Acta Psychologica 176 (2017) 58–70

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy

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

Dariusz Asanowicz[a,*], Anna Marzecová[b]

[a] Institute of Psychology, Jagiellonian University in Kraków, Poland
[b] Institute of Psychology, University of Leipzig, Germany

ARTICLE INFO

Keywords:
Attentional networks
Alerting
Executive attention
Warning signal
Conflict resolution

ABSTRACT

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

---

[*] Corresponding author at: Institute of Psychology, Jagiellonian University, Ingardena 6, 30-060 Kraków, Poland.
E-mail address: d.asanowicz@uj.edu.pl (D. Asanowicz).

http://dx.doi.org/10.1016/j.actpsy.2017.03.004
Received 30 September 2016; Received in revised form 24 February 2017; Accepted 12 March 2017

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.

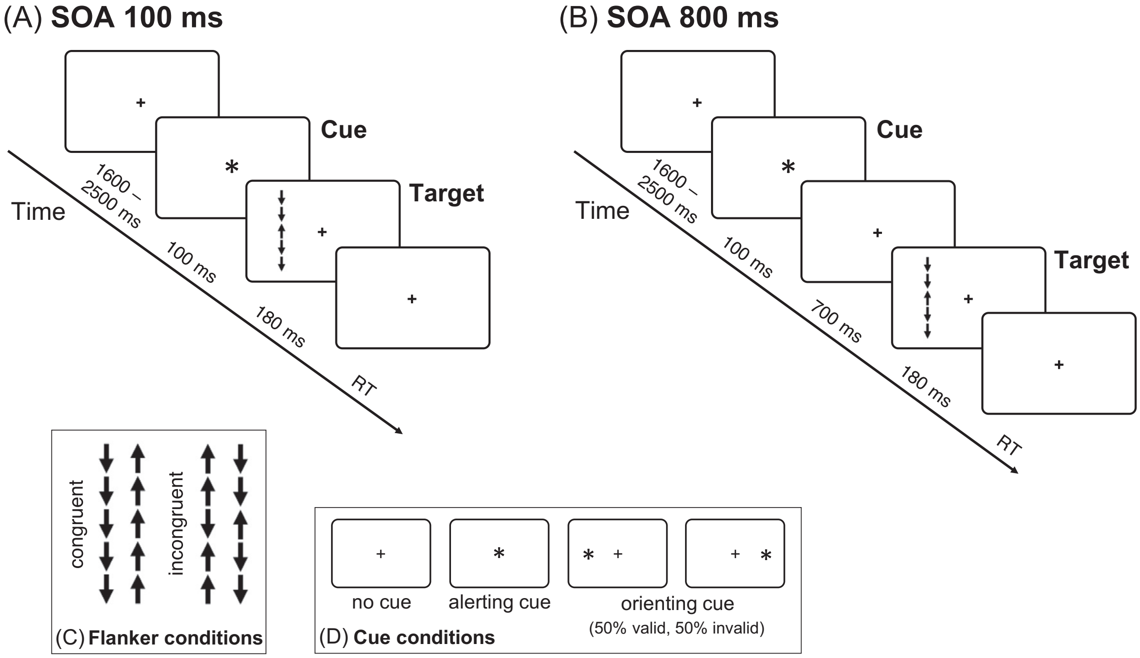

Fig. 1. The task used in Experiment 1. Sequence of events in trials with center alerting cue, incongruent flankers, and cue-target SOA interval of 100 ms (A), and of 800 ms (B), the two flanker conditions (C), and the three cue conditions (D). Similar tasks were used in Experiments 2 and 3, with few changes in terms of alerting cues and SOA (see Methods for details).

alerting on conflict, which was assumed to be captured with the shortest SOA, should be stronger with the double cue than with the single cue, whereas the effects of tonic alerting on conflict, assumed to be captured with both longer SOAs, were not expected to be modulated by the type of alerting cue.

2. Experiment 1

2.1. Method

2.1.1. Participants

Nineteen young adults participated in the study (14 females) in return for course credits. The average age was 20.6 years ($SD = 2.3$). All participants were university students with normal or corrected-to-normal vision and no history of neurological disorders. Written informed consent was obtained from the participants.

2.1.2. Experimental task

To reliably measure even small interactive effects, we used a version of the ANT that imposes relatively high processing demands, with the assumption that the effects of particular functions of attention become most evident when a task requires more intense involvement of these functions (cf. Evert, McGlinchey-Berroth, Verfaellie, & Milberg, 2003; Verleger et al., 2009). This ANT version has been shown to produce equally reliable RT and ERR results (Asanowicz, Marzecová, Jaśkowski, & Wolski, 2012; Marzecová, Asanowicz, Kriváá, & Wodniecka, 2013).

Examples of a trial and the stimuli used in the task are shown in Fig. 1. Each trial of the task began with a fixation point presented at the center of a computer screen for the duration of the whole trial. The target stimulus was an arrow pointing either up or down, presented in the left or in the right visual field (50/50%). In each trial, the target arrow was flanked by four additional arrows pointing in either the same (congruent flankers) or the opposite direction (incongruent flankers). Participants were asked to identify in which direction the target (middle) arrow was pointing. Speed and accuracy of responses were measured. The incongruent flanker condition involved conflict between two alternative and mutually exclusive responses. The difference between congruent and incongruent conditions indicates the cost of the conflict and is interpreted as an index of the executive network's efficiency in resolution of this conflict (Fan et al., 2002). In addition, two types of visual cue, a center cue and a spatial cue, were presented, constituting four cue conditions: the target could appear without any cue, or could be preceded by a center alerting cue presented in the same location as the fixation cross, or a spatial orienting cue presented in one of the two possible target location but with validity of 50% (spatial valid and invalid cue conditions). The center cue alerted participants by signaling that the target was about to occur, and the difference between conditions with the center cue and with no cue provides an index of the alerting effect (Fan, McCandliss, Fossella, Flombaum, & Posner, 2005).[3] The difference between conditions with the center and spatial valid cues provides an index of orienting (Fan et al., 2002).

To increase demands for attention, stimuli were presented with a larger eccentricity than in the standard ANT (cf. Asanowicz et al., 2012; Marzecová et al., 2013). With increased retinal eccentricity, visual acuity decreases and target discrimination requires more attention to boost the stimulus contrast and visibility (Bourne, 2006; Carrasco, Ling, & Read, 2004). The target arrow and the flankers were each 6 mm (0.57°) long and wide for 1/3 of their length (i.e., 0.2°). The length of all five arrows in the display was 32 mm (3.0°). The arrows' midpoints were displayed 35 mm (3.3°) to the left or right of the center of the screen. The fixation cross was 3 mm (0.3°) in width. An asterisk (5 mm, 0.47° diameter) was used as a cue and was displayed either in the position of the fixation cross or laterally at the same position as the target stimuli.

Each trial started with a fixation period of a random variable interval (1600–2500 ms), followed by a cue presented for 100 ms. The stimulus onset asynchrony (SOA) between the cue and target onsets was either 100 or 800 ms, thus the target and flankers were displayed for 180 ms either directly after the cue, or after the inter-stimulus interval of 700 ms. In the no cue condition, the target and flankers were presented immediately after the fixation period. A new trial began automatically after the participant's response, or after 2000 ms if the

---

[3] While in some studies an auditory cue is used to measure alerting effects (e.g., Callejas et al., 2005, 2004), here, we used visual cues to make the results comparable with the original ANT studies (Fan et al., 2009, 2005, 2002) and with our own previous studies. See Appendix A for an additional experiment with auditory alerting cues.

participant did not respond. The stimuli were presented via DMDX software (Forster & Forster, 2003).

2.1.3. Procedure

The task began with a practice session in which participants completed two blocks, each consisting of 16 trials, and received feedback on their accuracy after each response. The practice session was followed by 1152 experimental trials, divided into 6 blocks of 192 trials each. In each block, 50% of the trials were congruent and 50% were incongruent. On 384 trials the alerting center cue was presented, on another 384 trials targets were preceded by spatial cues (50% of these were valid), and no cue was presented on the remaining 384 trials. The two SOA conditions, 100 and 800 ms, were split 50/50 across all trials in which a cue was presented.

The task lasted up to one and a half hours. In between blocks, participants were asked to take breaks to rest their eyes, to keep head and body still, to fixate on the cross in the screen, and to respond to targets as quickly and as accurately as possible. Participants were asked to respond by pressing keys on a computer mouse. To make responding easier and more natural, spatial compatibility between the response pattern and the direction of the arrows was ensured. The mouse was placed at midline, parallel to the screen. In this way, the right and left buttons were positioned as the up and down buttons. Participants were asked to press the upper button for the up-pointing targets, and the lower button for the down-pointing ones. When participants used their right hands, they used their middle finger to press the right button (i.e., the ‘upper’ button) for the targets pointing up and their index fingers to press the left (i.e., ‘lower’) button for the targets pointing down. For the left hand, the mouse was turned by 180° and the response mapping was reversed, i.e., the right button became the down key, and the left button became the upper key. For each participant, the response hand alternated between blocks (including the practice blocks). The trials were presented in a new random order for each participant.

2.2. Results

Error trials and trials with response times (RT) below or above 3 standard deviations (*SD*) of the overall mean RT were excluded from RT analysis (overall 14.7% of responses). The overall mean RT for correct responses was 632 ms ($SD = 49$ ms) and the overall mean error rate (ERR) was 13.5% ($SD = 5\%$). Mean RT and ERR for each task condition are shown in Table 1 and results of an omnibus ANOVA of the data are shown in Table 2.

2.2.1. Alerting × conflict

Fig. 2 shows indices of flanker conflict (incongruent *minus* congruent flanker condition) for each alerting cue condition. To analyze the effects of the alerting cue on flanker conflict, we first performed a 3 × 2 repeated measure ANOVA with alerting cue (no cue, center cue with SOA 100 ms, and center cue with SOA 800 ms) and flanker type (congruent, incongruent). The ANOVA showed a significant effect of alerting cue in RT, $F_{2,36} = 10.44$, $p < 0.001$, $\eta_p^2 = 0.36$, and ERR, $F_{2,36} = 56.95$, $p < 0.001$, $\eta_p^2 = 0.76$, a significant effect of flanker type in RT, $F_{1,18} = 395.93$, $p < 0.001$, $\eta_p^2 = 0.95$, and ERR, $F_{1,18} = 120.09$, $p < 0.001$, $\eta_p^2 = 0.87$, and a significant cue × flanker interaction in RT, $F_{2,36} = 8.53$, $p = 0.001$, $\eta_p^2 = 0.32$, and ERR, $F_{2,36} = 69.68$, $p < 0.001$, $\eta_p^2 = 0.79$. This interaction was then examined by 2 × 2 ANOVAs with cue (no cue, cue with SOA 100 or 800 ms) and flanker (congruent, incongruent) performed separately for the two SOA conditions, in accordance with the hypothesis.

2.2.1.1. SOA 100 ms. The flanker effect was significantly larger in the center cue condition than in the no cue condition both in RT (121 vs. 102 ms, cue × flanker: $F_{1,18} = 33.16$, $p < 0.001$, $\eta_p^2 = 0.50$) and in ERR (32% vs. 20%, cue × flanker: $F_{1,18} = 65.93$, $p < 0.001$, $\eta_p^2 = 0.79$). In detail, the center cue decreased RT in the non-conflict trials, $F_{1,18} = 4.51$, $p = 0.048$; $\eta_p^2 = 0.20$, revealing a typical, albeit small, alerting effect (cf. Posner, 1978). The effect for ERR was not significant, $F < 1.0$. In the conflict trials, on the other hand, the cue increased both RT, $F_{1,18} = 12.13$, $p = 0.003$, $\eta_p^2 = 0.40$, and ERR, $F_{1,18} = 76.65$, $p < 0.001$, $\eta_p^2 = 0.81$.

2.2.1.2. SOA 800 ms. In RT analysis, a cue × flanker interaction showed a larger flanker effect in the center cue condition than in the no cue condition (10 ms of difference), $F_{1,18} = 4.83$, $p = 0.041$, $\eta_p^2 = 0.21$. However, in ERR analysis, this interaction revealed the opposite pattern: the flanker effect was significantly smaller in the center cue condition than in the no cue condition (13% vs. 20%), $F_{1,18} = 38.20$, $p < 0.001$, $\eta_p^2 = 0.68$. In detail, in the non-conflict trials the center cue decreased RT, $F_{1,18} = 17.20$, $p = 0.001$, $\eta_p^2 = 0.49$, and marginally also ERR, $F_{1,18} = 3.97$, $p = 0.062$, $\eta_p^2 = 0.18$, revealing a typical alerting effect. In the conflict trials, the cue marginally increased RT, $F_{1,18} = 3.49$, $p = 0.08$, $\eta_p^2 = 0.16$, but also significantly improved performance by decreasing ERR, $F_{1,18} = 31.22$, $p < 0.001$, $\eta_p^2 = 0.63$.

2.2.2. Orienting × conflict

To analyze the effects of spatial orienting (spatial valid cue vs. center cue, Fan et al., 2002) on flanker conflict, we first performed a 2 × 2 ANOVA with cue (valid, center), flanker (congruent, incongruent), and SOA (100, 800). The ANOVA showed a significant SOA × cue interaction in RT, $F_{1,18} = 45.46$, $p < 0.001$, and in ERR, $F_{1,18} = 68.97$, $p < 0.001$, and SOA × cue × flanker in ERR, $F_{1,18} = 58.67$, $p < 0.001$. These interactions were then examined by 2 × 2 ANOVAs with cue (valid, center) and flanker (congruent, incongruent) performed separately for the SOA 100 and 800. Fig. 3 shows indices of flanker conflict for the spatial valid and center cues in the two SOA conditions.

2.2.2.1. SOA 100 ms. The flanker effect was significantly smaller in the valid cue condition than in the center cue condition in both RT (107 vs 121 ms, cue × flanker: $F_{1,18} = 7.05$, $p = 0.016$, $\eta_p^2 = 0.28$), and in ERR (19% vs. 32%, cue × flanker: $F_{1,18} = 44.12$, $p < 0.001$, $\eta_p^2 = 0.71$). In detail, in RT the valid cue improved performance, as compared to the center cue, in both the congruent trials, $F_{1,18} = 36.81$, $p < 0.001$, $\eta_p^2 = 0.67$, and the incongruent trials, $F_{1,18} = 59.63$, $p < 0.001$, $\eta_p^2 = 0.77$, but this improvement was larger in the incongruent trials. In ERR, the valid cue improved performance only in the incongruent trials, $F_{1,18} = 48.27$, $p < 0.001$, $\eta_p^2 = 0.73$, and not in the congruent trials, $F = 1.3$, n.s.

2.2.2.2. SOA 800 ms. In RT, a cue × flanker interaction did not reach the significance level, $F_{1,18} = 3.30$, $p = 0.086$, $\eta_p^2 = 0.11$. However, in ERR measurement, flanker conflict was larger in the valid cue condition than in the center cue condition (17% vs 13%), as revealed by a significant cue × flanker interaction, $F_{1,18} = 6.29$, $p = 0.022$, $\eta_p^2 = 0.26$. In detail, ERR did not differ between the valid and center cue conditions in the congruent trials, $F = 1.75$, n.s., whereas in the incongruent trials, ERR was larger in the valid than in the center cue condition, $F_{1,18} = 7.40$, $p = 0.014$, $\eta_p^2 = 0.29$.

Other results regarding the orienting network replicate findings from previous studies (e.g., Asanowicz et al., 2012; Callejas et al., 2005, 2004; Fan et al., 2009; Marzecová et al., 2013).[4]

---

[4] Analysis of orienting validity effect (spatial valid cue vs. spatial invalid cue, cf. Callejas et al., 2005; Posner & Cohen, 1984) showed fairly typical results. With SOA 100ms, the effect yielded 68ms in RT, $F_{1,18}=119.74$, $p < 0.001$, $\eta_p^2=0.87$, and 20% in ERR, $F_{1,18}=137.91$, $p < 0.001$, $\eta_p^2=0.88$, showing faster and more accurate responses when the target was preceded by a valid cue. Since the cues were purely exogenous and non-informative (with cue validity 50/50%), the cueing effect was significantly decreased with SOA 800ms (as indicated by the cue × SOA interaction, RT: $F_{1,18}=43.18$, $p < 0.001$, $\eta_p^2=0.70$, ERR: $F_{1,18}=86.17$, $p < 0.001$, $\eta_p^2=0.82$), but the inhibition of return effect (Posner & Cohen, 1984) was not observed, which is rather typical for tasks requiring more complex responses, than simple target detection or even discrimination (cf. Callejas et al., 2005; Lupiáñez et al., 1997). Accordingly, with SOA 800ms, the orienting effect was much smaller and significant only for RT (16ms, $F_{1,18}=5.36$, $p=0.033$, $\eta_p^2=0.23$).

Table 1
Average response time of correct responses (RT) and average error rate (ERR) for each condition of Experiments 1, 2, and 3.

	Cue condition	SOA (ms)	Flanker type	RT (ms) mean (*SD*)	ERR (%) mean (*SD*)
Experiment 1	Center	100	Congruent	590 (56)	1.9 (2.3)
			Incongruent	712 (59)	34.3 (12.9)
		800	Congruent	577 (56)	1.2 (1.4)
			Incongruent	689 (57)	14.4 (7.2)
	Spatial valid	100	Congruent	559 (48)	1.2 (1.6)
			Incongruent	666 (49)	20.1 (10.1)
		800	Congruent	572 (56)	2.0 (2.2)
			Incongruent	673 (52)	19.1 (10.9)
	Spatial invalid	100	Congruent	639 (57)	7.1 (5.9)
			Incongruent	723 (45)	54.2 (14.5)
		800	Congruent	587 (54)	1.5 (2.8)
			Incongruent	690 (56)	15.6 (10)
	No cue	–	Congruent	597 (51)	2.1 (1.3)
			Incongruent	698 (52)	22.7 (9.1)
Experiment 2	Center cue	100	Congruent	626 (68)	3.3 (3)
			Incongruent	742 (78)	33.3 (13.3)
		400	Congruent	592 (61)	2.0 (3)
			Incongruent	701 (77)	17.8 (12.1)
		800	Congruent	605 (62)	2.5 (3.8)
			Incongruent	713 (77)	19.9 (11.7)
	No cue	–	Congruent	632 (62)	3.5 (4.6)
			Incongruent	724 (72)	25.8 (11)
Experiment 3	Single (center) cue	100	Congruent	655 (75)	1.7 (3.6)
			Incongruent	770 (83)	14.7 (11.7)
		500	Congruent	626 (67)	1.4 (2.9)
			Incongruent	735 (79)	9.6 (9.9)
		900	Congruent	629 (64)	1.6 (3.4)
			Incongruent	738 (79)	8.7 (9.7)
	Double cue	100	Congruent	661 (67)	1.7 (3.1)
			Incongruent	782 (78)	17 (10.7)
		500	Congruent	627 (65)	1.6 (3.5)
			Incongruent	736 (80)	9.4 (10.8)
		900	Congruent	624 (65)	1.3 (2.9)
			Incongruent	737 (78)	9.8 (9.3)
	No cue	–	Congruent	660 (66)	1.7 (2.9)
			Incongruent	765 (76)	12.2 (8.5)

2.3. Discussion

In Experiment 1, we hypothesized that early phasic alerting would decrease the efficiency of conflict resolution, whereas tonic alerting, which presumably unfolds at subsequent stages, would improve the ability to deal with the conflict. We assumed that the effects of phasic alerting would be captured by a behavioral measure with a short cue-target interval (SOA), whereas the effects of tonic alerting would be captured with a longer SOA. The overall accuracy was well below ceiling, which confirmed that, by posing sufficient demands, the revised ANT enabled reliable measurement of both RT and ERR. The ERR was higher than in the standard ANT (cf. MacLeod et al., 2010) and comparable with our previous studies employing tasks with similar parameters (Asanowicz et al., 2012; Marzecová et al., 2013). In line with the hypothesis, when the cue-target SOA was short, alerting cues increased conflict effect consistently in both RT and ERR. However, with the long SOA, alerting cues slightly increased the conflict effect in RT (as with the short SOA) and notably decreased the conflict effect in ERR.[5]

The results in the short SOA condition are consistent with the assumption of the negative impact of phasic alerting on the executive network. The results in the long SOA condition may also be consistent with the proposed scenario, but in a less straightforward way than we hypothesized. The effect of increased response time accompanied by the increased accuracy of conflict resolution suggests that tonic alerting may improve the efficiency of executive attention by lengthening the conflict processing time. This latter result may reflect a type of speed-accuracy trade-off (Bogacz, Wagenmakers, Forstmann, & Nieuwenhuis, 2010). Based on the classic theory of levels of processing (Craik & Lockhart, 1972), we assume that a deeper and more elaborate processing of information takes more time, but results in a more precise or detailed representation of stimuli and thereby in a less error-prone performance (analogous to a better memory of deeper processed events). Such slowing of responses for the conflict stimuli after the alerting cue may also reflect a strategic adjustment of behavior. It has been shown that errors in flanker tasks occur mainly when responses in conflict trials are too quick or premature, due to an automatic activation of an incorrect response by incongruent flankers (Ridderinkhof, van den Wildenberg, & Wylie, 2012). Delaying responses may therefore provide more time for effective dealing with the response conflict (cf. the activation - suppression hypothesis, Ridderinkhof, 2002; see also Posner, 2008). As such endogenous strategic adjustment takes time to develop (Ridderinkhof et al., 2012), it becomes effective only when the cue-target interval is long enough. Other related findings have been reported by Boulinguez, Ballanger, Granjon, and Benraiss (2009). They have shown that warning cues slow down RT, which, according to their interpretation, helps to prevent automatic erroneous responses, presumably by triggering a top-down strategic proactive control. Several recent studies have identified specific cortical-subcortical neuronal circuits that may be responsible for the longer but more accurate responses (Bogacz & Gurney, 2007; Frank, Samanta, Moustafa, & Sherman, 2007). In conclusion, the observed interaction pattern may be consistent with the proposed hypothesis that assumes positive effects of tonic alerting on conflict resolution.

---

[5] Similar asymmetry between exogenous and endogenous modes of attention in terms of RT and ERR results has been demonstrated for spatial orienting (Prinzmetal, McCool, & Park, 2005).

Table 2
Results of omnibus ANOVAs of RT and ERR data from Experiments 1, 2, and 3.

		Results	
	Factors and interactions	RT	ERR
Experiment 1, 7 × 2 repeated measure ANOVA	Cue condition (no cue, center cue with SOA 100 ms, center cue with SOA 800 ms, spatial valid cue with SOA 100 ms, spatial invalid cue with SOA 100 ms, spatial valid cue with SOA 800 ms, and spatial invalid cue with SOA 800 ms)	$F_{6,108} = 37.14$ $p < 0.001$ $\eta_p{}^2 = 0.67$	$F_{6,108} = 69.03$ $p < 0.001$ $\eta_p{}^2 = 0.79$
	Flanker type (congruent, incongruent)	$F_{1,18} = 542.64$ $p < 0.001$ $\eta_p{}^2 = 0.97$	$F_{1,18} = 160.76$ $p < 0.001$ $\eta_p{}^2 = 0.90$
	Cue × Flanker	$F_{6,108} = 5.49$ $p < 0.001$ $\eta_p{}^2 = 0.23$	$F_{6,108} = 55.08$ $p < 0.001$ $\eta_p{}^2 = 0.75$
Experiment 2, 4 × 2 repeated measure ANOVA	Cue condition (no cue, and center cue with the three SOAs: 100, 400, and 800 ms)	$F_{3,63} = 27.60$ $p < 0.001$ $\eta_p{}^2 = 0.57$	$F_{3,63} = 21.73$ $p < 0.001$ $\eta_p{}^2 = 0.51$
	Flanker type (congruent, incongruent)	$F_{1,21} = 159.34$ $p < 0.001$ $\eta_p{}^2 = 0.88$	$F_{1,21} = 126.27$ $p < 0.001$ $\eta_p{}^2 = 0.85$
	Cue × Flanker	$F_{3,63} = 3.39$ $p = 0.023$ $\eta_p{}^2 = 0.14$	$F_{3,63} = 17.58$ $p < 0.001$ $\eta_p{}^2 = 0.45$
Experiment 3, 7 × 2 repeated measure ANOVA	Cue condition (no cue, single cue with SOA 100, double cue with SOA 100, single cue with SOA 500, double cue with SOA 500, single cue with SOA 900, and double cue with SOA 900)	$F_{6,444} = 67.91$ $p < 0.001$ $\eta_p{}^2 = 0.48$	$F_{4,444} = 18.46$ $p < 0.001$ $\eta_p{}^2 = 0.20$
	Flanker type (congruent, incongruent)	$F_{1,74} = 761.59$ $p < 0.001$ $\eta_p{}^2 = 0.91$	$F_{1,74} = 145.61$ $p < 0.001$ $\eta_p{}^2 = 0.66$
	Cue × Flanker	$F_{6,444} = 2.01$ $p = 0.060$ $\eta_p{}^2 = 0.03$	$F_{6,444} = 15.91$ $p < 0.001$ $\eta_p{}^2 = 0.18$

Although the effects of alerting cues on conflict in the short SOA condition were large and unambiguous, the classic alerting effect of speeding up RTs in the non-conflict trials (Posner, 1978) was unusually small. This suggests that visual alerting cues may have been less effective under the SOA 100 condition and might question our interpretation of the phasic alerting effects on conflict resolution. To address this concern, we performed an additional flanker task experiment with the cue-target SOA 100 ms and auditory alerting cues instead of the visual ones (see Appendix A for a detailed description of this experiment). Auditory cues have been shown to be powerful enough to evoke large alerting effects already at SOA 100 ms (Fernandez-Duque & Posner, 1997) and to produce generally more reliable alerting effects than visual cues (Ishigami & Klein, 2010). The results showed that the auditory alerting cues unequivocally speeded up RTs in the congruent flanker condition, and significantly increased the flanker conflict effect in both RT and ERR, thereby confirming and expanding the results of Experiment 1.

Experiment 1 has also shown evidence on the modulation of conflict resolution by exogenous orienting. In the standard ANT task (Fan et al., 2002) an endogenous (top-down) orienting is measured (orienting cues point to target locations with 100% validity). In the present study, we used uninformative exogenous cues (i.e., with 50% of validity) with either 100 or 800 ms SOA. The results showed a typical cueing effect in the short SOA condition, i.e., quicker and more accurate responses for targets preceded by valid cues, along with a significant improvement of conflict resolution following valid cues as compared to center cues. With the long SOA, the effect of orienting on conflict was not present in RT, and even reversed in ERR, presumably due to attenuation of the orienting effect, as well as a larger improvement of conflict resolution by the center cue (tonic alerting) than by the spatial valid cue (exogenous orienting). Such a decrease of the orienting effect with a long SOA is typical for exogenous cueing (Wright & Ward, 2008). In simpler tasks, like detection tasks, the facilitation effect even reverses into an effect known as the inhibition of return (Lupiáñez, 2010; Posner & Cohen, 1984; see also Lupiáñez, Milán, Tornay, Madrid, & Tudela, 1997).

To sum up, we observed a coherent pattern of interactions between the attentional networks. With the short SOA, phasic (exogenous) alerting increased the conflict, whereas exogenous orienting decreased the conflict (see Callejas et al., 2005; Funes, Lupiáñez, & Milliken, 2007; Lupiáñez & Jesús Funes, 2005, for a discussion of possible mechanisms underlying the relationship between orienting and executive attention). With the long SOA, tonic (endogenous) alerting increased the accuracy of conflict resolution, while the positive impact of (exogenous) orienting had already faded.

3. Experiment 2

In Experiment 2, we used a task with three cue-target SOA intervals (100, 400, and 800 ms) to investigate whether the relation between alerting and executive attention is indeed limited to two phases, i.e., phasic and tonic alerting. According to our scenario, the same effects of tonic alerting on conflict resolution should be observed with the 400 ms as with the 800 ms SOA.

3.1. Method

3.1.1. Participants

Twenty-two undergraduate students (17 females) with average age of 21 years (*SD* = 2.3) took part in Experiment 2 in return for course credits. All participants had normal or corrected-to-normal vision and no history of neurological disorders. Written informed consent was obtained from the participants.

3.1.2. Stimuli and procedure

Two major changes with respect to E1 were introduced. First, only center cue and no cue conditions were included, while spatial cues were omitted. Second, three cue-target intervals (SOA) were used: 100, 400, and 800 ms (instead of previous 100 and 800 ms). The overall number of trials was 576, divided into 4 blocks of 144 trials each. On 1/4 of trials (144) no cue was presented, and on the remaining 3/4 of trials the center cue was presented with one of the three SOAs (144 trials per each SOA). The task lasted up to 1 h. All other parameters of the task, stimuli, and procedure were the same as in E1.

3.2. Results

Trials with errors and trials with RT below or above 3 *SD* were excluded from the RT analysis (overall 17%). The overall mean RT was 660 ms (*SD* = 61 ms), and the overall ERR mean was 13% (*SD* = 6%). Mean RT and ERR for each condition are shown in Table 1, and results of an omnibus ANOVA are shown in Table 2.

Indices of conflict effect (incongruent *minus* congruent flanker conditions) for each alerting cue condition are shown in Fig. 2. To evaluate the hypothesized effects of alerting on flanker conflict, 2 × 2 ANOVAs with alerting cue and flanker type were conducted separately for each SOA condition. With the 100 ms SOA, the flanker effect was larger in the alerting cue condition than in the no cue condition both for RT (by 24 ms): $F_{1,21} = 6.91$, $p = 0.016$, $\eta_p{}^2 = 0.25$, and for ERR (by 8%): $F_{1,22} = 24.77$, $p < 0.001$, $\eta_p{}^2 = 0.54$. With longer SOAs, a different pattern was obtained. With the 400 ms SOA, the center cue increased the flanker effect in the RT measurement (by 17 ms),

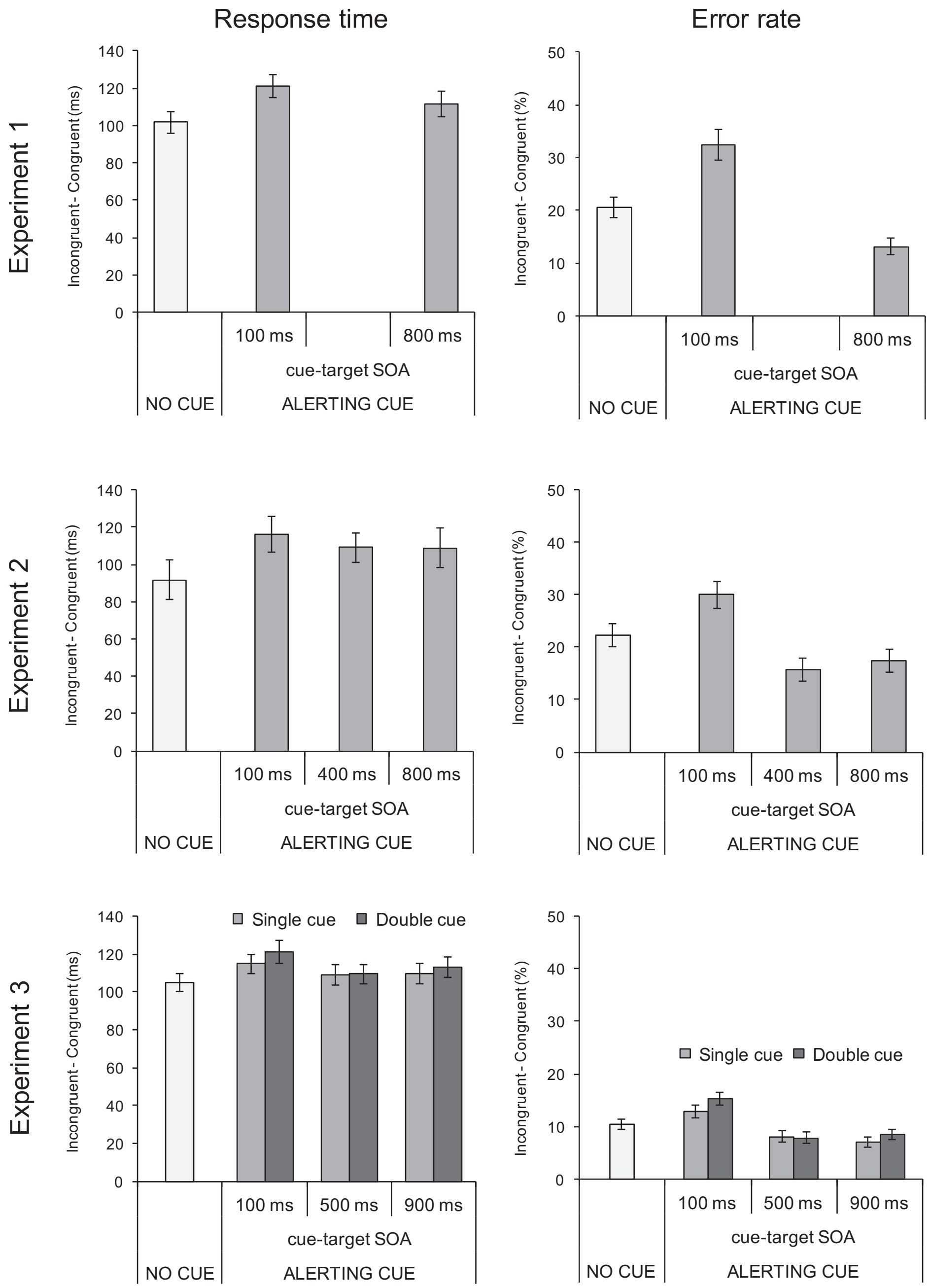

Fig. 2. Effects of alerting on conflict resolution. The bars represent conflict cost scores (incongruent flanker *minus* congruent flanker, with standard errors) for each alerting cue condition in Experiment 1 (upper panel), Experiment 2 (middle panel), and Experiment 3 (lower panel), calculated from response times (left panel) and error rates (right panel). The differences between the no cue condition and the conditions with alerting cues are interpreted as effects of alerting on conflict resolution.

$F_{1,21} = 7.36$, $p = 0.013$, $\eta_p^2 = 0.26$, but decreased the flanker effect in the ERR measurement (by 7%), $F_{1,21} = 5.85$, $p = 0.025$, $\eta_p^2 = 0.22$. Similarly, with the 800 ms SOA, the center cue increased the flanker effect in RT (by 17 ms), though this effect was only marginally significant, $F_{1,21} = 3.94$, $p = 0.060$, $\eta_p^2 = 0.16$. In ERR the center cue decreased the flanker effect (by 5%), $F_{1,21} = 9.85$, $p = 0.005$, $\eta_p^2 = 0.32$. The impact of alerting on flanker was therefore similar in both longer SOA conditions. To further evaluate this conclusion, we calculated a 2 × 2 ANOVA with flanker type (congruent, incongruent) and SOA (400 ms, 800 ms; only trials with the alerting cue were included, as no cue means no SOA between cue and targets). The analysis showed no significant difference between the two SOA conditions in terms of the alerting impact on flanker effects (SOA × flanker for RT and ERR: $F\text{s} < 1.0$).

3.3. Discussion

In Experiment 2, the time course of alerting influence on conflict resolution was further investigated by including three cue-target SOA intervals between cues and targets, 100, 400, and 800 ms. We assumed that in contrast with the short SOA, both longer SOAs would tap into the tonic alerting. Thus, the alerting was expected to decrease conflict with both longer SOAs.

The interaction between alerting and conflict resolution indeed had a similar pattern at the 400 ms and 800 ms SOA. This suggests that at 400 ms after the cue onset, tonic alerting may have already been developed and have influenced the conflict resolution in a similar way as at SOA 800 ms. Furthermore, the results obtained with the 100 ms SOA and the 800 ms SOA replicated the findings from Experiment 1. When SOA was 100 ms, alerting had a negative impact on conflict

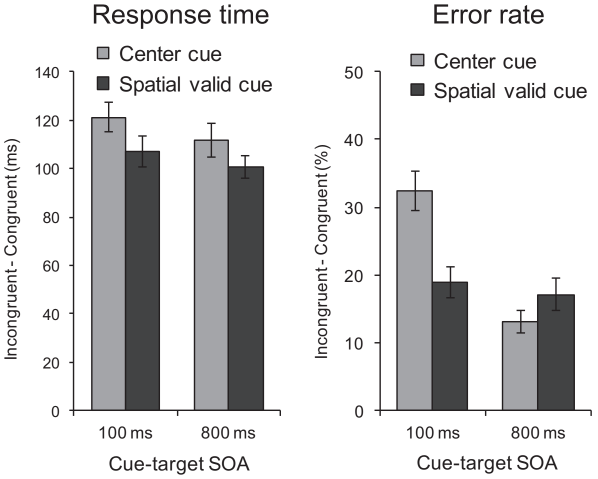

Fig. 3. Effects of orienting on conflict resolution in Experiment 1. The bars represent conflict cost scores (incongruent flanker *minus* congruent flanker, with standard errors) for the conditions with center cues and with spatial valid cues, calculated from response times (left panel) and error rates (right panel). The differences between the spatial valid cue and the center cue are interpreted as benefits (or costs) of orienting of attention to target location before the target onset.

resolution in both RT and ERR, whereas when SOA was 400 ms or 800 ms, a negative impact of alerting on conflict resolution in RT was accompanied by positive effects of alerting on conflict resolution in accuracy.

4. Experiment 3

The aim of Experiment 3 was to differentiate further between phasic and tonic alerting by manipulation of the psychophysical strength of alerting cues. Only the effects of phasic alerting were expected to increase with increased strength of alerting cues. In addition, we expected to replicate the findings of Experiment 1 and 2.

4.1. Method

4.1.1. Participants

Seventy-five undergraduate students (56 females) participated in the study in return for course credits. All participants had normal or corrected-to-normal vision and no history of neurological disorders. Written informed consent was obtained from the participants.

4.1.2. Stimuli and procedure

A similar task as in Experiment 2 was used, but with one major change: two types of alerting cue were employed. In 50% of alerting trials, a single center cue, identical to Experiments 1 and 2, was presented at the fixation point, whereas in the other 50% of alerting trials, a double cue was presented in the locations corresponding to target positions (as in the original ANT procedure; cf. Fan et al., 2002). In addition, in the present experiment, cue-target SOAs were 100, 500, or 900 ms, and the fixation-target eccentricity was decreased from 3.3° to 2.0°. The overall number of trials was 384, divided into 2 blocks of 192 trials each. On 1/4 of trials (96 trials) the cue was absent, and in the remaining 3/4 of trials, the alerting cue was presented (96 trials per each SOA). The cue was either single (center) or double (50/50), which yielded 48 trials with each type of cue per SOA. The task lasted up to 40 min. Other parameters of the task, stimuli, and procedure were identical to Experiment 2.

4.2. Results

Trials with errors and trials with RT of 3 SD above or below the mean were excluded from RT analyses (overall 8.5%). The overall mean RT of correct responses was 698 ms ($SD = 67$ ms). The overall ERR was 6.6% ($SD = 5\%$). Mean RT and ERR for each condition are shown in Table 1, and results of an omnibus ANOVA of these data are shown in Table 2. Indices of flanker conflict (incongruent *minus* congruent flanker conditions) for each alerting cue condition are presented in Fig. 2.

4.2.1. Single alerting cue vs. double alerting cue impact on flanker effect

The impact of the single (center) cue and double cue on flanker effect was evaluated with 3 × 2 ANOVA's with alerting cue (no cue, single cue, double cue) and flanker (congruent, incongruent), performed separately for each SOA condition. When the cue × flanker interactions were significant, they were followed by ANOVAs and *t*-tests on subsets of the data, according to the tested hypotheses.

4.2.1.1. SOA 100 ms. The flanker effect increased from the smallest in the no cue condition (105 ms), to intermediate in the single cue condition (115 ms), and to the largest in the double cue condition (121 ms), as indicated by the cue (no cue, single cue, double cue) × flanker interaction, $F_{2,148} = 5.32$, $p = 0.006$, $\eta_p{}^2 = 0.07$; as a linear trend: $F_{1,74} = 12.08$, $p = 0.001$, $\eta_p{}^2 = 0.14$. The same result was found for ERR: the flanker effect was 11% in the no cue condition, 13% in the single cue condition, and 15% in the double cue condition (cue × flanker interaction: $F_{2,148} = 12.15$, $p < 0.001$, $\eta_p{}^2 = 0.14$; as a linear trend: $F_{1,74} = 24.49$, $p < 0.001$, $\eta_p{}^2 = 0.25$).

Next, the impact of alerting on flanker effect was examined separately for the two types of cue, by 2 × 2 ANOVAs with cue (no cue, single cue; or no cue, double cue) and flanker (congruent, incongruent). For the single cue, the cue × flanker interaction was significant in RT, $F_{1,74} = 3.95$, $p = 0.05$, $\eta_p{}^2 = 0.05$, and ERR, $F_{1,74} = 5.84$, $p = 0.018$, $\eta_p{}^2 = 0.07$. For the double cue, this interaction was also significant in both RT, $F_{1,74} = 12.08$, $p = 0.001$, $\eta_p{}^2 = 0.14$, and ERR, $F_{1,74} = 24.49$, $p < 0.001$, $\eta_p{}^2 = 0.25$. Thus, in line with the first hypothesis, the alerting cues with the 100 ms SOA had a slightly negative impact on the conflict resolution, consistent with the results of Experiment 1 and 2. The second hypothesis predicted that with the 100 ms SOA, the alerting impact on flanker effect would be increased in the double cue condition, compared to the single cue condition. A significant interaction between cue (single, double) and flanker (congruent, incongruent) showed that the flanker effect was significantly larger in the double cue condition than in the single cue condition in ERR measurement, $F_{1,74} = 6.30$, $p = 0.014$, $\eta_p{}^2 = 0.08$, but not in RT, $F_{1,74} = 1.43$, $p = 0.23$, $\eta_p{}^2 = 0.02$.

4.2.1.2. SOA 500 ms. In RT measurement, the cue (no cue, single cue, double cue) × flanker (congruent, incongruent) interaction was not significant, $F < 1.0$, showing that alerting cues did not modulate the RT flanker effect, and that the single and double cues did not differ in their impact on conflict. However, in ERR measurement, the cue (no cue, single cue, double cue) × flanker (congruent, incongruent) interaction was significant, $F_{2,148} = 3.50$, $p = 0.033$, $\eta_p{}^2 = 0.04$. This interaction showed a decrease of the flanker effect (by 2.8%) when alerting cues were presented, compared to the no cue condition, which is consistent with the results of Experiments 1 and 2 (see Fig. 2). Further, there was no difference between the effects of single and double cues on the flanker effect, as indicated by a non-significant cue × flanker interaction with single and double cues (omitting the no cue condition), $F < 1.0$, n.s.

4.2.1.3. SOA 900 ms. The results obtained with the SOA 900 ms were very similar to the results obtained with the SOA 500 ms. In RT measurement, the cue (no cue, single cue, double cue) × flanker (congruent, incongruent) interaction was not significant, $F < 1.3$, whereas in ERR measurement this interaction was significant, $F_{2,148} = 7.68$, $p = 0.001$, $\eta_p^2 = 0.09$, reflecting a significant decrease of the ERR flanker effect with the alerting cues (by 2.7%, see Fig. 2). Again, no difference between the effects of single and double cues on the flanker effect was found, as shown by a non-significant cue × flanker interaction with single and double cues (omitting the no cue condition), $F = 2.0$, n.s.

4.3. Discussion

In Experiment 3, we aimed to differentiate further between the effects of phasic and tonic alerting on conflict resolution by manipulating the psychophysical strength of alerting cues (single vs. double cues). As in Experiments 1 and 2, we expected to capture the time course of the effects of alerting on conflict, and assumed that a 100 ms SOA would reflect phasic alerting effects, and a 500 ms and 900 ms SOA would reflect tonic alerting effects. Following the assumption that only phasic alerting is sensitive to stimulus physical properties, the impact of alerting on conflict was expected to increase with the double cues only in the SOA 100 condition.

The results showed that with the 100 ms SOA, the conflict effect was increased by alerting in both RT and ERR, as in E1 and E2. In addition, the predicted enhancement of the alerting impact on conflict with the double cue was observed, but only in ERR measurement. Still, a significant linear trend in the cue by flanker interaction was found for both ERR and RT, showing an increase of the conflict from the no cue, to center cue, and to double cue conditions, in line with the hypothesis. The two longer SOA conditions (500 and 900 ms) showed again a different pattern of results than the short SOA condition. The conflict effects measured in ERR were decreased with alerting cues, as in E1 and E2. However, in RT, no impact of alerting cues on conflict resolution was observed. This is inconsistent both with our initial hypothesis of decrease of conflict in RT with tonic alerting, and with the findings from E1 and E2 that show an increase of conflict in RT with tonic alerting. This discrepancy may be related to the lower task difficulty in E3 than in E1 and E2, due to the smaller fixation-target eccentricity, which might have influenced the dynamics of the interaction between alerting and conflict resolution (see General discussion for more details).[6] Finally, as expected, the results of E3 showed no difference between the effects of single and double cues on conflict at longer SOAs.

5. General discussion

5.1. Summary of results

We assumed that the time course of alerting could be differentiated in two phases: an initial phasic alerting followed by tonic alerting. Our predictions were: (1) phasic alerting (measured with a cue-target 100 ms SOA) was expected to increase flanker conflict; (2) tonic alerting (measured with a 400 ms SOA and longer) was expected to decrease flanker conflict; (3) phasic alerting effects on conflict were expected to increase with double cues, as compared to single cues (tested in Experiment 3).

The first prediction was confirmed in all three experiments (E1–3). Phasic alerting consistently increased the conflict costs in both response times and error rates. The results may reflect an inhibitory effect of phasic alerting on the executive network. Such an inhibitory modulation might presumably serve a function of redirecting the allocation of attentional resources, in order to prioritize processing and facilitate responding to external events (Callejas et al., 2005, 2004; Klein & Ivanoff, 2010; Petersen & Posner, 2012; Posner, 2008; Tang et al., 2012).

Regarding the second prediction, in the conditions with 400–900 ms of cue-target SOA, the conflict measured with ERR indices was consistently decreased by the alerting cues in all three experiments (E1, E2, E3). However, the conflict measured with RT indices was increased by the alerting cues in two experiments (E1, E2) and not affected in the third experiment (E3). In other words, in E1 and E2, tonic alerting increased the number of correct responses in conflict trials, but at the same time, it increased the processing/response time in these correct trials. In E3, tonic alerting also increased the number of correct responses in conflict trials, but did not affect the time of conflict processing. This pattern of results seems to indicate that tonic alerting may indeed improve the efficiency of conflict processing, but in a less straightforward way than we initially hypothesized. Namely, it is plausible that an increased readiness for stimulus processing results in more elaborated, deeper processing (cf. Craik & Lockhart, 1972), which takes more time, but leads to greater accuracy of conflict resolution (see E1 Discussion for more details). When the task was easier (E3), this slowing down might not have to be as substantial, resulting in the apparent lack of alerting impact on conflict in RT.

The third hypothesis was tested in E3 and found support in ERR measurement. The negative impact of phasic alerting (SOA 100 ms) on the accuracy of conflict resolution was increased with the double cues, compared to single cues. When tonic alerting was involved, no difference between the two types of alerting cue was found. This result does not yet allow for reliable conclusions, but it shows that the hypothesis might be worth further investigation. Especially, it needs to be determined whether the observed effect is indeed due to increased phasic alerting, since the double cues, as used in the present study, might also increase dispersal of spatial attention.

5.2. Present results vs. results of previous ANT studies

The pattern of the interaction between alerting and conflict was relatively consistent across the three experiments. However, it differs from a number of previous studies using the standard ANT (including our own unpublished ANT study with 190 participants, Marzecová & Asanowicz, 2012) and its modification called ANT-Interactions (ANTI, which employs auditory instead of visual alerting cues, Callejas et al., 2004; Callejas et al., 2005; Ishigami & Klein, 2010). Specifically, although 500 ms or longer cue-target SOA was used in those ANT and ANTI studies, the alerting cues still increased conflict cost in both RT and ERR (see Macleod et al., 2010 for the meta-analysis of ANT results).

Nevertheless, some ANT studies have reported findings that are consistent with the present account. For instance, in their study with 200 participants performing the standard ANT, Costa, Hernandez, and Sebastian-Galles (2008) found that alerting cues with 500 ms of cue-target SOA decreased conflict cost in both RT and ERR, compared to the no cue condition. The results from the standard ANT are therefore not entirely consistent. Furthermore, in several studies the ANT was slightly modified so that a target with flankers were presented only for 200 ms or less (instead of being presented until the response) and either peripheral eccentricity of the stimuli was increased (Asanowicz et al., 2012; Marzecová et al., 2013) or additional vigilance trials were added to the task (ANTI-Vigilance or ANTI-V; Roca, Castro, López-Ramón, & Lupiáñez, 2011). These changes considerably increased attentional demands of the tasks (Asanowicz et al., 2012; Roca et al., 2011) and led to three different patterns of the effects of alerting on conflict: 1) alerting on conflict effect was not significant in RT and ERR (Bukowski, Asanowicz, Marzecová, & Lupiáñez, 2015; Roca et al., 2011; Roca et al., 2012; Roca, Crundall, Moreno-Ríos,

---

[6] Also, a lower statistical power of E3 might be partially responsible: although a larger number of participants was tested, a smaller number of trials was utilized than in E1 and E2. Together with a smaller conflict effect (due to the lower task difficulty), this might have decreased the power of E3.

Castro, & Lupiáñez, 2013)[7]; 2) alerting decreased conflict cost in ERR with no effects in RT, resembling results of the present experiment 3 (Asanowicz et al., 2012; Marzecová et al., 2013; Roca, Lupiáñez, López-Ramón, & Castro, 2013); 3) alerting decreased conflict cost in ERR and increased in RT, resembling the results of the present experiments 1 and 2 (Tao, Marzecová, Taft, Asanowicz, & Wodniecka, 2011).[8] It is also worth mentioning that in a recent eye movement study, an alerting tone was found to both speed up saccades and enhance executive control (Tudge & Schubert, 2016; although it is possible that hand and eye movements are supervised by different control systems, Van der Stigchel, Meeter, & Theeuwes, 2007).

The reasons for these different patterns of the interaction between alerting and conflict are yet undetermined. One possible explanation hints at task difficulty. It has been suggested by Roca et al. (2011, 2012) that interactions between the attentional networks may depend on "*the specific requirements of the task, adjusting attentional control to the current demands*" and increased demands for attentional control may be responsible for the lack of alerting on conflict effects in the ANTI-V task (Roca et al., 2011, p.320). Indeed, in almost all of those studies with a non-standard ANT, in which different patterns of the interaction were observed, more attention-demanding tasks were used than in the standard ANT. Still, it remains unclear why and how this relationship may occur. We may speculate that when a task is easy, it can be performed very efficiently by one system in isolation and interactions with other systems may cause interference that reduces performance. This is like paying so much attention to riding a bicycle that it interferes with the ride. However, if a task is difficult, then any help from other systems may improve performance. Accordingly, in a very difficult task we should observe positive effects of tonic alerting on conflict in both ERR and RT.

To examine this latter case, we conducted an additional experiment (a detailed description is provided in Appendix B). The stimuli and procedure of the task were similar to Experiment 2, with two major changes. First, to ensure greater demands for attention, perceptual load was increased by presenting a target with flanker stimuli in one visual field simultaneously with a corresponding distractor set in the opposite visual field (five vertical lines without arrows that mirrored the target and flanker arrows; the procedure was adapted from the study by Evert et al. (2003). Second, only a 500 ms SOA was used so that tonic alerting was measured. The task proved to be demanding, as indicated by the overall ERR (22%) and RT (751 ms), which were markedly higher than in Experiment 1 and 2. Crucially, alerting significantly decreased the conflict effect in both RT and ERR, in line with the view proposed above. The result is not fully conclusive because the experiment did not compare different levels of task difficulty, but it suggests that the idea might hold true. In conclusion, task difficulty may be one of the factors determining the shape of interactions between attentional networks.

5.3. Other theoretical accounts of alerting effects on conflict resolution

In recent years, several other accounts of the negative impact of alerting on conflict resolution observed in ANT studies have been put forward. Nieuwenhuis and de Kleijn (2013) argue that alerting may decrease the efficiency of conflict resolution because alerting shortens overall RTs (cf. the early onset hypothesis, Hackley & Valle-Inclán, 1998), whereas executive control needs more time to fully develop and be applied over the course of a trial (cf. Fossella et al., 2002; Posner, 2008). Thus, the less time available for conflict processing, the less efficient the conflict resolution. However, Fischer, Plessow, and Kiesel (2010) provided evidence for an alternative account, emphasizing the facilitatory effect of alerting on the activation of stimulus-response links or response selection, which in turn increases the probability of activation and selection of incorrect responses in conflict trials (see Böckler, Alpay, & Stürmer, 2011; Fischer, Plessow, & Kiesel, 2012, for further evidence for this hypothesis). On the other hand, Weinbach and Henik (2012b) proposed that alerting may increase the flanker conflict effect, because alerting prioritizes processing of spatial information (or enhances global processing of visual stimuli, Weinbach & Henik, 2011), which comes at a cost when a task requires the filtering out of irrelevant spatial information, such as incongruent flankers surrounding the target.

Neither of these hypotheses, however, could explain the results of the present study, because they predict only negative effects of alerting cues on conflict resolution. Nonetheless, Weinbach & Henik's account might be in accord with our scenario. The hypothetical inhibitory effects of phasic alerting on conflict resolution, supposedly aiming to redirect the attentional resources to prioritize processing of incoming events (Petersen & Posner, 2012), may actually be a part of the process of prioritization of incoming spatial information through enhancement of global processing as proposed by Weinbach and Henik (2011, 2012b). Furthermore, a recent study by Weinbach and Henik (2013) differentiated between initial alerting/arousal, which corresponds to our phasic alerting, and temporal expectancy, which somewhat corresponds to our tonic alerting. Temporal expectancy was manipulated using a nonaging foreperiod distribution method (Niemi & Näätänen, 1981) that allows to control the predictability of targets presented with different foreperiod intervals (i.e., cue-target SOAs). In short, they showed that an initial alerting increased the RT flanker conflict effect, whereas temporal expectancy (target predictability) did not affect the conflict, which corresponds with the RT results of the present Experiment 3. Error rates were not reported in Weinbach and Henik's (2013) study, because the overall accuracy was at ceiling. We could thus speculate that if the task were more difficult, the lack of alerting on conflict effect in RT would be accompanied by a decreased conflict in ERR, as in the present Experiment 3. Therefore, despite some differences between the present study and that of Weinbach and Henik (2013), it seems that both the theoretical conceptualizations and the results of these two studies may generally be in agreement.

Another point to discuss concerns the generalization of the present results to different types of conflict tasks (see Egner, 2008 for a description of conflict paradigms). There is evidence that different conflict tasks involve at least partially different components of the executive network (Fan, Flombaum, McCandliss, Thomas, & Posner, 2003; Dosenbach et al., 2006; for review see Egner, 2008; Petersen & Posner, 2012). Moreover, it has been shown that alerting cues may yield task-specific effects on control processes. Soutschek, Müller, and Schubert (2013) found that, on one hand, in the Simon task, alerting cues increased conflict, but did not affect the process of post-conflict adjustments of executive control called conflict adaptation (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Gratton, Coles, & Donchin, 1992), while on the other hand, in the Stroop task, alerting cues did not increase conflict, but affected the conflict adaptation. Therefore, another question for future studies is whether the effects of phasic and tonic alerting on conflict resolution, as observed in the present study, are conflict-specific or rather domain-general phenomena.

5.4. Concluding remarks

The present study showed that phasic alerting consistently decreased the efficiency of conflict resolution in time and accuracy of

---

[7] In the study by Bukowski et al. (2015), an experience of uncontrollability was induced in four groups of participants. Here we refer only to the results from two control groups (with no uncontrollability manipulations).

[8] Tao et al. (2011) did not report the details of interactions between attentional networks, but we have reanalyzed the data from the whole sample ($N = 100$) for the purpose of the present study and have found significant interactions between alerting and flanker effect in both RT, $F_{1,99} = 15.32$, $p < 0.001$, $\eta_p^2 = 0.13$, and ERR, $F_{1,99} = 12.26$, $p = 0.001$, $\eta_p^2 = 0.11$, showing that alerting cues decreased the flanker conflict effect in ERR and increased it in RT.

responses, whereas tonic alerting increased the accuracy of conflict resolution, but at a cost in time of the conflict processing. The third experiment also showed that the effects of phasic alerting on conflict may be modulated by the psychophysical strength of alerting cues. The results seem to be in line with the suggested scenario assuming that phasic and tonic alerting may have, respectively, negative and positive effects on conflict resolution. Of note, these positive effects of tonic alerting are not as straightforward as we initially hypothesized. The proposed account and the obtained results are in disagreement with a number of previous ANT studies and other theoretical accounts of the interaction between alerting and conflict resolution. Since neither the present nor the other accounts could explain all of the results reported in the literature, it seems that these accounts can be seen as complementary rather than mutually exclusive alternatives.

Acknowledgments

D.A. was supported by Grant 2012/05/D/HS6/03363 from the National Science Centre of Poland, and A.M. was supported by the International Max Planck Research School on Neuroscience of Communication: Function, Structure, and Plasticity. The authors thank Juan Lupiáñez for his advice on this study, Kinga Wołoszyn for her contribution to the experiment with auditory alerting cues (Appendix A), and Diego Fernandez-Duque, the anonymous reviewer, and the editor Torsten Schubert for their constructive comments and suggestions.

Appendix A. Experiment with auditory alerting cues

A.1. Method

A.1.1. Participants

Thirty-four students (26 women) with average age of 21.3 years (*SD* = 2.7) took part in the experiment in return for course credits. All participants had normal or corrected-to-normal vision, and no history of neurological disorders. Written informed consent was obtained from the participants.

A.1.2. Stimuli and Procedure

The flanker arrow task was used, as in Experiments 1–3. The target and flankers were displayed horizontally, 2.6° above or below the fixation, so that the arrows pointed either left or right. Participants were asked to respond to the direction pointed to by the target arrow as quickly and as accurately as possible by pressing the left or right Ctrl key on the computer keyboard with their left or right hand, respectively. The task consisted of 640 trials (divided into 10 blocks). In half of the trials, a 2000 Hz 50 ms tone was presented as an alerting cue. The cue-target SOA was 100 ms, so that the effects of phasic alerting were measured.

A.1.3. Results

Trials with errors and trials with RT faster or slower than the 3rd *SD* (overall 10.2%) were excluded from RT analysis. The overall mean RT of correct responses was 523 ms (*SD* = 86 ms) and the overall mean ERR was 14% (*SD* = 5%). Mean RT and ERR for each task condition are shown in Table 3. The data were analyzed by means of a 2 × 2 repeated measure ANOVA with alerting cue (no cue, center cue) and flanker type (congruent, incongruent).

Table 3
Average response time of correct responses and average error rate for each condition of the additional experiment with auditory alerting cues (Appendix A).

Cue condition	Flanker type	RT (ms) mean (*SD*)	ERR (%) mean (*SD*)
Tone (SOA 100 ms)	Congruent	493 (52)	1.0 (1.2)
	Incongruent	604 (66)	13.9 (9.8)
No tone	Congruent	451 (51)	1.1 (1.4)
	Incongruent	580 (67)	18.4 (11.8)

The results showed that alerting cue decreased RT in average by 32 ms, $F_{1,33} = 191.23$, $p < 0.001$, $\eta_p^2 = 0.85$, and increased ERR by 2.3%, $F_{1,33} = 9.91$, $p = 0.003$, $\eta_p^2 = 0.23$. Importantly, the alerting cue facilitated RT in both the congruent (by 41 ms), $F_{1,33} = 252.68$, $p < 0.001$, $\eta_p^2 = 0.88$ and the incongruent flanker conditions (by 24 ms), $F_{1,33} = 42.41$, $p < 0.001$, $\eta_p^2 = 0.56$. The main effect of flanker conflict (incongruent vs. congruent) was also significant for RT, $F_{1,16} = 332.95$, $p < 0.001$, $\eta_p^2 = 0.91$, and ERR, $F_{1,33} = 86.64$, $p < 0.001$, $\eta_p^2 = 0.72$. Finally, the alerting cue × flanker interaction showed once again that alerting cues significantly increase the conflict effect in both RT (about 18 ms), $F_{1,33} = 17.52$, $p = 0.005$, $\eta_p^2 = 0.35$, and ERR (about 4%), $F_{1,33} = 8.30$, $p = 0.007$, $\eta_p^2 = 0.20$.

Appendix B. Experiment with increased attentional demands

B.1. Method

B.1.1. Participants

Seventeen undergraduate students (14 women) with average age of 21 years (*SD* = 0.8) took part in the experiment in return for course credits. All participants had normal or corrected-to-normal vision, and no history of neurological disorders. Written informed consent was obtained from the participants.

B.1.2. Stimuli and Procedure

Stimuli and procedure were identical to Experiment 2, except for two major changes. First, the cue-target SOA was 500 ms in all trials with alerting cue (50%), so that tonic alerting effects were measured. Second, to ensure larger attentional demands, perceptual load was increased by presenting distractors simultaneously with target and flankers. In detail, target with flanking stimuli were presented in one visual field, while a corresponding distractor set was simultaneously presented in the opposite visual field (see Evert et al., 2003, from which the procedure was adapted). The distractors consisted of five vertical lines without arrows that mirrored the target and flanker arrows.

B.1.3. Results

Trials with errors and trials with RT faster or slower than the 3rd *SD* (overall 25%) were excluded from RT analysis. The overall mean RT of correct responses was 751 ms ($SD = 142$ ms), and the overall ERR mean was 26% ($SD = 12\%$). Both, the RT and ERR were significantly larger than in Experiment 2 ($p < 0.001$). A 2 × 2 repeated measure ANOVA with alerting cue (no cue, center cue) and flanker type (congruent, incongruent) was performed. All effects were significant: the main effect of cue, RT: $F_{1,16} = 70.23$, $p < 0.001$, $\eta_p{}^2 = 0.81$, ERR: $F_{1,16} = 13.73$, $p < 0.001$, $\eta_p{}^2 = 0.46$, the main effect of flanker conflict, RT: $F_{1,16} = 54.60$, $p < 0.001$, $\eta_p{}^2 = 0.77$, ERR: $F_{1,16} = 184.58$, $p < 0.001$, $\eta_p{}^2 = 0.92$, and the alerting cue × flanker interaction. The interaction revealed that alerting cues significantly decreased the conflict effect (incongruent *minus* congruent flankers) in both, RT (about 46 ms), $F_{1,16} = 10.62$, $p = 0.005$, $\eta_p{}^2 = 0.40$, and ERR (about 12%), $F_{1,16} = 27.80$, $p < 0.001$, $\eta_p{}^2 = 0.63$.

References

Asanowicz, D., Marzecová, A., Jaśkowski, P., & Wolski, P. (2012). Hemispheric asymmetry in the efficiency of attentional networks. *Brain and Cognition*, *79*(2), 117–128.

Böckler, A., Alpay, G., & Stürmer, B. (2011). Accessory stimuli affect the emergence of conflict, not conflict control: A Simon-task ERP study. *Experimental Psychology*, *58*(2), 102–109.

Bogacz, R., & Gurney, K. (2007). The basal ganglia and cortex implement optimal decision making between alternative actions. *Neural Computation*, *19*(2), 442–477.

Bogacz, R., Wagenmakers, E. J., Forstmann, B. U., & Nieuwenhuis, S. (2010). The neural basis of the speed-accuracy tradeoff. *Trends in Cognitive Science*, *33*(1), 10–16.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review*, *108*(3), 624–652.

Boulinguez, P., Ballanger, B., Granjon, L., & Benraiss, A. (2009). The paradoxical effect of warning on reaction time: Demonstrating proactive response inhibition with event-related potentials. *Clinical Neurophysiology*, *120*(4), 730–737.

Bourne, V. J. (2006). The divided visual field paradigm: Methodological considerations. *Laterality*, *11*(4), 373–393.

Bukowski, M., Asanowicz, D., Marzecová, A., & Lupiáñez, J. (2015). Limits of control: The effects of uncontrollability experiences on the efficiency of attentional control. *Acta Psychologica*, *154*, 43–53.

Callejas, A., Lupiáñez, J., & Tudela, P. (2004). The three attentional networks: On their independence and interactions. *Brain and Cognition*, *54*(3), 225–227.

Callejas, A., Lupiáñez, J., Funes, M., & Tudela, P. (2005). Modulations among the alerting, orienting and executive control networks. *Experimental Brain Research*, *167*(1), 27–37.

Carrasco, M., Ling, S., & Read, S. (2004). Attention alters appearance. *Nature Neuroscience*, *7*(3), 308–313.

Carter, C. S., & Krug, M. K. (2012). Dynamic cognitive control and frontal-cingulate interactions. In M. I. Posner (Ed.), *Cognitive neuroscience of attention* (pp. 89–98). (2nd ed.). New York, London: Guilford Press.

Costa, A., Hernandez, M., & Sebastian-Galles, N. (2008). Bilingualism aids conflict resolution: Evidence from the ANT task. *Cognition*, *106*(1), 59–86.

Craik, F. I., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior*, *11*(6), 671–684.

Dosenbach, N. U., Visscher, K. M., Palmer, E. D., Miezin, F. M., Wenger, K. K., Kang, H. C., ... Petersen, S. E. (2006). A core system for the implementation of task sets. *Neuron*, *50*(5), 799–812.

Egner, T. (2008). Multiple conflict-driven control mechanisms in the human brain. *Trends in Cognitive Sciences*, *12*(10), 374–380.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics*, *16*(1), 143–149.

Evert, D. L., McGlinchey-Berroth, R., Verfaellie, M., & Milberg, W. P. (2003). Hemispheric asymmetries for selective attention apparent only with increased task demands in healthy participants. *Brain and Cognition*, *53*(1), 34–41.

Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience*, *14*(3), 340–347.

Fan, J., Flombaum, J., McCandliss, B., Thomas, K., & Posner, M. (2003). Cognitive and brain consequences of conflict. *NeuroImage*, *18*(1), 42–57.

Fan, J., McCandliss, B., Fossella, J., Flombaum, J., & Posner, M. (2005). The activation of attentional networks. *NeuroImage*, *26*(2), 471–479.

Fan, J., Kolster, R., Ghajar, J., Suh, M., Knight, R. T., Sarkar, R., & McCandliss, B. D. (2007). Response anticipation and response conflict: An event-related potential and functional magnetic resonance imaging study. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, *27*(9), 2272–2282.

Fan, J., Gu, X., Guise, K., Liu, X., Fossella, J., Wang, H., & Posner, M. (2009). Testing the behavioral interaction and integration of attentional networks. *Brain and Cognition*, *70*(2), 209–220.

Fernandez-Duque, D., & Posner, M. I. (1997). Relating the mechanisms of orienting and alerting. *Neuropsychologia*, *35*(4), 477–486.

Fernandez-Duque, D., & Posner, M. I. (2001). Brain imaging of attentional networks in normal and pathological states. *Journal of Clinical and Experimental Neuropsychology*, *23*(1), 74–93.

Fischer, R., Plessow, F., & Kiesel, A. (2010). Auditory warning signals affect mechanisms of response selection: Evidence from a Simon task. *Experimental Psychology*, *57*(2), 89–97.

Fischer, R., Plessow, F., & Kiesel, A. (2012). The effects of alerting signals in action control: Activation of S-R associations or inhibition of executive control processes? *Psychological Research*, *76*(3), 317–328.

Forster, K. I., & Forster, J. C. (2003). DMDX: A windows display program with millisecond accuracy. *Behavior Research Methods, Instruments, & Computers*, *35*(1), 116–124.

Fossella, J., Sommer, T., Fan, J., Wu, Y., Swanson, J., Pfaff, D., & Posner, M. (2002). Assessing the molecular genetics of attention networks. *BMC Neuroscience*, *3*(14).

Frank, M. J., Samanta, J., Moustafa, A. A., & Sherman, S. J. (2007). Hold your horses: Impulsivity, deep brain stimulation, and medication in parkinsonism. *Science*, *318*(5854), 1309–1312.

Funes, M. J., Lupiáñez, J., & Milliken, B. (2007). Separate mechanisms recruited by exogenous and endogenous spatial cues: Evidence from a spatial Stroop paradigm. *Journal of Experimental Psychology. Human Perception and Performance*, *33*(2), 348–362.

Gratton, G., Coles, M. G., & Donchin, E. (1992). Optimizing the use of information: Strategic control of activation of responses. *Journal of Experimental Psychology. General*, *121*(4), 480–506.

Hackley, S. A., & Valle-Inclán, F. (1998). Automatic alerting does not speed late motoric processes in a reaction-time task. *Nature*, *391*(6669), 786–788.

Hackley, S. A., Langner, R., Rolke, B., Erb, M., Grodd, W., & Ulrich, R. (2009). Separation of phasic arousal and expectancy effects in a speeded reaction time task via fMRI. *Psychophysiology*, *46*, 163–171.

Helton, W. S., Warm, J. S., Tripp, L. D., Matthews, G., Parasuraman, R., & Hancock, P. A. (2010). Cerebral lateralization of vigilance: A function of task difficulty. *Neuropsychologia*, *48*(6), 1683–1688.

Ishigami, Y., & Klein, R. M. (2010). Repeated measurement of the components of attention using two versions of the attention network test (ANT): Stability, isolability, robustness, and reliability. *Journal of Neuroscience Methods*, *190*(1), 117–128.

Klein, R. M., & Ivanoff, J. (2010). The components of visual attention and the ubiquitous Simon effect. *Acta Psychologica*, *136*(2), 225–234.

Lawrence, M. A., & Klein, R. M. (2012). Isolating exogenous and endogenous modes of temporal attention. *Journal of Experimental Psychology. General*, *142*(2), 560–572.

Lupiáñez, J. (2010). Inhibition of return. In A. C. Nobre, & J. T. Coull (Eds.), *Attention and time* (pp. 17–33). New York NY: Oxford University Press.

Lupiáñez, J., & Jesús Funes, M. (2005). Peripheral spatial cues modulate spatial congruency effects: Analysing the "locus" of the cueing modulation. *European Journal of Cognitive Psychology*, *17*(5), 727–752.

Lupiáñez, J., Milán, E. G., Tornay, F. J., Madrid, E., & Tudela, P. (1997). Does IOR occur in discrimination tasks? Yes, it does, but later. *Perception & Psychophysics*, *59*(8), 1241–1254.

Macleod, J. W., Lawrence, M. A., McConnell, M. M., Eskes, G. A., Klein, R. M., & Shore, D. I. (2010). Appraising the ANT: Psychometric and theoretical considerations of the attention network test. *Neuropsychology*, *24*(5), 637–651.

Marzecová, A., & Asanowicz, D. (2012, May). The relationship between alerting and executive attentional networks. *Paper presented at the joint meeting of the Belgian Psychological Society and the Sociedad Espanola de Psicologia Experimental (BAPS-SEPEX), Liège, Belgium*.

Marzecová, A., Asanowicz, D., Krivá, L., & Wodniecka, Z. (2013). The effects of bilingualism on efficiency and lateralization of attentional networks. *Bilingualism: Language and Cognition*, *16*(3), 608–623.

Niemi, P., & Näätänen, R. (1981). Foreperiod and simple reaction time. *Psychological Bulletin*, *89*(1), 133–162.

Nieuwenhuis, S., & de Kleijn, R. (2013). The impact of alertness on cognitive control. *Journal of Experimental Psychology. Human Perception and Performance*, *39*(6), 1797–1801.

Parasuraman, R. (1998). The attentive brain: Issues and prospects. In R. Parasuraman (Ed.), *The attentive brain* (pp. 3–15). Cambridge, MA: The MIT Press.

Périn, B., Godefroy, O., Fall, S., & de Marco, G. (2010). Alertness in young healthy subjects: An fMRI study of brain region interactivity enhanced by a warning signal. *Brain and Cognition*, *72*(2), 271–281.

Petersen, S. E., & Posner, M. I. (2012). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience*, *35*, 73–89.

Posner, M. I. (1978). *Mental chronometry. Chronometric explorations of mind*. Hillsdale, NJ: Erlbraum.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, *32*(1), 3–25.

Posner, M. I. (1994). Attention: The mechanisms of consciousness. *Proceedings of the National Academy of Sciences of the United States of America*, *91*(16), 7398–7403.

Posner, M. I. (2008). Measuring alertness. *Annals of the New York Academy of Sciences*, *1129*, 193–199.

Posner, M. I. (2012). Progress in attention research 2004–2011. In M. I. Posner (Ed.), *Cognitive neuroscience of attention* (pp. 1–10). (2nd ed.). New York, London: Guilford Press.

Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. Components of visual orienting. In H. Bouma, & D. G. Bouwhuis (Eds.), *Attention and performance X* (pp. 531–556). Hillsdale, NJ: Erlbaum.

Posner, M. I., & Fan, J. (2008). Attention as an organ system. In J. R. Pomerantz (Ed.), *Topics in integrative neuroscience: From cells to cognition* (pp. 31–61). New York: Cambridge University Press.

Posner, M. I., & Petersen, S. (1990). The attention system of the human brain. *Annual Review of Neuroscience*, *13*, 25–42.

Posner, M. I., & Rothbart, M. K. (2007). Research on attention networks as a model for the integration of psychological science. *Annual Review of Psychology*, *58*, 1–23.

Prinzmetal, W., McCool, C., & Park, S. (2005). Attention: Reaction time and accuracy reveal different mechanisms. *Journal of Experimental Psychology. General*, *134*(1), 73–92.

Ridderinkhof, K. R. (2002). Micro- and macro-adjustments of task set: Activation and suppression in conflict tasks. *Psychological Research*, *66*(4), 312–323.

Ridderinkhof, R. K., van den Wildenberg, W. P. M., & Wylie, S. A. (2012). Action control in times of conflict. Analysis of reaction time distributions in healthy and clinical populations. In M. I. Posner (Ed.), *Cognitive neuroscience of attention* (pp. 409–420). (2nd ed.). New York, London: Guilford Press.

Robertson, I. H. (2004). Examining attentional rehabilitation. In M. I. Posner (Ed.), *Cognitive neuroscience of attention* (pp. 407–419). NY: The Guilford Press.

Robertson, I. H., & O'Connell, R. (2010). Vigilant attention. In A. C. Nobre, & J. T. Coull (Eds.), *Attention and time* (pp. 79–88). New York NY: Oxford University Press.

Roca, J., Castro, C., López-Ramón, M. F., & Lupiáñez, J. (2011). Measuring vigilance while assessing the functioning of the three attentional networks: The anti-vigilance task. *Journal of Neuroscience Methods*, *198*(2), 312–324.

Roca, J., Fuentes, L. J., Marotta, A., López-Ramón, M. F., Castro, C., Lupiáñez, J., & Martella, D. (2012). The effects of sleep deprivation on the attentional functions and vigilance. *Acta Psychologica*, *140*(2), 164–176.

Roca, J., Crundall, D., Moreno-Ríos, S., Castro, C., & Lupiáñez, J. (2013a). The influence of differences in the functioning of the neurocognitive attentional networks on drivers' performance. *Accident Analysis and Prevention*, *50*, 1193–1206.

Roca, J., Lupiáñez, J., López-Ramón, M., & Castro, C. (2013b). Are drivers' attentional lapses associated with the functioning of the neurocognitive attentional networks and with cognitive failure in everyday life? *Transportation Research Part F: Traffic Psychology and Behaviour*, *17*, 98–113.

Schröger, E., Marzecová, A., & SanMiguel, I. (2015). Attention and prediction in human audition: A lesson from cognitive psychophysiology. *The European Journal of Neuroscience*, *41*(5), 641–664.

See, J. E., Howe, S. R., Warm, J. S., & Dember, W. N. (1995). Meta-analysis of the sensitivity decrement in vigilance. *Psychological Bulletin*, *117*(2), 230–249.

Shulman, G. L., & Corbetta, M. (2012). Two attentional networks. Identification and function within a larger cognitive architecture. In M. I. Posner (Ed.), *Cognitive neuroscience of attention* (pp. 113–128). (2nd ed.). New York, London: Guilford Press.

Soutschek, A., Müller, H. J., & Schubert, T. (2013). Conflict-specific effects of accessory stimuli on cognitive control in the Stroop task and the Simon task. *Experimental Psychology*, *60*(2), 140–147.

Summerfield, C., & Egner, T. (2009). Expectation (and attention) in visual cognition. *Trends in Cognitive Sciences*, *13*(9), 403–409.

Tang, Y. Y., Rothbart, M. K., & Posner, M. I. (2012). Neural correlates of establishing, maintaining, and switching brain states. *Trends in Cognitive Sciences*, *16*(6), 330–337.

Tao, L., Marzecová, A., Taft, M., Asanowicz, D., & Wodniecka, Z. (2011). The efficiency of attentional networks in early and late bilinguals: The role of age of acquisition. *Frontiers in Psychology*, *2*(123), 1–19.

Tudge, L., & Schubert, T. (2016). Accessory stimuli speed reaction times and reduce distraction in a target-distractor task. *Journal of Vision*, *16*(7), 1–11.

Van der Stigchel, S., Meeter, M., & Theeuwes, J. (2007). Top-down influences make saccades deviate away: The case of endogenous cues. *Acta Psychologica*, *125*(3), 279–290.

Verleger, R., Sprenger, A., Gebauer, S., Fritzmannova, M., Friedrich, M., Kraft, S., & Jaśkowski, P. (2009). On why left events are the right ones: Neural mechanisms underlying the left-hemifield advantage in rapid serial visual presentation. *Journal of Cognitive Neuroscience*, *21*(3), 474–488.

Weinbach, & Henik (2011). Phasic alertness can modulate executive control by enhancing global processing of visual stimuli. *Cognition*, *121*(3), 454–458.

Weinbach, N., & Henik, A. (2012a). Temporal orienting and alerting — The same or different? *Frontiers in Psychology*, *3*(236), 1–3.

Weinbach, N., & Henik, A. (2012b). The relationship between alertness and executive control. *Journal of Experimental Psychology. Human Perception and Performance*, *38*(6), 1530–1540.

Weinbach, N., & Henik, A. (2013). The interaction between alerting and executive control: Dissociating phasic arousal and temporal expectancy. *Attention, Perception & Psychophysics*, *75*(7), 1374–1381.

Wright, R. D., & Ward, L. M. (2008). *Orienting of attention*. New York NY: Oxford University Press.