ORIGINAL ARTICLE

The effects of alerting signals in action control: activation of S–R associations or inhibition of executive control processes?

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Abstract Non-informative, task-irrelevant auditory alerting signals often lead to increased interference effects in selective attention paradigms (e.g., Simon, Eriksen flanker). Some authors conclude that the alerting attentional network, activated by the alerting signal, reveals an inhibitory influence upon the executive attentional network, resulting in attenuated executive control. Alternatively, in the present study we argue that increased interference effects might be explained by alerting signals facilitating response activation processes (i.e., the activation of established S–R links). In a modified Eriksen-flanker paradigm, we contrasted these assumptions. We used word flanker stimuli for which S–R associations were established and word flanker stimuli without S–R associations. The presence of an alerting signal increased flanker compatibility only for flanker stimuli for which S–R associations existed while flanker compatibility effects were the same for all flanker types in conditions without alerting signals. Therefore, we conclude that alerting signals enhance stimulus triggered visuo-motor response activation processes.

Introduction

The execution of simple motor responses to visual stimuli has been shown to be speeded in the presence of a task-irrelevant auditory alerting signal (AS) that appears in close temporal proximity to the imperative stimulus (Niemi & Näätänen, 1981). Several accounts have been proposed to explain typical AS effects (for an overview see Jepma, Wagenmakers, Band, & Nieuwenhuis, 2009). Alerting signals have been found to facilitate early perceptual encoding processes (Bernstein, Rose, & Ashe, 1970; Correa, Lupiáñez, Madrid, & Tudela, 2006; Rolke & Hofmann, 2007) and/or late motor execution processes such as response force (Kiesel & Miller, 2007; Stahl & Rammsayer, 2005, Ulrich & Mattes, 1996) or motor reflexes (Low, Larson, Burke, & Hackley, 1996). Recent accounts suggested a response-selection locus of alerting signal effects (Fischer, Schubert, & Liepelt, 2007; Müller-Gethmann, Ulrich, & Rinkenauer, 2003; Stoffels, van der Molen, & Keuss, 1985).

Hackley and Valle-Inclán (1998, 1999), for example, recorded the lateralized readiness potential (LRP) that is extracted from event-related potentials (ERP). The LRP is considered to reflect movement-related brain activity measured over the lateralized motor cortices (e.g., Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988; Miller & Hackley, 1992). The LRP has often been used to study processes of response activation and response preparation (e.g., Leuthold, Sommer, & Ulrich, 1996; Osman & Moore, 1993; Osman, Moore, & Ulrich, 1995; Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002). In this respect, Hackley & Valle-Inclán (1998, 1999) demonstrated an alerting-signal-based shortening of the time interval between stimulus presentation and the onset of the LRP (stimulus-locked), whereas the time interval between the onset of the LRP and the response execution (response-locked) was not affected by an alerting signal. Hackley and Valle-Inclán (2003) interpret this finding as evidence that alerting signals facilitate early processes of response

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selection. This view is reflected in typical accumulation models (Logan & Gordon, 2001; Ratcliff & McKoon, 1988), which assume that alerting signals result in increased/faster accumulation of evidence in each response counter (Coles, Gratton, Bashore, Eriksen, & Donchin, 1985) or which alternatively assume that alerting signals nonspecifically reduce the decision criterion. Such accumulations models are corroborated by the finding that alerting signals in speeded responses are often associated with the cost of increased error rates (e.g., Posner, 1978).

Although research has advanced in determining the specific components of information processing that are affected by alerting signals, the question about the consequences of alerting signal effects especially on mechanisms of response selection and action control in general has only recently attracted attention. In particular, a number of studies reported not only the typical general speeding of responses but also alerting-signal-based increased interference effects in response-conflict tasks (Böckler, Alpay, & Stürmer, 2011; Callejas, Lupiáñez, Funes, & Tudela, 2005; Callejas, Lupiáñez, & Tudela, 2004; Fan, McCandliss, Sommer, Raz, & Posner, 2002; Fischer, Plessow, & Kiesel, 2010, Fischer et al., 2007).

Fischer, et al. (2007), for example, presented alerting signals in a subliminal priming paradigm. Participants responded to left- and right-pointing target arrows that were preceded by subliminal prime arrows. The prime arrow is assumed to trigger visuo-motor response-activation processes that facilitate target-related response activation in congruent conditions (i.e., faster responses when arrows point into the same direction) but produce costs in incongruent conditions (slower responses when arrows point into opposite directions) (e.g., Dehaene et al., 1998; Neumann & Klotz, 1994; Vorberg, Mattler, Heinecke, Schmidt, & Schwarzbach 2003). Fischer et al. investigated whether and how alerting signals influence prime-stimulus and target-stimulus related visuo-motor response-activation processes. Importantly, the presence of an alerting signal substantially increased the effects of the prime stimulus on target response selection, suggesting that the prime-triggered accumulation of response activation was enhanced by the presence of a task-irrelevant alerting signal.

In a related study, we extended these findings by investigating the influence of an alerting signal on the simultaneous processing of goal-relevant and goal-irrelevant stimulus information (Fischer et al., 2010). We used a Simon task (Simon, 1990) in which participants responded with left or right key presses to the identity of a stimulus that was presented to the left or to the right of central fixation. Responses were faster when the irrelevant stimulus location corresponded spatially with the location of the required response (compatible condition) than when stimulus location and response location did not correspond (incompatible condition). Importantly, we found that this Simon effect was increased by the presentation of an alerting signal. That is, the alerting signals amplified the activation of spatially corresponding response alternatives, resulting in faster responses in compatible trials and in slower responses in incompatible trials. Therefore, we assumed that alerting signals facilitate bottom-up response-activation processes by activating S–R associations.

A first direct test of this assumption has been put forward in a recent study that assessed the LRP in a vertical Simon task in order to investigate the influence of an alerting signal on competing response activation processes (Böckler et al., 2011). Böckler et al. (2011) showed that alerting signals increased the Simon effect. In addition, the presence of an alerting signal (compared to trials without an alerting signal) increased the amplitude of the LRP related to the incorrect response in incompatible Simon trials. This is direct evidence that alerting signals increase visuo-motor response activation and therewith hinder responding in incompatible trials. Based on these findings we call this assumption the *facilitated response activation account* of alerting signals.

Yet, there is an alternative to account for increased interference effects after alerting signals. Incorrect response activation due to alerting signals might be a mere consequence of reduced executive functioning. The idea that alerting signals have a negative impact on executive functioning has been put forward by Callejas and colleagues (e.g., Callejas et al., 2004, 2005; see also Fan et al., 2002). Their explanation is based on research on different attentional networks such as the alerting, orienting, and the executive control network of attention (e.g., Posner & Boies, 1971; Posner & Peterson, 1990; see Raz & Buhle, 2006 for an overview). Callejas et al. (2005) modified the original Attentional Network Task (ANT) to specifically investigate modulations and interactions between the attentional networks. They found increased interference effects in a selective attention task in conditions with an auditory alerting signal compared to conditions without an alerting signal (Callejas et al., 2004, 2005). The authors reason, however, that the alerting signal enhances arousal and activates the alerting network, which in turn inhibits the executive control network and, thus, reduces the efficiency of executive control mechanisms. It is plausible to assume that alerting-signal-based hampered executive control mechanisms result in increased interference effects. Therefore, we call this the *attenuated executive control account* of alerting signals.

The aim of the present study is to directly test these two accounts on how alerting signals increase response conflict. If alerting signals facilitate the activation of established links between specific stimulus codes and response codes (facilitated response activation account), alerting signal

effects should be restricted to conditions in which those links between stimulus and response codes exist (e.g., established S–R associations). Consequently, effects based on distracter stimuli that bear no direct associations between stimulus and response codes, should not be modulated by the presence of alerting signals. If on the other hand, alerting signals reduce the efficiency of the executive control network (attenuated executive control), alerting-signal-based increments in interference effects should be verifiable also for interfering stimulus dimensions that do not contain S–R associations.

Experiment 1

To pursue this aim, we used a version of the Eriksen-flanker paradigm (Eriksen & Schultz, 1979). In the original Eriksen-flanker task, participants respond to a central target letter either with a left response (e.g., for letters H and K) or with a right response (e.g., for letters C and S). The target letter is accompanied by irrelevant distracter letters displayed to the left or to the right of the target (Eriksen & Eriksen, 1974). Responses are faster and more accurate when both target and distracter letters activate the same response, than in conditions in which they activate competing responses. This flanker-compatibility effect has been demonstrated for flankers that serve as targets and for flankers that belong to the same category as targets. Consequently, the flanker-compatibility effect may result from acquired/direct S–R associations and/or from the extraction of semantic information from the irrelevant flanker words in parallel to target processing, which results in response competition (Eriksen, 1995). The assumption of direct S–R association holds that responding to target stimuli results in sensori-motor learning of stimuli mapped onto specific responses. Response competition arises because irrelevant flanker stimuli lead to automatic response-activation processes that run in parallel to that triggered by target stimuli (e.g., Coles et al., 1985; Eriksen, Coles, Morris, & O'Hara, 1985; Eriksen & Schultz, 1979; Heil, Osman, Wiegelmann, Rolke, & Hennighausen, 2000; Sanders & Lamers, 2002; see Magen & Cohen, 2002, and Mattler, 2005, for a discussion of stimulus-identification and response-selection mechanisms of flanker interference effects).

In the present study, however, we specifically implemented a modified Eriksen-flanker paradigm that allowed distinguishing flanker effects revealed by stimulus features that contained or did not contain S–R associations. We used a word-flanker version of the Eriksen-flanker task that in the past has successfully induced compatibility effects (see Fischer & Schubert, 2008). In particular, participants categorized target words as either "pleasant" or "unpleasant" in the presence of distracting pleasant or unpleasant flanker words presented above and below the target word. In contrast to the traditional Eriksen-flanker task, categories of items instead of individual items are assigned to a certain response. Responses are assumed to be faster when the valence category of target and flanker correspond (e.g., to kiss, to dance) than when the valence category does not correspond (e.g., to kiss, to kill) denoting the valence-flanker effect.

Previous studies have successfully demonstrated that semantic information extracted from irrelevant flankers interferes with simultaneous target processing. Shaffer and LaBerge (1979, Experiment 2), for example, used an Eriksen-flanker task with word stimuli and additionally included a non-word flanker condition. This allowed them to distinguish between the facilitation and the interference component of the flanker effect. They showed that irrelevant flanker words resulted in a significant 31 ms response slowing compared to a neutral non-word flanker condition, which they interpreted as flanker interference effect, probably arising at categorization and/or response selection stages. At the same time, they did not find a significant facilitation effect for flanker items that matched the target category compared to the neutral condition. Thus, we expect word-flanker effects in the valence-categorization task to mainly reflect flanker interference effect (see "General discussion" for a more elaborate discussion).

Importantly, we used two types of flanker stimuli in our valence-categorization task. Target flankers were flanker words that also served as target stimuli and therefore, were overtly categorized (as either pleasant vs. unpleasant) and responded to by participants. There are at least two possibilities (that are not mutually exclusive) of how interference by target flankers can arise. First, the meaning of the flanker word is semantically analyzed and thus, can match or mismatch with the semantic analysis of the target word. Second, flanker words are processed on a sub-semantic level based on visuo-motor associations (e.g., Neumann & Klotz, 1994). In this respect, Abrams, Klinger, and Greenwald (2002), for example, distinguished between a word-to-category mapping (seen as example of accessing semantic memory information) and word-to-response-mapping (seen as accessing over-learned S–R links). In a word-to-category mapping, stimuli are assumed to be semantically analyzed. The analysis of the word meaning activates the semantic category that is assigned to a pre-specified response. Thus, in the word flanker task, flanker interference arises most likely due to the simultaneous activation of different semantic categories and/or at the response selection level when the activated categories are assigned to competing responses (cf. Shaffer & LaBerge, 1979).

The alternative second assumption, the word-to-response mapping, holds that the semantic processing of the flanker word is bypassed by direct associations of the word with the response. In this view, flanker effects occur without deep semantic analysis of the flanker word (or at least in addition to semantic analysis). Especially the repeated presentation of target words (and the responses carried out to them) might lead to sensori-motor learning in the way that participants map low level visual stimulus features (e.g., visual word fragments) onto the appropriate response. Visual and response features are both integrated into a shared episode (e.g., Abrams & Greenwald, 2000; Kiesel, Wendt, & Peters, 2007; Logan, 1988; Wendt & Kiesel, 2008). The automatic retrieval of recent episodes can prime previously associated responses (Waszak & Hommel, 2007). In other words, the presentation of flanker stimuli that contain specific associations between stimulus codes and response codes (target flanker) result in the activation of the corresponding motor response by low-level visual stimulus features without detailed semantic processing, which has also been termed direct motor specification (Neumann & Klotz, 1994; see also Damian, 2001).

Category flanker, on the other hand, represent words that never appeared as targets. This manipulation ensured that flanker effects revealed by category-flanker stimuli cannot be based on sensori-motor learning because participants never responded to these words. This in fact eliminates the possibility of establishing associations between a specific stimulus and the execution of a particular response. Therefore, any influence on target categorization revealed by category flanker is assumed to be due to the activation of the semantic content of the flanker word and thus, represents a pure word-to-category mapping (e.g., Abrams et al., 2002; Fischer & Schubert, 2008).

Method

Participants

In the study, 20 students of the Technische Universität Dresden (10 males, mean age 22.1 years) participated. All participants had normal or corrected-to-normal vision.

Stimuli and apparatus

Stimuli were presented in white against a black background on a 15-inch monitor. The alerting signal was a 700 Hz sinus tone that lasted 150 ms (abrupt onset and offset). The tone was presented binaurally via headphones ($\sim$ 50 dB). At a viewing distance of 60 cm, target and flanker words subtended a visual angle of about 3.15° horizontally.

Flanker words above or below the target resulted in a vertical extension of about 2.29°. Participants responded with the left index finger (Alt key) to unpleasant target words and with the right index finger (Alt Gr key), to pleasant target words on a standard QWERTZ keyboard. Stimulus presentation and data recording were realized using Presentation software (Version 0.71, Neurobehavioral Systems).

Procedure

Participants performed a modified Eriksen-flanker valence-categorization task (Fischer & Schubert, 2008). For this, participants responded with their left and right index finger to centrally presented target words according to their emotional connotation (i.e., pleasant vs. unpleasant). In addition to the target word, irrelevant flanker words were displayed above and below the target. Both flanker words were identical in an individual trial, thus, flanker words were either pleasant or unpleasant. A list of ten pleasant and ten unpleasant German verbs (e.g., "to kiss" versus "to kill") served as stimulus material (Table 1; see also Fischer & Schubert, 2008). Target and flanker words formed a compatible relation when both matched the response category "pleasant" or the response category "unpleasant". In an incompatible condition, target and flanker categories mismatched.

In each block, each target stimulus (10 pleasant, 10 unpleasant) was presented four times resulting in 80 trials per block. We used two types of flanker stimulus. Target flankers were words that were randomly taken (without replacement) from the list of the pleasant or unpleasant target stimuli within each block. Thus, each target flanker was randomly paired three times with a target stimulus amounting to sixty target flanker trials per block (75% of trials). The remaining 20 trials in a block (25% of trials) were composed of category flanker. These were the words "positive" and "negative", representing the response categories "pleasant" versus "unpleasant" but were never presented as targets. The experiment consisted of six blocks amounting to a total of 480 trials.

A trial started with the presentation of a plus sign that served as fixation. It was presented in steps of 100 ms randomly between 1,100 and 2,000 ms. The offset of the plus sign was immediately followed by the onset of two flanker words (above and below the central location of the plus sign). The target word was presented in central location 85 ms after the onset of the flanker words. Flankers and targets were shown for a maximum of 385 ms and 300 ms, respectively. If a response exceeded 1,800 ms (beginning at target onset) the feedback "too slow" was presented, in case of a wrong response the word "false" was presented as visual feedback for 300 ms. A correct

Table 1 List of words that served as targets and as flankers for Experiment 1 and Experiment 2 according to flanker type

Flanker type	Experiment 1	Experiment 2
Targets and target flankers	Leben–live	Leben–live
	Blühen–blossom	Blühen–blossom
	Tanzen–dance	Tanzen–dance
	Heilen–heal	Heilen–heal
	Funkeln–sparkle	Funkeln–sparkle
	Schmusen–caress	Schmusen–caress
	Duften–smell	
	Flirten–flirt	
	Küssen–kiss	
	Schenken–present	
	Töten–kill	Töten–kill
	Hassen–hate	Hassen–hate
	Lügen–lie	Lügen–lie
	Foltern–torture	Foltern–torture
	Beissen–bite	Beissen–bite
	Schreien–cry	Schreien–cry
	Drohen–threaten	
	Frieren–freeze	
	Kotzen–throw up	
	Schlagen–beat	
Category flankers	Positiv–positive	Positiv–positive
	Negativ–negative	Negativ–negative
Non-target flankers		Duften–smell
		Flirten–flirt
		Küssen–kiss
		Schenken–present
		Drohen–threaten
		Frieren–freeze
		Kotzen–throw up
		Schlagen–beat

response was followed by the fixation stimulus for another 300 ms. In half of the trials an alerting signal (150 ms) was presented 250 ms prior to flanker onset. The variable fixation interval served to increase the effects of the alerting signal (e.g., Müller-Gethmann et al., 2003). Participants were instructed that the tone is completely task-irrelevant and therefore, can be ignored. Prior to the experiment participants completed 16 trials of practice.

Data analysis

Repeated measures ANOVAs on error rates and mean response times included the factors Alerting signal (AS vs. no AS), Flanker type (Target flanker vs. Category flanker), Flanker Compatibility (compatible vs. incompatible), and Target valence (unpleasant vs. pleasant).

Results

To avoid effect of perceptual matching of target and flanker stimuli, trials in which the flanker stimulus was identical to the target stimulus (3.8%) were excluded from the analyses. Furthermore, post-error trials (5.3%) were eliminated. For response time (RT) analysis only, error trials (5.3%) as well as RT differing more than three standard deviations from the mean RT of each participant and factorial combination (1.8%) were also excluded. Results are presented in Fig. 1 and in Table 2.

Response times

RTs were affected by Flanker compatibility with faster responses in compatible trials than in incompatible trials denoting a reliable valence-flanker effect, $F(1, 19) = 18.24$, $p < 0.001$, $\eta_p^2 = 0.49$. Important for the aim of the present study, the presence of an alerting signal not only speeded responses in general, $F(1, 19) = 11.24$, $p < 0.01$, $\eta_p^2 = 0.37$, but in addition, differentially affected the valence-flanker effect for target and for category flanker, respectively. This was indicated by the significant interaction between Alerting signal X Flanker type X Flanker compatibility, $F(1, 19) = 6.86$, $p < 0.05$, $\eta_p^2 = 0.27$. Separate ANOVAs on RTs for each flanker type confirmed an increased valence-flanker effect in conditions with an AS, 31 ms, $t(19) = 5.71$, $p < 0.001$ compared to conditions without an alerting signal, 13 ms, $t(19) = 2.29$, $p < 0.05$, for target flanker only, $F(1, 19) = 10.28$, $p < 0.01$, $\eta_p^2 = 0.35$. At the same time the valence-flanker effect for category flanker was similar with (14 ms), $t(19) = 2.26$, $p < 0.05$, and without, (14 ms), $t(19) = 2.46$, $p < 0.05$, an alerting signal, $F < 1$. Furthermore, for trials without an alerting signal the size of valence-flanker effect was similar for target and category flankers, $F < 1$.

Furthermore, the valence-flanker effect was larger for unpleasant targets (24 ms) than for pleasant targets (13 ms), $F(1, 19) = 11.89$, $p < 0.01$, $\eta_p^2 = 0.39$. Also, we found an interaction between all four factors, $F(1, 19) = 4.38$, $p = 0.05$, $\eta_p^2 = 0.19$. In the separate analyses for target and category flankers, the interaction between AS X flanker compatibility X target valence was not significant for either, target or category flankers, $F < 1$ and $F(1, 19) = 1.87$, $p = 0.19$, $\eta_p^2 = 0.09$, respectively.

Error rates

An alerting signal did not affect error rates, $F < 1$, ruling out the possibility of a speed-accuracy trade-off. In addition, more errors occurred for target flankers (6.1%) than for category flankers (4.6%), $F(1, 19) = 4.68$, $p < 0.05$, $\eta_p^2 = 0.20$. A significant valence-flanker effect was also
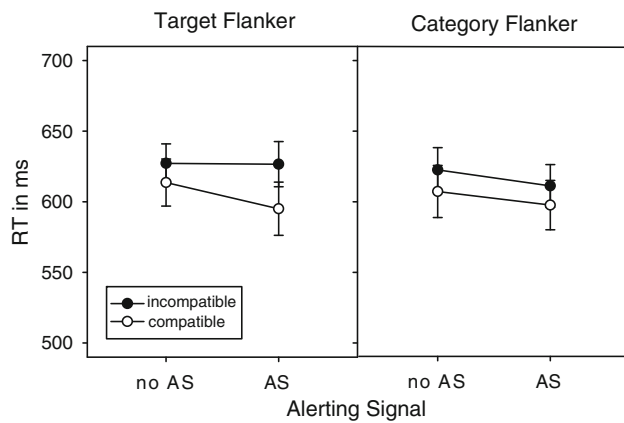
Fig. 1 Response times (RT) in Experiment 1 as a function of alerting signal (AS) for Target Flankers and Category Flankers, respectively. *Error bars* represent standard errors of the mean

found in the error data, $F(1, 19) = 12.78$, $p < 0.01$, $\eta_p^2 = 0.40$. We observed more errors in incompatible (6.8%) than in compatible trials (4.0%). Alerting signals increased the valence-flanker effect in error rates, $F(1, 19) = 6.89$, $p < 0.05$, $\eta_p^2 = 0.27$. The three-way interaction between Alerting signal X Flanker type X Flanker compatibility, however, was not significant, $F < 1$. Yet, to rule out opposing results than in RT analyses, we conducted separate ANOVAs for each flanker type. Alerting signals tended to increase the valence-flanker effect for trials with target flanker, $F(1, 19) = 4.19$, $p = 0.055$, $\eta_p^2 = 0.18$, but not for trials with category flanker, $F(1, 19) = 2.23$, $p = 0.152$, $\eta_p^2 = 0.11$ (see also Table 2). Further results include a trend towards more errors being committed for pleasant targets (6.1%) than for unpleasant targets (4.6%), $F(1, 19) = 4.20$, $p = 0.054$, $\eta_p^2 = 0.18$, as well as an interaction between all four factors, $F(1, 19) = 4.37$, $p = 0.05$, $\eta_p^2 = 0.19$. As in the RT data, the separate analyses for each flanker type did not reveal

interactions between AS X flanker compatibility X target valence for either, target flanker or category flanker trials, $F < 1$ and $F(1, 19) = 2.57$, $p = 0.125$, $\eta_p^2 = 0.12$, respectively.

Discussion

In Experiment 1, both types of flanker stimuli elicited a reliable valence-flanker effect that did not differ in size when no alerting signal was presented. The presence of an alerting signal speeded overall responses in spite of the complex word material, providing a reliable manipulation check. Importantly, the alerting signal considerably increased the valence-flanker effect exclusively for target flankers but not for category flankers. This selective influence of alerting signals on interference effects contradicts the assumption a general reduction of executive control mechanisms but fits with the assumption of facilitated response activation.

It should be noted further that the increased valence-flanker effect for target flankers in conditions of alerting signals is not related to the item-specific frequency of a particular flanker stimulus. Although category flanker occurred only in 25% of all trials, the specific category-flanker items (2 items in 25% of trials) were presented more than three times as often as each individual exemplar of the target flankers (20 items in 75% of trials). Yet, in conditions without an alerting signal, the size of the valence-flanker effect did not differ between flanker conditions with high specific item probability (i.e., category flanker) compared to flanker conditions with low specific item probability (i.e., target flanker).

Furthermore, target valence did not affect overall performance. Yet, the valence-flanker effect was smaller for pleasant than for unpleasant targets. At present, we do not have an explanation for this finding (for an opposite result

Table 2 Response times (RT), percent error (PE), and standard error (in parenthesis) in Experiment 1 depending on flanker type (Target- vs. Category Flanker), alerting signal (present vs. absent), flanker compatibility (C, compatible vs. I, incompatible), and target valence (pleasant vs. unpleasant). AS, alerting signal

			Target flanker		Category flanker	
			C	I	C	I
RT						
	Pleasant	No AS	617 (19)	628 (14)	621 (23)	620 (17)
		AS	596 (20)	624 (17)	600 (17)	612 (16)
	Unpleasant	No AS	611 (16)	626 (14)	596 (17)	626 (16)
		AS	595 (19)	629 (15)	595 (19)	611 (16)
PE						
	Pleasant	No AS	5.7 (1.0)	8.1 (1.1)	5.9 (1.8)	5.7 (1.4)
		AS	4.3 (0.8)	8.9 (1.7)	2.8 (1.1)	7.5 (2.0)
	Unpleasant	No AS	4.7 (1.0)	5.4 (1.2)	1.3 (0.6)	5.1 (1.0)
		AS	4.0 (0.9)	7.8 (1.4)	2.8 (0.9)	5.6 (2.1)

pattern using face stimuli in a flanker task, see Fenske & Eastwood, 2003).

Experiment 2

The aim of Experiment 2 was to provide further evidence that alerting signals facilitate response-activation processes on the basis of established direct visuo-motor associations. In addition, in Experiment 1, one may conjecture that the facilitated response-code activation by alerting signals for target flankers is difficult to compare with effects of category flankers as the nature of both flanker types differ in many ways. Firstly, target flanker represented stimuli on an exemplar level, whereas category flanker represented stimuli on a categorical level. In addition, target flankers were drawn from a list of 20 verbs, whereas category flanker consisted of only two adjectives. Furthermore, irrespective of the specific item frequency, participants encountered trials with category flankers less often (25%) than trials containing target flankers (75%). Due to the less common word-flanker version of the Eriksen-flanker paradigm, we aimed at replicating our results from Experiment 1 to increase reliability of our findings. In addition, we wanted to provide further evidence of different alerting signal effects on more comparable flanker types. Therefore, we introduced a third type of flanker stimuli, so-called non-target flanker. That is, from the set of target words from Experiment 1, four pleasant and four unpleasant words were selected that served as non-target flanker in Experiment 2. These non-target flankers were never presented as target stimuli. Therefore, participants never responded to these words and did not acquire stimulus–response associations for these stimuli. The inclusion of the non-target flankers has the advantage that the effects of alerting signals can be studied for flanker types that both consist of verb stimuli on an exemplar level. If alerting signals facilitate response-activation processes on the basis of established visuo-motor links, only target-flanker effects should be increased by alerting signals. In contrast, effects of non-target flankers and category flankers should not be affected by alerting signals. If however, executive control is attenuated by alerting signals, increased valence-flanker effects should be observed irrespective of the flanker type.

Furthermore, including a sub-set of target flankers from Experiment 1 as non-target flankers in Experiment 2 enables a between-experiment comparison for the identical flanker items. Whereas the items of this sub-set served as target flanker in Experiment 1, and thus, may have established S–R links, the same items were presented as non-target flanker in Experiment 2 in which the establishment of S–R links is prevented. Therefore, if alerting signals facilitate response activation processes via visuo-motor links, alerting signals

should increase the valence-flanker effect only in Experiment 1 but not for the same stimuli in Experiment 2. Put differently, in conditions of alerting signal stimulation we expect a larger valence-flanker effect for target flanker in Experiment 1 compared to the valence-flanker effect by the identical flanker items in Experiment 2.[1]

Method

Participants

In the study, 28 new students of the Technische Universität Dresden (19 males, mean age 22.3 years) participated. All participants had normal or corrected-to-normal vision.

Stimuli, apparatus, and procedure

Experiment 2 was identical to Experiment 1 except that a third flanker type was introduced. Out of the list of 10 pleasant and 10 unpleasant words four pleasant and four unpleasant exemplars were chosen to serve as non-target flanker stimuli exclusively (see Table 1). The remaining six pleasant and six unpleasant words served as target stimuli and also as flanker stimuli in the target-flanker condition, which was presented in 25% of trials. In contrast to Experiment 1, category-flanker trials were now presented equally often as target-flanker trials (25% of trials). Non-target flankers were presented in 50% of all trials to reduce the effects of novelty (non-target flanker items never occurred as targets and were thus, much less often presented than target flanker items that also served as target stimuli) and to ensure sufficiently fast processing in order to obtain reliable flanker effects. The experiment started with 16 trials of practice, which was followed by six blocks of 96 trials each.
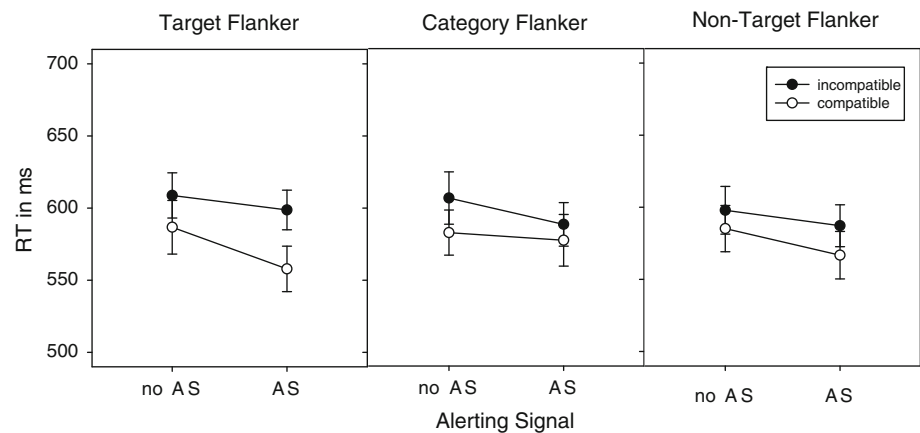
Data analysis

A repeated measures ANOVAs on mean RTs and error rates included the factors Alerting signal (AS vs. no AS), Flanker type (Target flanker, Category flanker, vs. Non-target flanker), Flanker Compatibility (compatible vs. incompatible), and Target valence (unpleasant vs. pleasant).

Results

As in Experiment 1, trials with identical flanker and target stimuli (2.1%) as well as post-error trials (4.5%) were not

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included in the analyses. For response time (RT) analyses only, error trials (4.5%) as well as RT differing more than three standard deviations from the mean RT of each participant and factorial combination (1.7%) were also excluded. Results are presented in Fig. 2 and in Table 3.

Response times

The factor Flanker compatibility affected RTs, $F(1, 27) = 57.01$, $p < 0.001$, $\eta_p^2 = 0.68$. In particular, responses were 22 ms faster in compatible trials than in incompatible trials. Responses were also speeded by the presence of an alerting signal (579 ms) compared to the absence of an alerting signal (595 ms), $F(1, 27) = 19.14$, $p < 0.001$, $\eta_p^2 = 0.42$. Further, there was a significant interaction between Flanker compatibility and Flanker type, $F(1, 27) = 1.47$, $p = 0.24$, $\eta_p^2 = 0.05$ (valence-flanker effect: 31, 17, and 17 ms for target, category, and non-target flanker, respectively). As in Experiment 1, the presence of an alerting signal revealed differential effects upon the valence-flanker effect depending on the type of flanker stimulus. This was reflected in the significant three-way interaction between Alerting signal, the three types of flanker stimuli, and Flanker compatibility, $F(1, 27) = 3.66$, $p < 0.05$, $\eta_p^2 = 0.20$. Separate ANOVAs on RTs for each flanker type confirmed an alerting-signal-based increase of the valence-flanker effect only for target flankers, $F(1, 27) = 5.37$, $p < 0.05$, $\eta_p^2 = 0.17$. In particular, the presence of an alerting signal increased the valence-flanker effect from 22 ms, $t(27) = 3.31$, $p < 0.01$ (without an alerting signal), to 40 ms, $t(27) = 6.45$, $p < 0.001$. At the same time, the absence (21 ms), $t(27) = 2.92$, $p < 0.01$, or presence (10 ms), $t(27) = 1.45$, $p = 0.16$, of an alerting signal did not significantly affect RTs in category-flanker conditions $F(1, 27) = 1.66$, $p = 0.21$, $\eta_p^2 = 0.06$. The same was found for non-target flankers. The valence-flanker effect in conditions without an alerting signal (13 ms), $t(27) = 2.29$, $p < 0.05$, did not significantly differ to that in conditions with an alerting signal (20 ms), $t(27) = 4.15$,

$p < 0.001$; $F(1, 27) = 1.47$, $p = 0.24$, $\eta_p^2 = 0.05$. As in Experiment 1, target valence did not interact with AS X flanker compatibility in the target flanker condition, $F(1, 27) = 2.42$, $p = 0.132$, $\eta_p^2 = 0.08$, the category flanker condition, $F < 1$, or in the non-target flanker condition $F < 1$, respectively. In addition, the four-way interaction between all factors was not significant, $F < 1$. No other effects were significant.

Error rates

Error rates were not affected by alerting signals, $F < 1$. More errors were produced for incompatible flankers (6.2%) compared to compatible flankers (4.1%), denoting a reliable valence-flanker effect, $F(1, 27) = 13.25$, $p < 0.01$, $\eta_p^2 = 0.33$. The valence-flanker effect was elevated in conditions including an alerting signal (3.0%) compared to conditions without an alerting signal (1.1%), $F(1, 27) = 5.22$, $p < 0.05$, $\eta_p^2 = 0.16$. Post-hoc analyses revealed that this elevation did not reach the level of statistical significance in either non-target or target flanker condition (both $ps > 0.05$). Unexpectedly, however, in the category-flanker condition, a significant increase in the valence-flanker effect was observed, $F(1, 27) = 4.29$, $p < 0.05$, $\eta_p^2 = 0.14$. Similarly to RT data, target valence did not interact with AS X flanker compatibility in either flanker condition, all $Fs < 1.12$. The four-way interaction was also not significant, $F < 1$. Finally, slightly more errors were committed for pleasant targets (5.3%) than for unpleasant targets (5.0%), $F(1, 27) = 6.08$, $p < 0.05$, $\eta_p^2 = 0.18$.

Between-experiment comparison

We further compared valence-flanker effects under alerting-signal stimulation for those specific target-flanker items in Experiment 1 that served as non-target flanker items in Experiment 2. To control for individual RT differences we conducted an ANCOVA with the factor flanker

Table 3 Percent error (PE) and standard error (in parenthesis) in Experiment 2 depending on flanker type (Target-, Category-, and Non-Target Flanker), alerting signal (present vs. absent), flanker compatibility (C, compatible vs. I, incompatible), and target valence (pleasant vs. unpleasant). AS, alerting signal

		Target flanker		Category flanker		Non-target flanker	
		C	I	C	I	C	I
RT							
Pleasant	No AS	587 (19)	603 (16)	588 (17)	602 (19)	584 (16)	600 (15)
	AS	552 (17)	597 (13)	573 (19)	582 (14)	568 (18)	591 (16)
Unpleasant	No AS	586 (19)	615 (17)	577 (16)	611 (19)	586 (17)	596 (19)
	AS	564 (16)	601 (15)	581 (18)	594 (17)	566 (15)	583 (14)
PE							
Pleasant	No AS	3.5 (1.0)	6.3 (1.5)	5.5 (1.1)	5.6 (0.9)	3.8 (0.8)	5.4 (1.3)
	AS	3.4 (1.5)	8.7 (1.6)	3.4 (1.0)	7.0 (1.6)	4.4 (0.9)	6.8 (1.2)
Unpleasant	No AS	5.0 (1.2)	8.0 (1.3)	4.7 (1.5)	4.1 (1.7)	5.0 (1.1)	5.1 (0.9)
	AS	4.6 (1.3)	6.6 (1.7)	3.0 (0.9)	5.1 (1.4)	3.0 (0.8)	5.9 (1.1)

compatibility (compatible vs. incompatible) as within- and the factor experiment (Experiment 1 vs. 2) as between-subject factor. The individual RT-level served as covariate. Importantly, in conditions of alerting signals the identical flanker stimuli produced a significantly larger valence-flanker effect when S–R associations existed (36 ms, Experiment 1) compared to those conditions without existing S–R associations (18 ms, Experiment 2), $F(1, 45) = 5.95$, $p < 0.05$, $\eta_p^2 = 0.12$. In addition, including the factor Alerting signal, the presence (compared to the absence) of an alerting signal seemed to reveal a larger influence on the valence-flanker effect for items with S–R associations (Experiment 1) compared to items without S–R associations (Experiment 2). This interaction, however, slightly missed the conventional level of significance, $F(1, 45) = 3.21$, $p = 0.08$, $\eta_p^2 = 0.07$.

Discussion

The results of Experiment 2 replicate and extend the findings from Experiment 1. Firstly, in all three flanker conditions, the alerting signal reduced the overall RT level. Second, and most importantly, the alerting signal increased the valence-flanker effect only in conditions in which stimulus–response associations have been formed, namely in the target-flanker condition. As in Experiment 1, no alerting-signal-based increment of valence-flanker effect was found in conditions of category flanker. Furthermore, even in the additional exemplar-level flanker condition, no impact on the size of flanker effects was obtained by alerting signals. Therefore, the results converge with the assumption of a facilitated response-activation account of alerting signals.

General discussion

The presentation of an alerting signal has often been found to increase interference effects in response conflict paradigms (Böckler et al., 2011; Callejas et al., 2004, 2005; Fischer et al., 2007, 2010). The facilitated response-activation account states that alerting signals increase interference effects by facilitating bottom-up response-activation processes on the basis of visuo-motor associations. According to the attenuated executive control account, alerting signals increase interference effects by revealing an inhibitory influence upon the executive control network, thus reducing the efficiency of executive functions. In the present study, we aimed at dissociating between these two theoretical assumptions. We implemented an Eriksen-flanker valence-categorization task including different types of flankers that allowed (target flanker) or did not allow (category and non-target flanker) the formation of direct stimulus–response associations (see Fischer & Schubert, 2008).

The results are straightforward. In both experiments, increased valence-flanker effects due to alerting signals were found exclusively in flanker conditions with the possibility of S–R link formation (target flanker). More specifically, we argued that interference by target flankers can either arise on the basis of semantic analysis of the flanker word that matches or mismatches with the categorization of the target word or on a sub-semantic level, namely, on the basis of established visuo-motor associations (Neumann & Klotz, 1994). For the latter mechanism, it is important that target flanker items also appear as target stimuli. The overt execution of a response to specific target items is assumed to result in the formation of direct S–R links. If those target items are presented as flanker items in

other trials, the flanker will automatically activate the response that it is associated with. A facilitation of automatic response activation by alerting signals will therefore result in an increased activation of target- and flanker-related response associations thus, amplifying the flanker effect. It should be noted that in the present study we cannot dissociate between interference and facilitation effects by flanker stimuli because we did not include neutral flankers. Based on findings of Shaffer and La Berge (1979), indicating that the word flanker effect primarily arises from interference rather than facilitation, we consequently conjecture, however, that the observed flanker effects in this study likewise are mainly composed of interference effects. Yet, even if main parts of the obtained effect should reflect facilitation instead of interference effects, the main point of interest, that is, whether alerting signals mainly affect response activation or executive control processes can be answered with the current design.

Importantly, alerting signals did not increase flanker effects in the category condition (i.e., on category level, Experiment 1 & 2) and in the non-target flanker condition (i.e., on exemplar level, Experiment 2). This differential influence of alerting signals on the valence-flanker effect was further supported by a between-experiment comparison restricted to non-target flanker items in Experiment 2 that served as target flanker items in Experiment 1. Again, larger valence-flanker effects under alerting signal stimulation were found for conditions in which S–R links existed (Experiment 1) compared to conditions in which the same items were presented without the possibility of direct S–R links (Experiment 2). The valence-flanker effects by category and non-target flankers are related to semantic processing of the flanker word, because those flankers never served as target stimuli. The fact that alerting signals are ineffective in modulating category and non-target flanker effects has several consequences:

First, an additive effect of alerting signal on category and non-target flanker effects suggests that alerting signals do not affect semantic processing of flankers. Second, an AS based increase of the valence-flanker effect exclusively for flankers with S–R links speaks rather against an AS based inhibitory influence on the executive control systems, limiting its efficiency. In fact, any AS related reduction in the efficiency of the executive control system should affect valence-flanker effects in all flanker conditions and thus, should be independent of the presence or absence of established S–R associations.[2]

It should also be noted that the alerting signal did not contain any response-selection relevant information. Alerting signals typically provide information about the temporal onset of the target and flanker stimuli (reducing temporal uncertainty) and are often associated with increased levels of phasic arousal. In the present study we cannot dissociate whether the obtained effects are due to temporal prediction and/or increased arousal. However, our results demonstrate that even in complex word-categorization tasks the typical alerting signal effects of speeded information processing can be found. This general speeding of performance might be attributed, for example, to facilitated stimulus encoding—a major component of alerting signal effects (cf. Jepma, et al., 2009). At the same time, however, facilitated encoding of the perceptual word structure is unlikely to account for the selective alerting signal based increase in valence-flanker effects for target flankers. First, trials with identical target and flanker words were removed prior to analyses. Second, in Experiment 2, for example, item frequency (as potential factor for improved stimulus encoding) was higher for category flanker words, which were presented 72 times each (144 trials) than for words that served as targets and as target flankers. Here each of the 12 target words was presented 48 times (576 trials in total) and, additionally, was presented 12 times as target flanker word (144 trials).

Therefore, based on the selective alerting signal effect in the target-flanker condition we argue that in addition to facilitated stimulus encoding, alerting signals also facilitate mechanisms involved in translating the visual stimulus code into the associated motor code. Alerting signals might increase the overall readiness for execution of potential responses (see also Coles et al., 1985). This non-specific priming of all response alternatives particularly benefits those stimuli that contain established links between stimulus features and response features (i.e., target flanker). Flanker items that require additional steps in information processing (e.g., semantic analysis) to determine a response might therefore not benefit from this increased response readiness. Therefore, we take our results as further evidence that alerting signals reveal effects on visuo-motor response activation processes.

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[2] It should be noted that there is a theoretical possibility to preserve the assumption that alerting signals negatively influence the executive control system. This, however, requires a number of additional assumptions. For example, one would have to assume that interference effects based on semantic analysis of the stimulus are less vulnerable to modulations by the reduced efficiency of the executive

Footnote 2 continued
control system than interference effects based on S-R link processing. In consequence, however, this means that different stages of processing (e.g., semantic classification vs. response selection) are controlled by specialized executive control systems with specific susceptibilities to alerting signals. We thank an anonymous reviewer for mentioning this possibility.

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