracting visual information, especially when it is perceptually similar to the target, would require local processing. A tendency to process visual items in a global manner could interfere with this task. If this mechanism underlies the effects showing a negative impact of alertness on executive control, it could shed light on how these two distinct systems of attention interact.

One of the limitations of Van Vleet et al. (2010) was that the alertness training task in their study involved both phasic and tonic components of alertness and therefore could not be dissociated. In addition, phasic alertness effects represent the ability to achieve a high level of alertness for a very short period of time (Posner, 1978). Since the alertness training session occurred prior to the global/local tasks, the direct influence of phasic alertness on global and local processing could not be measured. This is important since the interaction between alertness and executive control in the ANT relates to the phasic component of alertness. The current work examined whether phasic alertness modulates global/local processing.

There is reason to suspect that the phasic component of alertness is directly linked to global processing. Global processing is more related to right hemisphere functioning whereas local processing is attributed to left hemisphere functioning (Delis, Robertson, & Efron, 1986; Flevaris, Bentin, & Robertson, 2010; Lamb, Robertson, & Knight, 1989, 1990; Martinez et al., 1997; Robertson, Lamb, & Knight, 1988). Specifically, there are indications that patients with right posterior superior temporal gyrus (STG) lesions show less efficient global processing (i.e., local processing advantage) while patients with lesions in the left STG demonstrate less efficient local processing (Lamb et al., 1989, 1990; Robertson et al., 1988). Although the reports concerning hemispherical dominance of phasic alertness are somewhat inconsistent (see discussion of these inconsistencies in: Matthias et al., 2010; Périn, Godefroy, Fall, & de Marco, 2010; Thiel & Fink, 2007), there are several reports indicating activation of the right STG following alerting cues (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005; Thiel & Fink, 2007). In fact, a recent fMRI research by Thiel and Fink (2007) revealed that the only region involved in both visual and auditory phasic alertness was the right posterior STG. This may imply an overlap between phasic alertness and global processing.

In the current study we tested the prediction that phasic alertness, induced by auditory warning signals prior to a target, will enhance global processing. The target used was a large arrow comprised of smaller arrows. The large and small arrows could hold congruent information (when

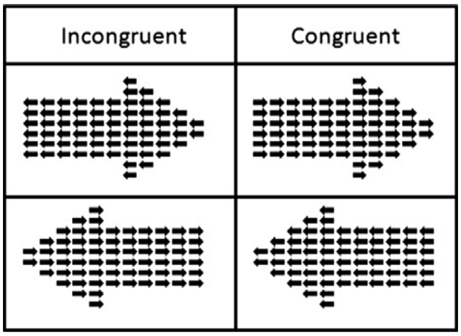

Fig. 1. Stimuli used in the current task. The congruent condition is when the large and small arrows point to the same direction. In the incongruent trials the arrows point in opposite directions.

the arrows pointed in the same direction) or incongruent information (when the large arrow and the smaller arrows pointed in opposite directions) (see Fig. 1). If phasic alertness enhances global processing, then in the local processing task (i.e., identifying the direction of the smaller arrows) global interference (caused by the large arrow) should be greater in warning-cue trials compared to no-warning-cue trials. In contrast, in the global processing task (i.e., identifying the large arrow), local interference should be comparable in warning trials and no-warning trials.

2. Methods

2.1. Participants

Thirty-two undergraduate students from the Department of Psychology at Ben-Gurion University of the Negev took part in this experiment (7 males, 4 left-handed, ages ranged from 20–30 years) for course credit. All participants reported normal or corrected-to-normal vision. All the participants gave their informed consent prior to their inclusion in the study.

2.2. Apparatus

The experiment was run on an IBM-PC computer with a 17-inch color screen monitor. E-Prime software was used for programming, presentation of stimuli, and timing operations. Responses were collected through the computer keyboard and a headphone set was used to deliver the auditory warning tone.

2.3. Stimuli

All visual stimuli were black figures presented in the center of a screen on a light gray background. Fixation was a plus sign and subtended a 0.5° visual angle. The global figures were arrows made up of smaller arrows pointing to the left or right and subtended a visual angle of 8.5°. The local figures were smaller arrows (1° of visual field), which were spatially organized to create the global figure. For the alerting signal, a 50 ms, 2000 Hz sound was delivered via headphones in half of the trials.

2.4. Procedure

Participants were seated 57 cm from the computer screen. All participants completed two tasks: attending to the global figure (i.e., global task) and attending local figures (i.e., local task). In the global task, participants were asked to respond according to the direction of the large arrow. In the local task, participants were asked to respond according to the direction of the smaller arrows and ignore the large arrow figure. The two tasks were presented in two separate blocks, the order of which was counter-balanced between participants. Left and right choices were indicated by left and right key presses (the letters ‘c’ and ‘m’ on the keyboard, respectively). In both tasks, congruency had two levels: congruent—when the large arrow figure and the smaller arrows pointed in the same direction, and incongruent—when the large arrow figure and smaller arrows pointed in opposite directions.

The time frame was the same for the global and local tasks and was as follows (see Fig. 2 for an illustration of a typical trial). Each trial began with a fixation that lasted for 2500 ms and was replaced by the arrow target. In 50% of the trials, an auditory warning signal was presented 500 ms prior to the target. This cue-to-target interval allowed alertness to reach its optimal value (Posner & Boies, 1971). The target remained in view until the subject’s response or until 3000 ms had passed.

2.5. Design

The experimental design consisted of three within subject variables—task (global/local), congruency (congruent/incongruent) and alertness (warning/no warning); and one between subject variable—order of presentation (global first/local first).

The training blocks consisted of 10 trials that were selected randomly from the full set of trials. In the practice block, feedback was given in the case of an error response. In each of the two experimental blocks (i.e., global processing block and local processing block), each condition was repeated 12 times resulting in 96 trials per block (2 tasks $\times$ 2 congruencies $\times$ 2 alertness $\times$ 12 repetitions) and 192 trials overall.

3. Results

RTs shorter than 200 ms or longer than 1000 ms were excluded from the analysis and represented less than 1% of the trials. Table 1 shows mean RTs and standard errors per condition. Error responses were relatively rare—less than 1% of trials—and therefore were not analyzed. A 2 (task) X 2 (congruency) X 2 (alertness) X 2 (presentation order) mixed model analysis of variance (ANOVA) was carried out.

The analysis revealed a main effect for task, $F(1,30) = 69.06$, $p < .0001$, $\eta_p^2 = .69$, as RTs in the local task were slower than in the global task; a main effect for congruency, $F(1,30) = 155.84$, $p < .0001$, $\eta_p^2 = .83$, as incongruent trials were slower than congruent ones; and a main effect for alertness, $F(1,30) = 92.28$, $p < .0001$, $\eta_p^2 = .75$, as there was a general benefit in RTs when a warning signal preceded the target. There was no effect for order of presentation, $F < 1$ and it did not interact with any other variable. The most intriguing finding was a three-way interaction between task (global/local), congruency (incongruent/congruent), and alertness (warning/no warning), $F(1,30) = 13.66$, $p < .001$, $\eta_p^2 = .31$. As we predicted, in the local task there was a significant interaction between alertness and congruency, $F(1,30) = 13.52$, $p < .001$; the congruency effect (i.e., incongruent RT vs. congruent RT), which represents global level interference, was significantly larger when a warning signal preceded the target compared to a no-warning condition (84 ms vs. 56 ms, respectively, see “congruency effects” in Table 1 and Fig. 3). In the global task, on the other hand, the interaction between alertness

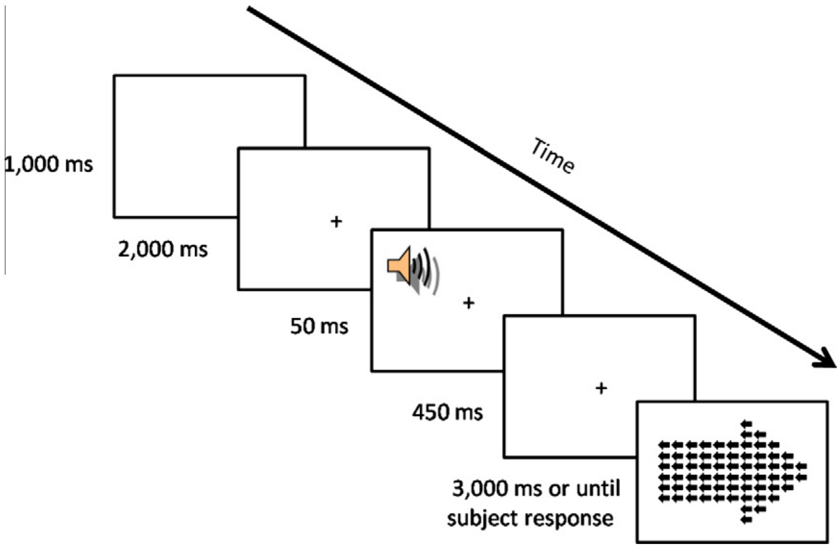

Fig. 2. Example of a typical trial. In this trial an auditory warning tone was presented prior to an incongruent target.

Table 1
Mean reaction time of the congruency conditions in the various tasks.

	Task					
	Global			Local		
	No warning	With warning	Alertness effect (ms)	No warning	With warning	Alertness effect (ms)
Congruency						
Congruent	428 (12)	389 (9)	39	487 (14)	439 (12)	48
Incongruent	456 (16)	409 (13)	47	543 (15)	523 (14)	20
Congruency effect (ms)	28	20		56	84	

Note. RT is in milliseconds. Standard errors are in parenthesis. The congruency effects represent incongruent RTs minus congruent RTs. Alerting effects represents no warning RTs minus with warning RTs.

and congruency was not significant, $F(1,30) = 1.34$, $p = .25$ (the congruency effect was 28 ms and 20 ms, for the no-warning and warning conditions, respectively).

In order to determine whether the larger congruency effect following warning cues in the local processing task was due to a change in cost in the incongruent condition or a change in benefit in the congruent condition, we compared the alerting effect (no warning vs. with warning) in the congruent and incongruent conditions between the tasks (see "alertness effect" in Table 1). The alerting effect in the congruent condition in the local task was not significantly different from that in the global task (48 ms vs. 39 ms, respectively, $F(1,30) = 2.64$, $p = .11$). In contrast, the alerting effect in the incongruent conditions was smaller in the local task compared to the global task (20 ms vs. 47 ms, respectively, $F(1,30) = 13.28$, $p < .01$).

4. Discussion

The results of the current study are clear cut: phasic alertness can enhance global processing. In the local processing task (attending the smaller arrows), the interference caused by the global level (large arrow) was greater when participants were alerted by a warning cue compared to a no-warning condition. In contrast, when participants performed the global task (attending the large arrow), the local level interference was not modulated by a

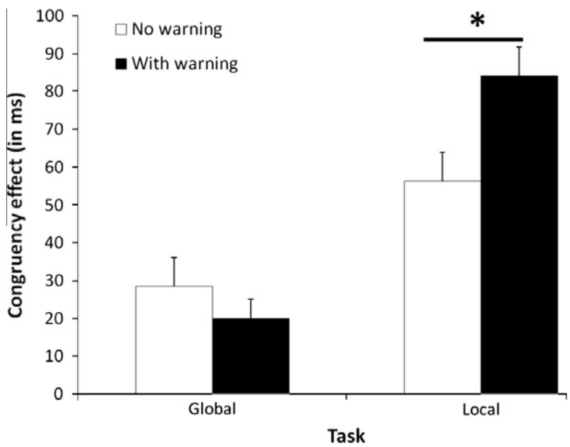

Fig. 3. Congruency as a function of task. The *y*-axis represent the congruency effect in milliseconds (incongruent RT minus congruent RT). These results demonstrate that in the local task, global interference is larger when an uninformative warning tone precedes the target. In the global task, the local level did not interfere with task performance. *indicates $p < .05$.

warning cue. We were able to show that this pattern was due to a change in cost in the incongruent condition in the local task as the alerting effect was smaller for this condition compared to its equivalent in the global task. The alerting effect in the congruent condition was comparable between the two tasks.

These results are in line with recent findings by Van Vleet et al. (2010), showing that immediately after a sustained attention task, subjects show global processing bias. The current study dissociated phasic from non-phasic components of alertness during actual performance of the global and local processing tasks. We showed that the phasic component of alertness can enhance global processing of visual items. This effect may be related to activation of the right posterior STG, an area that has been previously associated with both global processing (Lamb et al., 1990) and phasic alertness (Fan et al., 2005; Thiel & Fink, 2007).

Results of the current study could explain findings from the flanker task that show increased flanker interference when participants are phasically alerted. This effect was interpreted as an interaction between two systems of attention—alertness and executive control (Callejas et al., 2005). We suggest that this interaction might be mediated by modulation of global processing; specifically, by biasing global processing following alerting cues. This bias makes it more difficult to engage in local processing demands, such as extracting a target from similar flankers and can result in allocation of attention to irrelevant competing stimuli in the visual field.

From an evolutionary perspective, when one is in a state of high alertness, preference in global processing of the environment should be adaptive, improving attention to threats coming from the surrounding visual field. However, this ability might be less useful when one needs to simultaneously select between competing targets in the visual field.

Finally, our findings can also account for evidence that phasic alerting of right hemisphere neglect patients alleviates their spatial bias (Robertson et al., 1998). Enhancing global processing of the visual field probably increases attention for visual items in the environment. However, if we are correct, this improvement comes with a cost. In particular, it can compromise selective attention to details.

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