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Differential effects of phasic and tonic alerting on the efficiency of executive attention

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A B S T R A C T

The study examined how alerting and executive attention interact in a task involving conflict resolution. We proposed a tentative scenario in which an initial exogenous phasic alerting phase is followed by an endogenous tonic alerting phase, and hypothesized that these two processes may have distinct effects on conflict resolution. Phasic alerting was expected to increase the conflict, whereas tonic alerting was expected to decrease the conflict. Three experiments were conducted using different variants of the flanker task with visual alerting cues and varied cue-target intervals (SOA), to differentiate between effects of phasic alerting (short SOA) and tonic alerting (long SOA). The results showed that phasic alerting consistently decreased the efficiency of conflict resolution indexed by response time and accuracy, whereas tonic alerting increased the accuracy of conflict resolution, but at a cost in the speed of processing the conflict. The third experiment additionally showed that the effects of phasic alerting may be modulated by the psychophysical strength of alerting cues. Discussed are possible mechanisms that could account for the observed interactions between alerting and conflict resolution, as well as some discrepancies between the current and previous studies.

1. Introduction

1.1. Attentional networks

Attention has been described as a system of three neural networks controlling three sets of functions (Parasuraman, 1998; Posner & Petersen, 1990; Robertson, 2004) defined by Posner and colleagues as alerting, orienting, and executive attention (Petersen & Posner, 2012). The alerting network controls achieving a state of readiness to process and respond to external stimuli (Posner, 2008; Tang, Rothbart, & Posner, 2012). The orienting network controls processes of selection and orienting to sensory or mental events (Shulman & Corbetta, 2012). The executive network controls behavior by suppressing interference or resolving conflicts between alternative actions or response programs (Carter & Krug, 2012). A number of behavioral, lesion, imaging, electrophysiological, pharmacological, and even genetic studies have shown that the three networks are relatively independent of each other on both the behavioral and the neuroanatomical level (for review see Petersen & Posner, 2012; Posner & Rothbart, 2007). Nevertheless, the notion of separation of the networks does not imply that they work completely independently of each other. On the contrary, the networks have been shown to interact (Callejas, Lupiáñez, Funes, & Tudela, 2005; Callejas, Lupiáñez, & Tudela, 2004; Fan et al., 2009) and to work together like an "*organ system*" in accomplishing cognitive tasks or actions (Posner & Fan, 2008). However, as Posner states, "*how these networks function together in a coordinated fashion during the complex natural tasks of daily life is still largely a mystery*" (Posner, 2012, p.2). The question of interdependence and interaction of attentional networks thus remains amongst the main issues in the current research on attention. The present study aimed to investigate the relationship between two of these networks: alerting and executive. Specifically, we focused on the influence of alerting on the efficiency of conflict resolution.

The functioning of the attentional networks is most commonly assessed with the attention network test (ANT, Fan, McCandliss, Sommer, Raz, & Posner, 2002), which combines two classic experimental tasks: Posner's cueing task (Posner, 1980) and the flanker task (Eriksen & Eriksen, 1974). Alerting is measured by comparison of responses to a target signaled by a visual or an auditory warning cue with responses to a target occurring without any warning. The difference shows the extent to which responses are improved by the alerting cue. Executive attention is measured by comparison of responses to a target (e.g., an arrow) surrounded by congruent flankers (e.g., arrows pointing in the same direction as the target) with

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responses to a target surrounded by incongruent flankers (e.g., arrows pointing in the direction opposite to the target arrow and thereby activating an incorrect response program). The flanker effect reflects the cost of conflict or interference caused by the incongruent flankers. A larger flanker effect is assumed to reflect lower efficiency of executive attention in resolution of this conflict. Orienting is measured by comparison of responses to a target preceded by spatial cues that provide either valid, invalid, or no specific information about the target location.

1.2. Impact of alerting on conflict resolution

It has been suggested that alerting may suppress ongoing activity within the executive network and thereby decrease the efficiency of conflict resolution (Callejas et al., 2004; Callejas et al., 2005; Klein & Ivanoff, 2010; Posner, 1994, 2008). The functional meaning of such an inhibitory mechanism would be to prevent the missing of upcoming relevant stimuli and/or to facilitate rapid responding to external events (Petersen & Posner, 2012; Tang et al., 2012). Results of a number of ANT studies have conformed to this hypothesis, showing that while alerting usually decreases the overall response time (RT), it simultaneously increases the cost of conflict, i.e., a larger conflict effect is observed when an alerting cue precedes the target (Callejas et al., 2004; Callejas et al., 2005; Fan et al., 2009; Fossella et al., 2002). Alertness, however, is not a unitary construct and involves at least two components: phasic and tonic alerting (Fernandez-Duque & Posner, 2001; Klein & Ivanoff, 2010; Posner, 2008). Phasic alerting is assumed to be a fast, exogenous, but short-lived and nonspecific activation or adjustment of perceptual systems that can be evoked by any warning stimulus. Tonic alerting, on the other hand, is a slower and more sustained activation that allows endogenous increase of expectancy and readiness to process stimuli, thereby facilitating better response preparation (Dosenbach et al., 2006; Fan et al., 2007; Périn, Godefroy, Fall, & de Marco, 2010; Posner, 2008; Weinbach & Henik, 2012a; see also Lawrence & Klein, 2012). Tonic alerting can be developed when a cue signals an upcoming target that is expected to appear. In the present study, we aimed to disentangle these two alerting components that are assumed to operate in different time scales, in order to draw a more detailed picture of the influence of alerting on conflict resolution.[1]

Considering the ANT procedure, we propose a tentative schema of an interaction between alerting and conflict resolution. When an alerting cue is presented, it initially triggers phasic alerting in a quick, exogenous, and automatic manner. This effect is presumably short-lasting, as is typical for involuntary exogenous attentional processes (e.g., about 100–300 ms in the case of exogenous spatial orienting, Wright & Ward, 2008). However, because the alerting cue signals an occurrence of an expected event, the system does not return to its initial state, but an endogenous tonic alert state develops subsequently. Tonic alerting takes some time to initiate and build up (cf. Hackley et al., 2009; Weinbach & Henik, 2012a), possibly 200–300 ms or more, as in the case of spatial endogenous orienting. Hence, the impact of tonic alerting becomes effective only after a given amount of time, plausibly influencing the later phase of conflict processing.

1.3. Present study

Based on this tentative scenario, we hypothesize differential effects of phasic and tonic alerting on conflict resolution. First, if phasic alerting automatically suppresses the ongoing activity of the executive network, then it should quickly decrease the efficiency of conflict resolution. Tonic alerting, on the other hand, should increase the efficiency of conflict processing due to endogenously increased readiness for processing incoming stimuli and better response preparation, but it takes more time to develop. Second, the effects of phasic alerting might be amplified with an increased psychophysical strength or saliency of alerting stimuli, since such manipulation has been proven to effectively increase alertness in vigilance tasks (Helton et al., 2010; See, Howe, Warm, & Dember, 1995). Tonic alerting effects should remain relatively independent of psychophysical properties of alerting stimuli, because in this case we assume that the effect is based on the informational value of the cue. In other words, the psychophysical strength of the alerting cue should modulate the alerting effect on conflict resolution only when phasic alerting is involved, i.e., at the initial stage of conflict processing.

We tested these hypotheses in three experiments with modified variants of the ANT. In Experiment 1 (E1), we investigated the time course of the alerting effect on conflict resolution by using two cue-target intervals (SOA): 100 and 800 ms. With the short SOA, behavioral responses were assumed to reflect the impact of phasic alerting on conflict resolution, thus an increased conflict cost in the alerting cue condition was expected to be observed compared to the no cue condition. With the long SOA, tonic alerting was assumed to come into play, hence the conflict effect was expected to decrease in the alerting cue condition. In addition, in E1, as in some of the previous studies on interactions between attentional networks (Callejas et al., 2005, 2004), uninformative exogenous spatial orienting cues were used, which allowed for comparison of the effects of alerting cues on conflict with the effects of orienting cues on conflict.

In Experiment 2 (E2), we investigated whether the relation between alerting and executive attention would indeed be limited to two phases, i.e., phasic and tonic alerting, or whether a gradual pattern of interaction between alerting and conflict would emerge when using different cue-target intervals. We used a task with three SOAs: 100, 400, and 800 ms (the orienting conditions were omitted to simplify the task). The effect of alerting on conflict resolution with SOA 400 was expected to mimic the effect obtained with SOA 800, because in both cases the effects of tonic alerting were assumed to be captured.

The objective of Experiment 3 (E3) was to differentiate further between phasic and tonic alerting by examining the effects of the psychophysical strength of alerting cues.[2] We assumed that only phasic alerting would be related to physical properties of stimuli. Therefore, the stronger the alerting stimulation, the larger should be the effect of phasic alerting on conflict, whereas the effects of tonic alerting on conflict should not be modulated by the strength of alerting cues. We used two types of visual alerting cues: a single cue and a double cue. The double cue was assumed to have more psychophysical strength than the single cue. Stimuli were presented with three SOA intervals: 100, 500, and 900 ms. In line with the hypothesis, the impact of phasic

[1] There are several issues in terms of terminology and definitions of alertness. For instance, while Weinbach and Henik (2012a) also differentiate phasic and tonic alerting in line with the exogenous and endogenous modes, they define *tonic alerting* as "the general ability to stay alert and prepared for detecting infrequent stimuli during a task (usually measured in vigilance and continuous performance tasks)" (pp.2–3). However, in our view, *tonic alerting* is a more dynamic process lasting presumably from a few hundred milliseconds to several seconds, and *vigilance* is a more static or sustained state of attention (cf. Robertson & O'Connell, 2010; Roca et al., 2011) that might be described as a process of sustaining or maintaining tonic alertness for a long period. Furthermore, *alerting* is often linked with *arousal*, and these two terms are even used alternately (e.g., Weinbach & Henik, 2013). But arousal may refer to very different processes such as excitement, emotions, physiological states, circadian rhythms, etc., and not necessary to information processing systems in the brain in an alert state (as an opposite e.g., to the resting state, Tang et al., 2012). Finally, the term *temporal expectancy* (Weinbach & Henik, 2013) may confound two phenomena: tonic alerting, and expectation or prediction (Schröger, Marzecová, & SanMiguel, 2015; Summerfield & Egner, 2009). It is, however, very difficult to dissociate these processes empirically on the level of both operationalization and measurement (cf. Summerfield & Egner, 2009; Weinbach & Henik, 2012a). Likewise, in the present study, the term *tonic alerting* entails increased perceptual readiness, response preparation, and expectancy or prediction. New theoretical criteria and more systematic studies are needed to resolve these issues. At present, the differences in terminology and definitions should be taken into account to avoid confusion or misinterpretations.

[2] We thank Juan Lupiáñez for suggesting this idea.