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The Relationship Between Alertness and Executive Control

Noam Weinbach and Avishai Henik
Ben-Gurion University of the Negev

The current study focuses on the relationship between alerting and executive attention. Previous studies reported an increased flanker congruency effect following alerting cues. In the first two experiments, we found that the alertness–congruency interaction did not exist for all executive tasks (it appeared for a flanker task but not for a Stroop task). In Experiments 3 and 4, we show that alerting increases the congruency effect in a response selection task only when the relevant and irrelevant information is spatially separated. We suggest that alerting modulates the allocation of attention by prioritizing processing of spatial information presented in the visual field. This process can be adaptive under many circumstances, but it comes at a cost. Alerting could possibly compromise our performance when required to filter out irrelevant spatial information.

Keywords: attentional networks, phasic alertness, executive control, visual attention

Goal-directed behavior requires the operation of the attention system, which encompasses various processes. Researchers have suggested that attention is composed of several networks that serve different functions. Recent reports discussed interactions between alerting and the executive network. In particular, it has been suggested that alertness modulates the effect of selection. What is the nature of this interaction and what are the mental operations involved? The current study examines the relationship between alertness and executive functions, particularly selection.

Alertness is commonly divided into two different 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 in a top-down manner (Sturm et al., 1999; Sturm & Willmes, 2001). Phasic alertness, on the other hand, is a short-lived effect of achieving high levels of alertness following a salient external event (Posner, 1978; Posner, 2008; Sturm & Willmes, 2001). In the current study, we will mainly focus on the phasic mode of function. Phasic alertness is typically evaluated by measuring reaction times (RTs) to targets that are preceded by warning cues compared with conditions when such warning cues are absent. The warning cues usually deliver no information regarding the location or identity of the upcoming target. The common effect of a warning cue is faster RTs compared with a no-cue condition. This effect can be achieved by using different modalities of warning cues such as auditory, visual, or tactile cues (e.g., Rodway, 2005; Thiel & Fink, 2007).

A different system of attention that is associated with higher and more complex cognitive functions is the executive control system. This system is responsible for detecting and resolving cognitive conflicts. The executive network is mainly associated with activity in frontal brain regions, such as the anterior cingulate cortex (ACC) and the dorso-lateral prefrontal cortex (DLPFC; Casey et al., 2000; Kerns et al., 2004; MacDonald, Cohen, Stenger, & Carter, 2000). According to the conflict monitoring theory, the ACC has an important role in monitoring conflicts and triggering strategic adjustments in the DLPFC (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Botvinick, Cohen, & Carter, 2004; Botvinick, Nystrom, Fissell, Carter, & Cohen, 1999; Kerns et al., 2004). Executive control is often measured in tasks that involve responding to a target stimulus while attempting to suppress other conflicting information or irrelevant response tendencies.

Many studies examined alertness and executive control independently; however, there is a growing body of evidence that suggests these two systems interact under certain conditions. This evidence comes mainly from studies that used a comprehensive test of attention named the "attentional network test" (ANT; Fan, McCandliss, Sommer, Raz, & Posner, 2002). This test allows measuring three attentional networks simultaneously. These networks include executive control, alertness, and orienting (selection of sensory stimuli in space) (Posner & Petersen, 1990). In the ANT, participants perform an arrow-flanker task. They are presented with a stimulus consisting of a line of 5 arrows that can appear either below or above central fixation. Responses are made according to the direction of the central arrow while attempting to ignore the irrelevant distracting arrows on both sides (i.e., flankers). The direction of the flanking arrows can be congruent (→→→→→) or incongruent (→→←→→) with respect to the central arrow. In the incongruent trials, there is a cost in RTs because of the difficulty in ignoring the conflicting flankers. The congruency effect (mean RTs of incongruent trials minus mean RTs of congruent trials) represents the effect of conflict and is considered a measure of executive control. Alertness is measured in the ANT by introducing an alerting visual cue prior to the flanker target. The cue is an asterisk that appears simultaneously above and below fixation (i.e., double-cue) and therefore delivers no information regarding the location of the upcoming target. The

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Noam Weinbach and Avishai Henik, Department of Psychology and the Zlotowski Center for Neuroscience, Ben-Gurion University of the Negev, Beer-Sheva, Israel.

Correspondence concerning this article should be addressed to Noam Weinbach, Department of Psychology, Ben-Gurion University of the Negev, P.O. Box 635, Beer-Sheva, Israel 84105. E-mail: noam.weinbach@gmail.com

effect of the alerting network is reflected in reduced RTs following an alerting cue compared with RTs in a no-cue condition. Orienting is measured by comparing RTs in trials where a visual cue is presented (above or below fixation, indicating the location of the upcoming target) to RTs in trials where a visual cue is presented in the center of the screen.

The ANT and its variants have been used in a vast amount of researches, such as for neuropsychological assessment of attention in physically or mentally impaired populations (e.g., Breton et al., 2010; Fernandez-Duque & Black, 2006; Preiss, Kramska, Dockalova, Holubova, & Kucerova, 2010; Urbanek et al., 2010), investigating the development of attention (e.g., Rueda et al., 2004; Vazquez-Marrufo et al., 2011), exploring the neural substrates of attention (e.g., Fan, McCandliss, Fossella, Flombaum, & Posner, 2005; Neuhaus et al., 2010), and for many other experimental purposes.

When the ANT was first introduced, the three attentional networks were argued to function independently (Fan et al., 2002). However, in recent years, it has generally been agreed that there are certain dependencies among the attentional networks. Callejas and colleagues (Callejas, Lupiáñez, Funes, & Tudela, 2005; Callejas, Lupiáñez, & Tudela, 2004) modified the ANT to create a design aimed at investigating interactions between the networks (i.e., ANT-Interaction). One of their main findings was an interaction between alerting and executive control. Specifically, they reported that auditory warning cues prior to the target induced larger congruency effects compared with the no-cue condition. In other words, the conflict effect was larger when alerting cues preceded the target. Since then, the same effect has been replicated in many other studies using different versions of the ANT for various experimental purposes (Chica et al., 2011; Costa, Hernández, & Sebastián-Gallés, 2008; Dye, Baril, & Bavelier, 2007; Fan et al., 2009; Ishigami & Klein, 2009, 2010; J. W. MacLeod et al., 2010; McConnell & Shore, 2011; Redick & Engle, 2006; Roberts, Summerfield, & Hall, 2006). Why is there an increase in conflict following alerting cues? What attentional/perceptual processes are involved? Here we will present three previously proposed explanations of this effect and conduct a series of experiments aimed at testing predictions derived from these explanations.

The first interpretation of this phenomenon was made by Callejas et al. (2005), who proposed alertness directly inhibits executive control. It was suggested that the ACC, which is involved in executive attention, might be inhibited following alerting cues. According to this interpretation, the value of inhibiting executive control while one is alerted is to allow the organism to focus on producing fast responses following alerting stimuli rather than concentrating on control. This idea was inspired by Posner's notion of "clearing the consciousness" according to which: "*When one attends to detect an infrequent target, the subjective feeling is of emptying the head of thoughts or feelings*" (Posner, 1994). Other authors have also supported the idea that this effect might reflect a direct negative impact of alertness on executive control (Callejas et al., 2005; Fan et al., 2009; Klein & Ivanoff, 2010; MacLeod et al., 2010).

A competing interpretation was made recently by several authors that argued against the idea of direct inhibition of executive control following alerting cues (Böckler, Alpay, & Stürmer, 2011; Fischer, Plessow, & Kiesel, 2010, 2011). In these studies, it was demonstrated that alerting cues do not seem to influence electrophysiological measures associated with executive attention, nor sequential, dependent conflict adaptation. Both Böckler et al. and Fischer et al. (2010) replicated the interfering effect of an alerting cue on performance in the Simon task. In this task, participants press left or right keys on a keyboard, dependent on the identity of the target, and ignore the target's spatial location. Conflict occurs when the identity of the target and the response are incompatible (e.g., target appears on the left side of the screen but requires a right key press). Böckler et al. suggested that alerting cues do not hamper executive attention but alter earlier processes that cause greater conflict. Specifically, they suggested that alerting cues modulate response selection processes and induce amplification of automatic response activation related to the irrelevant dimension (spatial location in the Simon task). This process occurs in parallel with facilitation in processing the relevant dimension (stimulus identity in the Simon task); hence, there are faster RTs following alerting cues but greater congruency effects.

Another recent interpretation of the interaction between alerting cues and conflict that also discussed modulation of earlier attentional processes was made by McConnell and Shore (2011). They replicated the effect of a larger congruency effect following alerting cues in the framework of the ANT and suggested that uncertainty regarding the location of the target might play an important role in the interaction between alerting and conflict. They argued that because the target in the ANT can appear either below or above fixation, alerting cues encourage diffusing attention between the two possible target locations. When the target suddenly appears, diffusion of attention results in a greater influence of conflicting flankers around the target. In the no-cue condition on the other hand, the participant's strategy is to keep attention in a focused state, making it easier to ignore distracting stimuli. Note that this interpretation can also account for the same finding in the Simon task because uncertainty regarding the spatial location of the target is inherent to this task.

The effect of alertness on conflict resolution draws a lot of interest, although until now, not many studies have been conducted to systematically explore the mechanisms underlying this effect. In the current study, we will explore predictions derived from the different explanations presented and try to uncover the mechanisms that are responsible for larger conflict following an alerting cue. The importance of understanding how alertness and executive control interact goes beyond the boundaries of attention and can further our knowledge on the way low subcortical systems (such as alerting) interact with higher cognitive functions associated with frontal brain regions. We present a series of four experiments, all of which include alerting cues and cognitive conflict that requires recruitment of control. Based on the results, we will offer a mechanism that underlies the reported interaction between alertness and executive control.

Experiment 1

In this experiment, we tested whether uncertainty regarding the location of the target plays a role in the interaction between alerting and conflict. According to McConnell and Shore (2011), this uncertainty may cause attention to spread between the two possible locations of the target. They suggested this would cause a diffused mode of attention following alerting cues, which in turn would increase the influence of conflicting flankers. However, when alerting cues are absent, a more focused strategy would be adopted.

In the ANT, the target can appear either below or above fixation so uncertainty regarding the target location is inherent. This uncertainty allows measuring orienting of attention but makes it hard to assess whether uncertainty regarding the location of the target contributes to the larger flanker congruency effect following alerting cues. As mentioned earlier, the interaction between alerting cues and conflict was also found in the Simon task (Böckler et al., 2011; Fischer et al., 2010). The source of conflict in the Simon task is the irrelevant spatial location of the target; therefore, uncertainty concerning the location of the target is also inherent to this task, which again prevents a direct study of its influence.

In the current study, we were interested in the relation between alerting and executive control and not in measuring orienting. Therefore, we used the same arrow-flanker task as the one used in the ANT but abolished uncertainty regarding the location of the target. This was done by always presenting the target in the same location (center of the screen). In addition, to avoid any visual cues that might have shifted visual attention, auditory alerting cues were used. This allowed participants to keep their gaze at the designated fixation, which was only replaced by the target itself. Our hypothesis was that if, under all these conditions, alerting cues still induced a greater flanker congruency effect, it could not be explained by uncertainty regarding the location of the target.

In addition, many studies that demonstrated the alertness–congruency interaction did not dissociate between processes that were related to interference in the conflicting situation and processes related to facilitation in the congruent condition. To discriminate between these two processes, we included a neutral condition. Comparing RTs in the neutral trials with RTs in the congruent trials would provide us with a measure of the facilitation effect. Comparison of RTs in incongruent trials to RTs in neutral trials would provide us with a measure of the interference effect.

Method

Participants. Thirteen undergraduate students (1 man, ages ranged from 22–24 years) from the Department of Psychology at Ben-Gurion University of the Negev took part in this experiment for course credit. All participants reported normal or corrected-to-normal vision. All the participants signed an informed consent prior to their inclusion in the study.

Apparatus. The experiment was run on an IBM-PC computer with a 17-inch color screen monitor. E-Prime software (Psychology Software Tools, Pittsburgh, PA) 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 alerting tone.

Stimuli. In each trial, participants were presented with five white arrows on a black background, appearing at the center of the screen. The length of each arrow subtended a visual angle of 0.8° from a viewing distance of approximately 57 cm. The distance between the arrows was fixed at 0.1°. In the congruent condition, the central target arrow was flanked by arrows pointing in the same direction (see stimuli illustration in Figure 1). In the neutral trials, the target was flanked by two double-headed arrows. Incongruent trials included flanking arrows that pointed in the opposite direction to that of the target arrow. Left and right choices were indicated by left and right key presses (the letters "c" and "m" on the keyboard, respectively). The proportion of trials for each condition was equal. Alerting was induced by presenting a 50-ms, 2,000-Hz beep sound via headphones in half of the trials. The experiment included three experimental blocks of 72 trials per block and a practice block of 12 trials. All trials were presented in random order.

Procedure. Participants were requested to indicate the pointing direction of a central arrow and ignore flanking arrows. Each trial began with a fixation (a plus sign that subtended a visual angle of 0.6°) that lasted for 2,500 ms and was replaced by the arrow target (Figure 2 illustrates a typical trial). In half of the trials, an auditory warning tone 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 participant's response or until 3,000 ms had passed. After response, a blank screen was presented for 1,000 ms. The session began with a practice block in which feedback was given in the case of an error response. Following this practice, participants began the first of three experimental blocks. A short brake was offered between the blocks.

Results

Extreme RTs shorter than 200 ms or longer than 1,000 ms were excluded from the analysis and represented less than 2% of the trials. Table 1 shows mean RTs and error rates for each experimental condition and effect. The accuracy rate was very high (99% correct trials), therefore, errors were not analyzed. Mean RTs of correct trials in each condition for each participant were analyzed, with alertness (with warning, no warning) and congruency (congruent, neutral, and incongruent) as independent variables, in a repeated measures analysis of variance (ANOVA).

The analysis revealed a significant main effect for alertness, $F(1, 12) = 75.42$, $MSE = 218$, $p < .00001$, $\eta_p^2 = .86$. RTs in trials with a warning signal were faster than RTs in trials with no warning cue. There was a main effect for congruency as well, $F(2, 24) = 130.03$, $MSE = 210$, $p < .00001$, $\eta_p^2 = .91$. This effect was composed of a significant facilitation effect (RTs were slower for the neutral trials compared to congruent trials), $F(1, 12) = 14.49$, $MSE = 85.23$, $p < .01$, $\eta_p^2 = .54$, and a significant interference effect (RTs were slower for the incongruent trials compared to the neutral trials), $F(1, 12) = 144.61$, $MSE = 230.19$, $p < .00001$, $\eta_p^2 = .92$. It is important to note that the analysis also revealed a significant interaction between alertness and congruency, F(2,

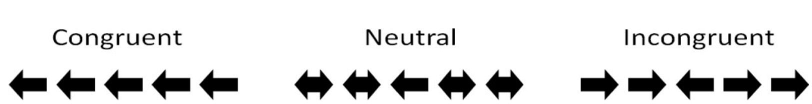

Figure 1. Example of stimuli used in Experiment 1. In all of these examples participants were requested to press a left key for the central feature.

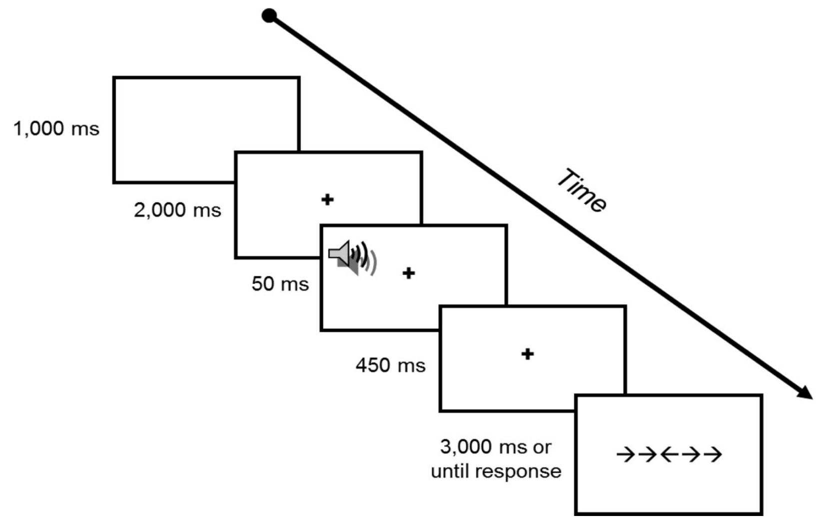

Figure 2. Example of a typical trial. In this trial an auditory warning tone was presented prior to an incongruent target.

24) = 9.10, *MSE* = 209, $p < .01$, $\eta_p^2 = .43$. The congruency effect (incongruent RT minus congruent RT) was greater in warning-cue trials (73 ms) compared with no-cue trials (48 ms), $F(1, 12) = 7.45$, *MSE* = 283.42, $p < .05$, $\eta_p^2 = .38$. Furthermore, this interaction was a result of a larger interference effect in the warning-cue trials (67 ms with warning compared with 35 ms without warning), $F(1, 12) = 19.62$, *MSE* = 175.14, $p < .001$, $\eta_p^2 = .62$, while the facilitation effect was not modulated by the alerting cue (6 ms with warning compared with 13 ms without warning), $F > 1$.

Discussion

Experiment 1 was aimed at testing whether alerting cues produced a greater flanker congruency effect even when participants kept their attention at fixation, and there was no uncertainty concerning the location of the target. The results demonstrated a highly significant interaction between phasic alertness and congruency. The congruency effect, which is a measure of the executive network, was larger following a warning cue compared with a no-cue condition. It is important to note that our results show that this interaction results from modulation of the interference effect following alerting cues while the facilitation effect remains the same. In contrast with McConnell and Shores' (2011) suggestion, it seems that larger conflict following alerting signals was not a result of diffused attention because of uncertainty regarding the location of the target. This effect can be achieved even when the target is always centrally presented.

Table 1
Mean Reaction Time (RT) and Error Rate of the Congruency Conditions and Effects in Experiment 1

	Alertness	
Congruency	No warning	With warning
Congruent	477 (0.9%)	442 (0.2%)
Neutral	490 (0.5%)	448 (0.5%)
Incongruent	525 (2.4%)	515 (1.6%)
Congruency effect (ms)	48	73
Facilitation effect (ms)	13	6
Interference effect (ms)	35	67

Note. RT is in milliseconds. Percentage of errors is in parenthesis. The congruency effect represents incongruent RTs minus congruent RTs. The facilitation effect represents neutral RTs minus congruent RTs and the interference effect represents incongruent RTs minus neutral RTs.

However, diffused attention following alerting cues may be an inherent characteristic of phasic alertness, not dependent on the spatial organization of the task. Cumulative evidence has demonstrated a link between levels of alertness and allocation of spatial attention. Robertson, Mattingley, Rorden, and Driver (1998) showed that phasic alertness (induced by auditory alerting cues) ameliorates spatial bias in right hemisphere neglect patients. Indeed, many works demonstrated that the level of alertness or arousal modulates spatial bias in lesion patients and healthy individuals (Bellgrove, Dockree, Aimola, & Robertson, 2004; DeGutis & Van Vleet, 2010; Fimm, Willmes, & Spijkers, 2006; Heber, Valvoda, Kuhlen, & Fimm, 2008; Manly, Dobler, Dodds, & George, 2005; Matthias et al., 2010; Robertson et al., 1998; Shapiro & Johnson, 1987; Thimm, Fink, Küst, Karbe, & Sturm, 2006). It is important to note that recent data indicate that high levels of alertness can induce a global processing bias (Van Vleet, Hoangduc, DeGutis, & Robertson, 2010; Weinbach & Henik, 2011). In the flanker task, a tendency toward global processing may compromise the ability to focus on or select a central arrow when it is embedded among arrows pointing in another direction. As such, a tendency toward global processing can prioritize processing of spatial events in the visual field and create a cost when the spatial information conflicts with the response associated with the target. If this is correct, alerting will not always disrupt performance; for example, in the case of an executive task that requires control processes but not spatial selection. The color-word Stroop task (Stroop, 1935) is a good candidate for testing this prediction.

Experiment 2

In the Stroop task, participants indicate the ink color of a printed color word. The incongruent condition is created when the ink color of the word does not match the meaning of the word (e.g., the word red printed in green ink). In the congruent condition, the word and ink color are the same (e.g., the word red printed in red ink). The involvement of the executive network and ACC activation following incongruent trials in the Stroop task is well documented (e.g., Botvinick et al., 2001; Carter et al., 2000; Kerns et al., 2004; MacDonald et al., 2000; Pardo, Pardo, Janer, & Raichle, 1990). In the Stroop task, the relevant and irrelevant dimensions (color and word, respectively) are integrated into one object. In this way, there are no other competing stimuli to process in space, only one object. Prioritized processing of spatial events should not interfere with performance in this case. However, if alertness does have direct negative impact over executive control, as has been suggested (Callejas et al., 2005), results should be similar to those in other executive tasks such as the flanker task and the Simon task, namely, a greater congruency effect following alerting cues.

In Experiment 2, we used the same design that was introduced in Experiment 1 but instead of using the arrow-flanker task as the executive task, we used the color-word Stroop task. Our prediction was that if phasic alertness had a direct negative impact over executive attention, by inhibiting control-related activity in the frontal lobe, this should be evident by a larger Stroop interference when participants were alerted following auditory warning cues.

Method

Participants. Fourteen undergraduate students (3 men, ages ranged from 21–25 years) from the Department of Psychology at Ben-Gurion University of the Negev took part in this experiment for course credit. All participants reported normal or corrected-to-normal vision and gave their informed consent prior to their inclusion in the study.

Stimuli. Two color words were used: red and green. These color words in Hebrew consist of four letters. The congruent stimuli were created by printing each of the two color names in their matching color. The neutral condition was created by the letter string “”XXXX” (i.e., 4 Xs) printed in either red or green. The incongruent stimuli were created by presenting the color words in a mismatching color (e.g., the word red colored in green). All stimuli were subtended by a visual angle of approximately 2° from a viewing distance of approximately 57 cm. Participants were requested to indicate the ink color of a printed word and ignore the word meaning. Responses were recorded by pressing one of two color patches on a keyboard (a red patch over the “c” key or a green patch over the “m” key). The alerting auditory tone, sequence of events, and number of blocks and trials were identical to those in Experiment 1.

Results

Extreme RTs shorter than 200 ms or longer than 1,000 ms were excluded from the analysis and represented less than 4% of the trials. Accuracy rate was very high (98% correct trials), therefore errors were not analyzed. Mean RTs of correct trials in each condition for each participant were analyzed, with alertness (with warning, no warning) and congruency (congruent, neutral, and incongruent) as independent variables, in a repeated measures ANOVA (Table 2 shows mean RTs and error rates for each experimental condition and effect).

As in Experiment 1, the two main effects for alertness and congruency were significant, $F(1, 13) = 115.99$, $MSE = 555$, $p < .00001$, $\eta_p^2 = .89$, and $F(2, 26) = 17.37$, $MSE = 1{,}016$, $p < .0001$, $\eta_p^2 = .57$, respectively. However, unlike in Experiment 1, there was no interaction between alertness and congruency, $F < 1$. The congruency effect was comparable in the warning and no warning conditions (42 ms and 44 ms, respectively), $F < 1$.

Discussion

Results of Experiment 2 demonstrate additive effects of alertness and executive control in the Stroop task. These results do not support the idea that phasic alertness shuts down control-related activity in a direct manner (Callejas et al., 2005). The Stroop task is an executive task that demands executive control and recruits frontal brain regions that are associated with cognitive control (e.g., Botvinick et al., 2001; Carter et al., 2000; Kerns et al., 2004; MacDonald et al., 2000; Pardo et al., 1990), yet alerting did not increase conflict interference in this task. Our results suggest that the effects of alertness on executive attention in the flanker task are mediated by processes that do not affect performance in the Stroop task. In an earlier work, we showed that alerting cues induce a global processing bias (Weinbach & Henik, 2011). This may result in prioritized processing of spatial events in the visual field. This could explain why alertness did not modulate conflict in the Stroop task—in the Stroop task, the target and distracters are integrated into one object so modulating the allocation of attention to spatial events following alerting cues did not interfere as there were no spatial distracters to processes. This explanation suggests the source of the interaction between alertness and congruency in the flanker task is at an early attentional processing stage that is in charge of allocation of attention in space. Indeed, in a recent study on the interaction between alerting and executive control, Böckler et al. (2011) demonstrated that alerting cues modulate electrophysiological measures related to allocation of attention and response selection. However, their explanation of the interaction between alerting and executive control was different from the one we

Table 2
Mean Reaction Time (RT) and Error Rates of the Congruency Conditions and Effects in Experiment 2

Congruency	Alertness	
	No warning	With warning
Congruent	541 (1.3%)	485 (0.9%)
Neutral	538 (1.4%)	486 (0.2%)
Incongruent	585 (3.3%)	527 (1.9%)
Congruency effect (ms)	44	42
Facilitation effect (ms)	−3	1
Interference effect (ms)	47	41

Note. RT is in milliseconds. Percentage of errors is in parenthesis. The congruency effect represents incongruent RTs minus congruent RTs. The facilitation effect represents neutral RTs minus congruency RTs and the interference effect represents incongruent RTs minus neutral RTs.

suggested. Böckler et al., as well as Fischer et al. (2010, 2011), argued that the reason for the larger conflict effect following alerting cues is a result of response selection processes. Specifically, they suggested that alerting stimuli increase the stimulus-response (S-R) association. This amplifies the automatic activation of the response associated with the irrelevant dimension in the task. If this is correct, then it is possible that the absence of the interaction in the Stroop task is because this task also relies on perceptual processes and not only response selection (see Henik, Merrill, Ro, Rafal, & Safadi, 1999; MacLeod, 1991). A similar suggestion was made recently by Correa, Cappucci, Nobre, and Lupiáñez (2010), who investigated the effects of temporal expectation on conflict interference. They reported that high levels of response readiness disrupt response selection processes by enhancing simultaneous activation of the response to the target and distracters. On the other hand, they emphasized that response readiness also facilitates perceptual processing. Their conclusion was that increased response readiness would disrupt performance in conflict tasks that are based on response selection processes, such as the Simon task and the Flanker task, but would spare tasks that encompass conflict at earlier processing stages than response selection, such as the Stroop task. Because the Stroop task and the flanker task are different in many ways, it is hard to assess whether the absence of the interaction between alerting and congruency in the Stroop task in our study was because of the integration of the relevant and irrelevant information as we suggested or because the perceptual processes involved in the Stroop task cancelled the interfering effect of alerting. Therefore, the critical question is whether alerting would increase the congruency effect in a pure response selection task (no perceptual conflict) where the target and distracter are integrated into one object (no spatial distracters). This was tested in Experiment 3.

Experiment 3

In Experiment 3, we created a task in which the relevant and irrelevant information were integrated in one object, much like the Stroop task. However, unlike the Stroop task, the conflict in this task was solely based on response selection processes. In other words, the conflict was produced by manipulating the S-R mapping. Participants viewed a single colored arrow (red or green) in the center of the screen (Figure 3). The arrow pointed to the left or to the right. Note that just viewing a red arrow does not hold any conflict (unlike viewing the word red in green ink in the Stroop task). Participants were asked to respond to the color of the arrow and to ignore its direction. In this task, conflict can occur only when the response for the color does not correspond with the arrow direction (e.g., right pointing arrow colored red when the color red means pressing a left key).

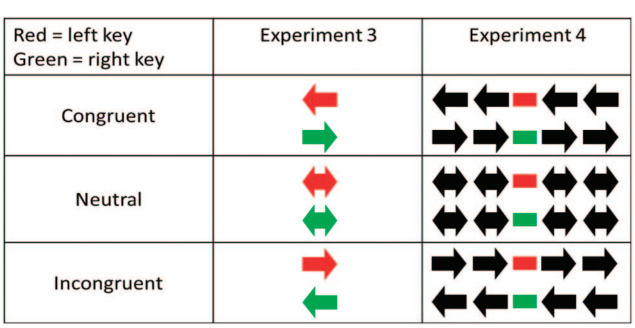

Figure 3. Stimuli used in Experiments 3 and 4.

If the source of the interaction between alerting and executive control is due to modulation of response selection processes (i.e., amplification of the S-R mapping), we expect a larger congruency effect following an alerting cue. In contrast, if the interaction between alerting and executive control depends on allocation of spatial attention, then alerting will not modulate executive control measures in this task since there is no peripheral-spatial information to process in the visual field.

Method

Participants. Twenty-four undergraduate students (10 men, ages ranged from 21–34 years) from the Department of Psychology at Ben-Gurion University of the Negev took part in this experiment for course credit or payment of 20 NIS. All participants reported normal or corrected-to-normal vision and gave their informed consent prior to their inclusion in the study.

Stimuli and procedure. In every trial a single arrow (same size as in Experiment 1) was presented in the middle of the screen (Figure 3). The arrow could point to the left, to the right or in the case of neutral trials a double headed arrow was presented. The arrow was colored red or green. Participants were asked to press the left key (letter "c" on the keyboard) if the arrow was red and the right key (letter "m" on the keyboard) if it was green. Participants were instructed to ignore the direction the arrow pointed in and respond to the color. As in the previous experiments, an alerting auditory tone was presented in half of the trials prior to the target appearance.

Results

RTs shorter than 200 ms or longer than 1,000 ms were excluded from the analysis (less than 2% of the trials) and accuracy was high (97.1% correct trials). Mean RTs for correct responses in each experimental condition were analyzed, with alertness (with warning, no warning) and congruency (congruent, neutral, and incongruent) as independent variables, in a repeated measures ANOVA (Table 3 shows mean RTs and error rates for each experimental condition).

As in Experiments 1 and 2, both main effects for alertness and congruency were significant, $F(1, 23) = 49.98$, $MSE = 1{,}405$, $p < .00001$, $\eta_p^2 = .68$ and $F(2, 46) = 43.43$, $MSE = 701$, $p < .00001$, $\eta_p^2 = .65$, respectively. The interaction between alertness and congruency was not significant, $F < 1$. The congruency effect was not significantly different in the warning trials (48 ms) compared with no-warning trials (52 ms), $F < 1$.

Discussion

Experiment 3 reveals that alerting does not interfere with executive control in a pure response selection task in which the relevant and irrelevant information is integrated into one object (no spatial distracters). This pattern of results is inconsistent with previous ideas indicating that the reason for the larger congruency effect following alerting cues in the flanker and Simon tasks is modula-

Table 3
Mean Reaction Time (RT) and Error Rates of the Congruency Conditions and Effects in Experiments 3 and 4

	Experiment 3: Integration		Experiment 4: Separation	
	Alertness		Alertness	
Congruency	No warning	With warning	No warning	With warning
Congruent	473 (1.6%)	433 (0.6%)	478 (1.3%)	424 (0.7%)
Neutral	498 (2.8%)	450 (1.3%)	489 (2.9%)	440 (2%)
Incongruent	525 (6.5%)	481 (4.7%)	504 (3.5%)	471 (4%)
Congruency effect (ms)	52	48	26	47
Facilitation effect (ms)	25	17	11	16
Interference effect (ms)	27	31	15	31

Note. RT is in milliseconds. Percentage of errors is in parenthesis. The congruency effect represents incongruent RTs minus congruent RTs. The facilitation effect represents neutral RTs minus congruency RTs and the interference effect represents incongruent RTs minus neutral RTs.

tion of response selection processes (Böckler et al., 2011; Fischer et al., 2010, 2011). Because there was no interaction between alerting and congruency when the target and distracters were integrated (i.e., not in the Stroop task in Experiment 2 and not in the current experiment), this may mean that alerting modulates congruency only when processing of spatial information is required. The critical question is whether the mere separation of the relevant and irrelevant information in Experiment 3 (color and arrow) is sufficient to reveal an interaction between alerting and congruency. This was tested in Experiment 4.

Experiment 4

In Experiment 4, participants responded to a color patch in the center of the screen while trying to ignore white arrows in close proximity. Note that this is the same response selection task as in Experiment 3; namely, conflict can only occur when mapping left and right responses to the colors while attempting to ignore left and right pointing arrows. Our hypothesis was that if alerting prioritizes processing of spatial information in the visual field, the arrows next to the target will be processed more efficiently. This will result in a larger congruency effect following alerting cues.

Method

Participants. Twenty-four undergraduate students (4 men, ages ranged from 21–24 years) from the Department of Psychology at Ben-Gurion University of the Negev took part in this experiment for course credit. All participants reported normal or corrected-to-normal vision and gave their informed consent prior to their inclusion in the study.

Stimuli. The stimuli used in this experiment were a color patch presented in the middle of the screen and two flanking arrows on either side (Figure 3). The arrows were white on a black background and were of the same size as in Experiment 3. The color patch was a rectangle that subtended a visual angle of 0.6° in length and 0.4° in height. As in Experiment 3, participants were instructed to respond to the color of the patch (red-left, green-right) and ignore the arrows.

Results

RTs shorter than 200 ms or longer than 1,000 ms were excluded from the analysis (less than 1% of the trials) and accuracy was high (97.6% correct trials). Mean RTs for correct responses in each experimental condition were analyzed, with alertness (with warning, no warning) and congruency (congruent, neutral, and incongruent) as independent variables, in a repeated measures ANOVA (Table 3 shows mean RTs and error rates for each experimental condition).

The analysis revealed main effects for alertness and congruency, $F(1, 23) = 54.37$, $MSE = 1{,}371$, $p < .00001$, $\eta_p^2 = .70$ and $F(2, 46) = 31.02$, $MSE = 520$, $p < .00001$, $\eta_p^2 = .57$, respectively. It is important to note that the interaction between alertness and congruency was significant, $F(2, 46) = 3.38$, $MSE = 419$, $p < .05$, $\eta_p^2 = .12$. The congruency effect was larger in the warning trials (47 ms) compared to no-warning trials (26 ms, see the congruency effects in all four experiments in Figure 4), $F(1, 23) = 7.16$, $MSE = 358$, $p < .05$, $\eta_p^2 = .23$. The interaction between alerting and the facilitation effect was far from significant, $F < 1$, and the interaction between alerting and the interference effect showed a trend toward significance, $F(1, 23) = 2.57$, $MSE = 602$, $p = .12$, $\eta_p^2 = .10$. We also carried out a combined analysis of Experiments 3 and 4 when the stimuli (integrated in Experiment 3 vs. separated in Experiment 4) were defined as a between-subjects variable. The three-way interaction between task, alertness and congruency was marginally significant, $F(2, 92) = 2.69$, $MSE = 352$, $p = .07$, $\eta_p^2 = .05$, and the interaction between alertness and the congruency effect was significantly different in the integration task compared with the separation task, $F(1, 46) = 5.01$, $MSE = 378$, $p < .05$, $\eta_p^2 = .09$. The analysis also revealed that the congruency effect in the no-warning trials was greater in Experiment 3 (52 ms) compared with Experiment 4 (26 ms), $F(1, 46) = 8.75$, $MSE = 478$, $p < .01$, $\eta_p^2 = .15$. This indicates that the overall conflict was greater in Experiment 3.

Discussion

Remarkably, the results of Experiment 4 revealed a significant interaction between alerting and congruency. The congruency ef-

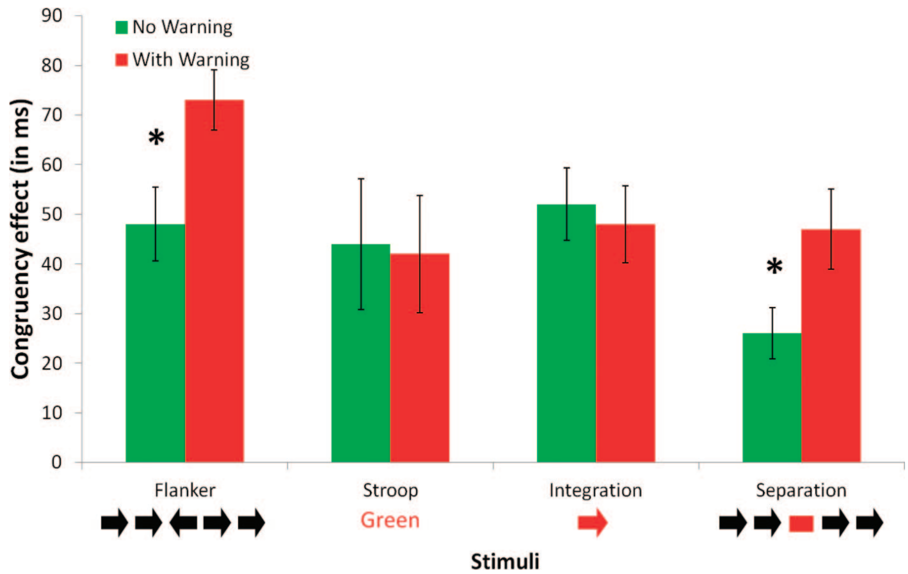

Figure 4. Mean congruency effect as a function of stimuli and alertness. The *y* -axis represents the congruency effect (incongruent reaction time [RT] minus congruent RT). The *x* -axis shows the different stimuli employed in each experiment. Below each task there is an example of a stimulus in the task. Green represents trials with no warning cue preceeding the target, and red represents trials with a warning cue. $^{*}p < .05$.

fect was significantly larger following an alerting cue than in a no-cue condition. This implies that alerting increases accessibility of spatial events in the visual fiend. When these events hold conflicting information, they increase measures of conflict in the task. It is worth noting that this effect was less dramatic in Experiment 4 compared with that in the flanker task conducted in Experiment 1. This is reasonable when considering that the overall conflict caused by the arrows in Experiment 4 was not as robust as in the arrow flanker task. Most participants found it relatively easy to differentiate the color patch in the middle of the screen from the flanking arrows. In the flanker task, it is relatively hard to select an arrow when it is embedded among other arrows, making the distracters more influential following alerting cues.

Taken together, the results of Experiment 3 and 4 are conclusive. Alertness does not interfere in a response selection task when the relevant and irrelevant information are spatially integrated. The mere separation of the relevant and irrelevant features results in a greater congruency effect following alerting cues. This suggests that the source of the interaction between alerting and executive control does not rely on response selection processes. This does not mean that response selection processes do not play a role in the interaction. Fischer et al. (2011) recently demonstrated that in the flanker task, there is a larger congruency effect following alerting cues only when the flankers are part of the response set, meaning that there is an establishment of the S-R association. It is reasonable to believe that when the flankers are more conflicting (e.g., when a stronger S-R association exists), alerting cues will have greater influence on congruency. However, our key finding suggests that the critical mechanism responsible for the appearance of the interaction is modulation of spatial attention following alerting cues.

General Discussion

The goal of the current study was to investigate the mechanisms underlying an interaction between two attentional networks—alertness and executive control. We addressed an effect that was reported in many studies regarding an increased cognitive conflict in the flanker and Simon tasks following presentation of alerting stimuli. The processes that underlie this effect were unclear and various explanations were suggested. In the current study we found that the alertness–congruency interaction can occur even when the target is continuously presented at the center of the screen (i.e., no uncertainty regarding the location of the target), takes place only in specific executive tasks, and does not necessarily exist in tasks that are based on an S-R mapping. Instead, it seems to be modulated by spatial attention processes inducing higher accessibility of spatial visual events under an alert state. Figure 4 presents the congruency effect with a warning or no-warning cue for the various stimuli used in the different experiments. Alerting increased the congruency effect when the distracters and target were spatially separated (i.e., in the flanker and the separated-stimuli tasks) and did not modulate congruency when the distracter and target were integrated (i.e., the Stroop and integrated-stimuli tasks). These results imply the involvement of spatial attention in the interaction between alerting and congruency.

In the series of experiments we presented, we also took under consideration various explanations previously made for the larger conflict (i.e., congruency) effect following alerting cues. Experiment 1 examined whether the interaction between alertness and congruency results from uncertainty regarding the location of the target. McConnell and Shore (2011) recently suggested that when the target can appear in several locations, attention is diffused between these locations following an alerting event and this may result in greater influence of spatial distracters. In contrast, when such an alerting event is absent, a more focused strategy is taken. Experiment 1 revealed that the interaction between congruency and alerting is obtained even when the target is constantly presented in the center of the visual field. Therefore, the interaction cannot be explained by target location uncertainty (at least for central targets). Experiment 2 revealed that the interaction between alertness and congruency does not occur in the color-word Stroop task, which is another executive task associated with cognitive control (Casey et al., 2000; Kerns et al., 2004; MacDonald et al., 2000). This does not fit the notion of alerting having a direct negative impact on executive control (Callejas et al., 2005). Another explanation for the larger congruency effect following alerting signals discussed modulation of response selection processes that eventually result in a larger conflict (Böckler et al., 2011; Fischer et al., 2010, 2011). This hypothesis was tested in a pure response selection task where the relevant and irrelevant information were integrated in the same object, similar to in the Stroop task, but with no perceptual conflict. In this task, alerting did not increase the congruency effect. We suggested that alerting can influence the congruency effect only when there is spatial information to processes. This was inspired by previous findings from our lab indicating that alertness induces a global processing bias (Weinbach & Henik, 2011). Global processing bias may mean higher accessibility to any spatial information in the visual field (be it relevant for the task or not). This was tested by spatially separating the target and distracter that were presented in Experiment 3. The mere separation of the relevant and irrelevant information of the task (Experiment 4) was sufficient to reveal a significant interaction between alertness and congruency. The results of Experiments 3 and 4 demonstrate that when the distracter and target are separated, alerting seems to increase the congruency effect. However, it is important to mention that the mere separateness of the target object and distracter objects cannot be the core element underlying the interaction between alertness and congruency. Previous studies reported that the interaction is also apparent in the Simon or spatial Stroop tasks (Böckler et al., 2011; Fischer et al., 2010; Funes & Lupiáñez, 2003; Klein & Ivanoff, 2010). In these tasks, the target (stimulus identity) and distracter (stimulus spatial location) are integrated. What may be the common ground for the interaction is the involvement of spatial attention. We suggest that alerting increases the accessibility of spatial events in the visual field. Accordingly, in the flanker task it increases processing of spatially presented distracters while in the Simon task it may increase the saliency of the target's spatial location (i.e., the irrelevant distracting feature). Indeed, the idea that the level of alertness modulates spatial attention is not new. In 1998, Robertson et al. found that alerting signals prior to a target can help neglect patients allocate attention to their neglected hemifield. Accordingly, DeGutis and Van Vleet (2010) recently demonstrated that training in an alertness task also improves various measures of spatial attention among patients suffering from neglect disorder. Another recent study reported that alerting cues improve visual conscious perception in healthy individuals as well (Kusnir, Chica, Mitsumasu, & Bartolomeo, 2011). Results of the current study complement these findings and can help better understand the influence of alertness on processing of visual information. Furthermore, results from the current study give insight into the way alertness, which originates in a subcortical system, modulates measures of a higher cortical system; namely, executive control. We suggested that alerting signals increase accessibility of visual events in the spatial surrounding (be it conscious or unconscious). An important question to be asked is how exactly this increased accessibility is achieved. One option to consider is that alertness possibly expands the focus of attention. Visual attention has often been described as a mental spotlight, illuminating circumscribed regions of the visual field (Posner, 1980). The spotlight model, as well as related conceptualizations such as the zoom lens model (Eriksen & St. James, 1986), suggests that spatial distracters receive more attention when the focus of attention is diffused. In this way, expansion of the attentional spotlight would mean more processing of spatial distracters. As mentioned, such broadening of the attentional beam could also account for the appearance of the alertness-congruency interaction in the Simon task. In this task, spatial processing is inherent because the to-be-ignored dimension is the stimulus spatial location. Broadening the attentional beam could increase the system's sensitivity to the spatial location of the target, which is the irrelevant distracter. Further research is required to empirically examine this prediction and in order to understand if and to what extent, alerting expands the attentional spotlight. It is reasonable to consider that such a mechanism could be very useful in many circumstances because it allows one to pay more attention to surrounding spatial events in an alerted state. From an evolutionary perspective, greater sensitivity toward spatial events should be helpful in dealing with threats more efficiently. However, this ability seems to come at a cost. Under some circumstances alerting can reduce our ability to filter irrelevant spatial information in the visual field.

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