Research Article

Accessory Stimuli Affect the Emergence of Conflict, Not Conflict Control

A Simon-Task ERP Study

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Abstract. Accessory signals that precede stimuli in interference tasks lead to faster overall responses while conflict increases. Two opposing accounts exist for the latter finding: one is based on dual-route frameworks of response preparation and proposes amplification of both direct response activation and indirect response selection processes; the other refers to attentional networks and suggests inhibition of executive attention, thereby hampering conflict control. The present study replicated previous behavioral findings in a Simon task and extended them by electrophysiological evidence. Accessory tones facilitated stimulus classification and attentional allocation in the Simon task as reflected by an increased N1 amplitude and an overall decrease of the N2 amplitude, respectively. The conflict-related N2 amplitude, which is larger in conflict trials compared with nonconflict trials, was not modulated by accessory tones. Moreover, accessory tones did not affect sequence-dependent conflict adaptation. In terms of a dual-route framework present results suggest amplification of both response preparation routes by accessory stimuli. An executive attention approach proposing accessory stimuli to hamper control of conflict is not supported.

Keywords: stimulus-response interference, accessory stimuli, conflict control, event-related brain potentials

Recent research showed that preceding accessory stimuli, such as arbitrary tones, accelerate performance in interference tasks – even when no relevant information for response selection is provided. Apart from enhancing overall performance accessory stimuli considerably increased the interference effect (Callejas, Lupianez, Funes, & Tudela, 2005; Fan, McCandliss, Sommer, Raz, & Posner, 2002; Fischer, Plessow, & Kiesel, 2010). Due to an attentional network account (Posner & Petersen, 1990) an inhibitory relation exists between an arousal network and an executive attention network. Accessory stimuli are assumed to enhance arousal, thereby inhibiting executive attention (Callejas et al., 2005; Fan et al., 2002). Because the resolution of conflict in interference tasks as the flanker task (Eriksen & Eriksen, 1974) depends on executive attention, the enlarged interference effect was proposed to be due to hampered executive control.

An alternative explanation – based on a dual-route framework of response preparation (De Jong, Liang, & Lauber, 1994; Kornblum, Hasbroucq, & Osman, 1990) – was recently proposed by Fischer et al. (2010) who reported faster reaction times (RTs) and increased interference effects when accessory tones were presented in a Simon task (Simon, 1990). In a Simon task, spatially oriented responses are assigned to nonspatial stimulus features (e.g., shape). The stimulus position alters randomly and either matches or mismatches response location resulting in compatible and incompatible trials, respectively. According to dual-route models (De Jong et al., 1994; Kornblum et al., 1990), a stimulus in the Simon task activates two parallel processes of response preparation: The *direct* processing route primes responses that most closely correspond to the task-irrelevant stimulus location while the *indirect* processing route selects responses on the basis of the task-relevant (nonspatial) stimulus feature. The outcomes of both processing routes differ and elicit response conflict in incompatible trials, resulting in slower responses and higher error rates as compared to compatible trials, where the outcome of both routes matches. Fischer et al. explained the general speed-up of performance in trials with accessory stimuli by facilitation of response selection via the indirect route. The simultaneous increase of the interference effect was accounted for by a concurrent amplification of automatic bottom-up response activation related to direct route processing. In sum, while Fan and colleagues (2002) suggested that accessory stimuli hamper processes of executive conflict control, Fischer and colleagues (2010) accounted for increased conflict by assuming a boost of visuomotor priming related to direct route response activation.

The objective of the present study was to clarify the origin and the processes underlying both the general performance benefit and the increased interference effects by accessory stimuli. We were interested in distinguishing whether accessory stimuli in interference tasks alter early processes that cause conflict or later reactive processes of conflict control that resolve cognitive conflicts to assure

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appropriate behavioral performance. For this reason, we employed a Simon task and analyzed event-related brain potentials (ERPs). Concerning the general performance benefit, Fischer and co-workers proposed accessory stimuli to facilitate indirect route processing. However, they could not localize whether this facilitation affected perceptual processes, response selection, or motor preparation. We assessed response activation by recording the lateralized readiness potential (LRP), an electrophysiological correlate of motor preparation. The onset of stimulus-locked LRP (S-LRP) activity provides a chronometric index for the duration of premotor processing stages (cf. Leuthold, Sommer, & Ulrich, 1996; Masaki, Wild-Wall, Sangals, & Sommer, 2004), while onset differences in the response-locked LRP (LRP-R) indicate processing differences at late motor-related stages (Hackley & Valle-Inclán, 1998). Therefore, the LRP can be utilized to localize the effect of accessory stimuli within the stream of information processing.

Concerning the increase of response conflict, negative and positive LRP polarity can be used to indicate activation of the correct and incorrect response hand, respectively (e.g., Coles, 1989). An initial phase of incorrect response hand activation in incompatible trials (usually around 200 ms after stimulus onset) can be attributed to direct route response priming that is later on replaced by correct response hand activation (Stürmer, Siggelkow, Dengler, & Leuthold, 2000). This early incorrect hand activation in the LRP of incompatible trials is typically regarded as automatic response priming mediated by the frontal motor cortex (De Jong et al., 1994; Eimer, 1998; Valle-Inclán, 1996). If accessory stimuli have an effect on direct route processing, as suggested by Fischer et al., this should be reflected in an enlarged early incorrect LRP activation in incompatible events.

Early perceptual processes of stimulus classification are further reflected in the amplitude of the N1 component (Mangun & Hillyard, 1995). The N1 was reported to be larger in discrimination tasks as compared to detection tasks and therefore was interpreted as reflecting discriminative processing in stimulus classification. The N1 amplitude is sensitive to the allocation of attention (Griffin, Miniussi, & Nobre, 2002) and its enhancement is related to a facilitation of perceptual processes (Jepma, Wagenmakers, Band, & Nieuwenhuis, 2008). This allows exploring whether accessory stimuli in a Simon task affect early perceptual stages of information processing. We analyzed ERP deflections in the N2 range because two different components of the N2 amplitude are known to be sensitive to (1) the allocation of attention and (2) cognitive conflict control (see Folstein & Van Petten, 2008, for an overview). On the one hand, the N2 reflects the degree of attention required for stimulus processing (Suwazono, Machado, & Knight, 2000). The allocation of attention reduces the N2 component. If accessory stimuli enhance attentional processing of the target the attention allocation-related N2 (difference between trials with and without accessory tones) should be reduced. On the other hand, the N2 amplitude is related to cognitive control of conflict (Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003). Incompatible trials elicit a more negative ERP in the N2 range than compatible trials (Kopp, Mattler, Goertz, & Rist, 1996; for an overview, see Falkenstein, 2006). This conflict-related N2 is correlated to fronto-medial brain activation (Nieuwenhuis et al., 2003) and functionally related to the monitoring of response conflicts serving as a signal to trigger conflict resolution (Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004). We analyzed the conflict-related N2 amplitude (difference between incompatible and compatible events) in order to explore whether accessory tones alter processes of conflict control.

In order to shed light on the effect of accessory tones on processes of conflict control Fischer and co-workers analyzed the interaction with intertrial adaptation processes in the Simon task. There are numerous reports to suggest that interference effects are reduced in trials immediately following an incompatible event (for the flanker task, see Gratton, Coles, & Donchin, 1992; for the Simon task, see Praamstra, Kleine, & Schnitzler, 1999; Stürmer, Soetens, Sommer, Leuthold, & Schröter, 2002; Stürmer, Seiss, & Leuthold, 2005; Valle-Inclán, Hackley, & de Labra, 2002). Referring to the dual-route model, Stürmer et al. (2002; Stürmer & Leuthold, 2003) proposed an adaptive suppression of the direct route in trials following incompatible events to prevent conflict in the next trial. This type of intertrial adaptation can therefore be seen as a proactive process of conflict control. Presenting tones prior to pairs of trials, Fischer et al. (2010) tested the effect of accessory stimuli on the Simon effect (first trial) and on its sequential modulation in the second trial. Interestingly, the authors did not find an effect of accessory stimuli on the intertrial adaptation. The missing influence on intertrial adaptive control serves as a hint that accessory stimuli do not affect executive processes of conflict control. Adaptive control processes relevant for intertrial adaptation are proposed to be triggered by preceding conflict and to operate in the intertrial interval immediately before the actual trial (Praamstra et al., 1999; Stürmer, Redlich, Irlbacher, & Brandt, 2007). Fischer et al., however, presented tones solely prior to the first of two trials and accessed the intertrial adaptation in the second trial. In the present study we aimed at extending previous findings by using a consecutive sequence of Simon trials and presented accessory tones randomly ahead of 50% of the trials. We employed a Simon task in which tones appeared 200 or 500 ms prior to visual target onset, because these are the time intervals relevant for intertrial adaptation (Praamstra et al., 1999; Stürmer et al., 2007). To summarize, we expect accessory tones to result in overall performance benefits and in an enlarged interference effect. If accessory signals facilitate perceptual processing of stimuli, an enhanced N1 amplitude is expected. Moreover, enhanced allocation of attention to the visual target by a preceding tone should reduce the attention-related N2 amplitude to the visual target. Effects on the direct route serving automatic location-based response priming should be reflected in enlarged early incorrect S-LRP activation in incompatible trials. In the present study we investigate intertrial conflict adaptation as a measure of proactive conflict control and the conflict-related N2 in the current incompatible trials as a measure of reactive conflict control. If accessory signals hamper conflict control we expect reduced intertrial adaptation and a decrease of the conflict-related N2.

Methods

Participants

Sixteen students (mean age 22, 7 years; 12 females; 15 right-handed) participated in the experiment and received course credits or payment for participation. All of them reported normal or corrected-to-normal vision and signed informed consent prior to the experiment.

Apparatus, Stimuli, and Design

Stimuli were presented in white on a dark gray screen of a 17-in TFT monitor controlled by an IBM-compatible PC. Participants were seated in a sound-attenuated chamber at a constant viewing distance of 100 cm to the monitor. Ambient light was kept at a constant level. A small filled circle (size 0.09° visual angle) presented in the center of the screen constituted the fixation mark. Stimuli of the Simon task consisted of filled squares and diamonds (each 0.75° visual angle) presented in a vertical arrangement above or below fixation (0.5° visual angle). Manual choice responses on the basis of stimulus shapes were collected using two response keys vertically arranged on a table in front of the participants. Participants responded by pressing each of these keys with one of their index fingers. The accessory signal was a computer-generated tone presented via a loudspeaker box at 700 Hz and 65 dB for 150 ms.

A 3 (Accessory stimulus condition) × 2 (Compatibility) × 2 (Preceding trial compatibility) factorial within subject design was employed. Accessory tones were randomly presented in 50% of the trials. Stimulus onset asynchrony (SOA) between the accessory signal and visual target onset was varied blockwise and was either 200 or 500 ms. The factor compatibility varied according to the congruency of stimulus location and response position within a trial, therefore forming two levels, namely compatible and incompatible allocation of target and response. The same held for the factor preceding trial compatibility (compatible and incompatible).

Procedure

Participants were instructed to respond as fast and as accurate as possible to the appearance of either of the two targets (square or diamond) by pressing one of the two keys with their index fingers. One practice block was employed ahead of eight experimental blocks. Each experimental block consisted of 60 trials, overall resulting in 240 trials without any accessory tones, 120 trials with an SOA of 200 ms between tone and visual target, and 120 trials with an SOA of 500 ms. Trials with and without accessory tones alternated randomly within blocks. Different SOA conditions alternated blockwise. The order of blocks with different SOAs, as well as the assignment of targets (squares and diamonds) to responses (press of upper or lower key), and the hand-key mapping was counterbalanced. Overall, the experimental session took about 40 min. Each trial started with the presentation of a fixation dot. In order to make trial durations equally long in trials with and without accessory stimuli, fixation dot duration ranged between 2,000 and 3,000 ms and between 2,550 and 3,250 ms in trials with and without accessory tone, respectively. In 50% of the trials, a 150 ms tone was presented starting – according to SOA condition – 200 or 500 ms prior to the target, while the fixation dot was still visible on the screen. In the other 50% of the trials the visual target was immediately presented above or below the fixation dot for 200 ms. The fixation dot stayed in the center of the screen up to participants' responses, though not exceeding 1,500 ms.

Electrophysiological Recordings and Data Analysis

The EEG was recorded continuously from 64 Ag/AgCl electrodes according to the extended international 10–20 system. AFz served as ground electrode. All electrodes were referenced to a left mastoid electrode. Vertical electrooculer (vEOG) and horizontal EOG (hEOG) activity were registered above and below the left eye and from the left and right outer canthi. Electrode impedance was kept below 5 kΩ. EEG and EOG were filtered online using a 70 Hz low pass filter and a time constant of 15 s. All EEG signals were digitized with a sample frequency of 250 Hz. Trials containing blinks were corrected off-line (Berg, 1986) utilizing the Brain Electrical Source Analysis software. Remaining artifacts were eliminated according to visual inspection. Trials with hEOG or vEOG activity exceeding a range of 25 μV during the epoch were discarded from all analyses. Off-line data were average referenced. The EEG epochs were then averaged separately for each participant and experimental condition.

The LRP was recorded at the electrode sites C3 and C4 and was calculated by subtracting out the ipsilateral signal from the contralateral signal related to the required response hand (Coles, 1989). Positive LRP deflections indicate incorrect response hand activation, whereas negative LRP deflections denote activation of the correct response hand (Gratton, Coles, & Donchin, 1988). S-LRP activity was aligned to a 100 ms baseline period immediately preceding target onset. Initial incorrect LRP activation for the incompatible condition was detected in the time range of 0–400 ms following stimulus onset using automatic peak detection. By means of single peak analysis incorrect LRP was calculated and analyzed using one-tailed *t* tests against zero. For correct LRP activation the S-LRP and LRP-R onsets were determined as the point in time when 30% of the peak amplitude was exceeded while latency differences were statistically analyzed with a jackknifing procedure (see Miller, Patterson, & Ulrich, 1998).

Because accessory tones affected the baseline ahead of the presentation of visual stimuli, baseline-independent peak-to-peak measures were employed for comparing the N1 amplitudes between different accessory stimuli conditions. To this end, voltage differences between the

P1 (positive peak preceding the N1) and the negative N1 peak were calculated for every subject and condition. Comparable to earlier N1 literature (Doherty, Rao, Mesulam, & Nobre, 2005) we focused on electrodes with largest N1 amplitudes, namely O1, O2, PO7, and PO8. By means of automatic peak detection positive peaks were identified between 100 and 130 ms whereas negative peaks ranged between 160 and 200 ms following stimulus onset.

This baseline-independent peak-to-peak measure was also used for the analysis of N2 amplitudes at frontocentral electrode sites (Fz, FCz, and Cz). Positive peaks lay in the range between 200 and 250 ms and negative peaks lay in the range between 280 and 330 ms. Peaks were identified by automatic peak detection.

Repeated measures ANOVAs were performed on RTs, error rates, and ERP measures including the variables accessory stimulus condition, compatibility, and preceding trial compatibility. Huynh-Feldt corrections (Huynh & Feldt, 1976) were applied if necessary and p values were adjusted by the given ε value. Planned single comparisons were performed by means of one-tailed t tests.

Table 1. Means (*M*) and standard deviations (*SD*) for RTs (in ms) and error rates (in percent) in all factor levels

	Factors		Results	
			RTs *M*	Errors *M*
Tone	Comp *N*−1	Comp *N*	(*SD*)	(*SD*)
No	c	c	518.7 (96.2)	0.4 (0.4)
		ic	570.7 (108.1)	1.8 (0.9)
	ic	c	542.4 (96.7)	0.7 (0.7)
		ic	551.9 (98.0)	0.7 (0.8)
200 ms	c	c	461.1 (89.9)	0.2 (0.3)
		ic	539.5 (107.5)	0.5 (0.5)
	ic	c	489.0 (98.3)	0.3 (0.4)
		ic	514.8 (112.5)	0.3 (0.3)
500 ms	c	c	457.8 (97.7)	0.1 (0.2)
		ic	535.1 (114.8)	0.5 (0.5)
	ic	c	494.4 (111.0)	0.2 (0.2)
		ic	508.5 (105.1)	0.2 (0.3)

Note. Tone depicts accessory signal condition (no tone, SOA 200 ms, and SOA 500 ms), Comp *N*−1 depicts preceding trial compatibility (c, compatible; ic, incompatible), and Comp *N* depicts current compatibility (c, compatible; ic, incompatible).

Results

Performance

Trials with incorrect responses or incorrect predecessors and trials with responses faster than 100 ms or slower than 1,000 ms were discarded (5.8%). In a first analysis, we examined whether blocks with different SOAs of the accessory stimulus (200 vs. 500 ms) revealed different results. As the variable block did not affect any of the other factors, Fs < 1, we collapsed trials without accessory stimuli across blocks for further analyses and will only report the variables accessory stimulus condition, compatibility, and preceding trial compatibility. Reaction times were significantly speeded up by the presentation of an accessory tone, $F(2, 30) = 41.9$, $MSE = 1{,}074.9$, $p < .001$. There was no difference between the two SOA conditions, $F < 1$. Participants responded more accurately when accessory signals had been presented, $F(2, 30) = 15.2$, $MSE = 0.4$, $p < .001$. Because lowest error rates accompanied fastest RTs (cf. Table 1) a general speed-accuracy trade-off can be excluded and in the following only RTs will be reported (for error rates, see Table 1).

The Simon effect was significant, $F(1, 15) = 116.3$, $MSE = 757.9$, $p < .001$, and so was the intertrial adaptation (Compatibility × Preceding trial compatibility), $F(1, 15) = 46.8$, $MSE = 714.3$, $p < .001$. This interaction was due to an enlarged Simon effect following compatible as compared to incompatible trials, $t(15) = 6.84$, $p < .001$; one-tailed. Excluding exact trial repetition did not change the intertrial adaptation as the Simon effect was still larger following compatible than following incompatible trials, $t(15) = 4.46$, $p < .001$, one-tailed.

A significant Accessory stimulus condition × Compatibility interaction was found, $F(2, 30) = 13.8$, $MSE = 148.2$, $p < .001$, $\varepsilon = .94$, due to an enlargement of the compatibility effect when a tone had been presented, ts(15) > 4.7, ps < .001, one-tailed. Again, there was no difference between SOA conditions, $F < 1$. There was also no three-way interaction of Accessory stimulus condition × Compatibility × Preceding trial compatibility, $F(2, 30) = 1.8$, $MSE = 249.7$, $p = .19$, $\varepsilon = .98$, implying that the accessory stimulus did not affect the sequential modulation of the Simon effect. An additional factor "accessory signal in the preceding trial" indicated whether accessory stimuli influence target processing in immediately following trials. This variable consisted of two levels, namely with and without accessory stimulus. Whether an accessory stimulus was presented in the preceding trial did not yield a significant main effect, $F(1, 15) = 3.1$, $MSE = 407.0$, $p = .10$. Neither was there a significant interaction of this variable with compatibility, $F(1, 15) = 2.3$, $MSE = 525.8$, $p = .15$, nor with intertrial adaptation (Compatibility × Preceding trial compatibility), $F < 1$. The preceding accessory stimulus condition, however, interacted significantly with the present accessory stimulus condition, $F(2, 30) = 11.7$, $MSE = 594.5$, $p < .001$, $\varepsilon = .85$. This two-way interaction was due to the fact that responses were faster by 11 ms when accessory stimulus conditions were repeated than when they were not.

Electrophysiological Results

Figure 1 depicts the S-LRP and LRP-R waveforms as a function of compatibility and accessory stimulus condition. The onsets of the S-LRP mirrored the RT findings. S-LRP onsets were significantly earlier for compatible as compared

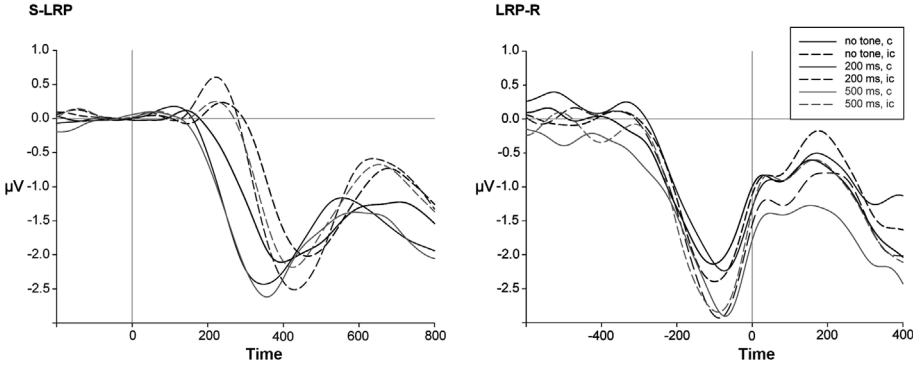

Figure 1. Stimulus-locked (left side) and response-locked (right side) LRPs. The compatible (c) condition is depicted in solid lines, the incompatible (ic) condition in dashed lines. Black lines reflect the no accessory stimulus condition, dark gray lines reflect the 200 ms SOA condition, and light gray lines mirror the 500 ms SOA condition.

to incompatible trials (c: $M = 234$ vs. ic: $M = 323$ ms), $F(1, 15) = 77.6$, $MSE = 14.2$, $p < .001$. The presentation of an accessory signal evoked an earlier S-LRP onset ($M = 268$ vs. 301 ms), leading to a main effect of accessory stimulus type, $F(2, 30) = 7.5$, $MSE = 14.1$, $p < .001$. No difference between SOA conditions was found, $F < 1$. The intertrial adaptation reached significance, $F(1, 15) = 16.1$, $MSE = 8.7$, $p < 001$, due to a larger compatibility effect in S-LRP onset when the preceding trial was compatible, $t(15) = 2.2$, $p < .05$, one-tailed. Response-locked LRP onset did not differ significantly between experimental conditions (cf. Figure 1); all Fs < 1.

Incompatible trials in all accessory stimulus conditions elicited incorrect LRP activation that significantly differed

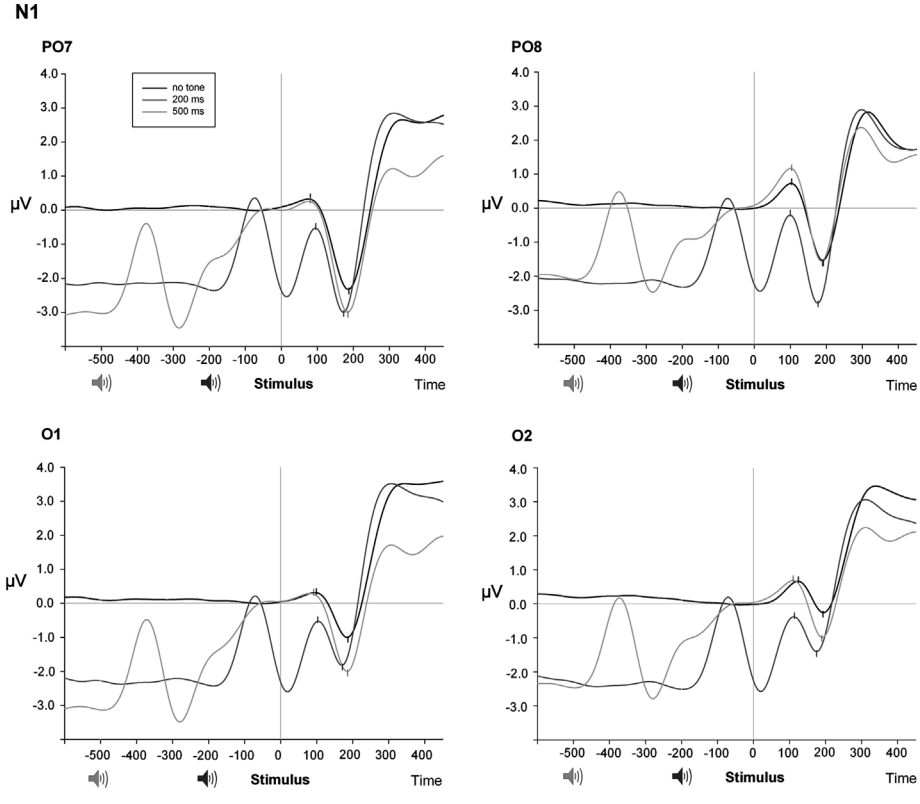

Figure 2. The N1 for occipito-parietal electrode sites (O1, O2, PO7, and PO8), averaged over compatibility conditions. Black curves reflect the no accessory signal condition, dark gray lines reflect the 200 ms SOA condition, and light gray lines the 500 ms SOA condition. The means of automatically detected positive and negative peaks are labeled by dots in ERP curves. Onsets of tones are marked by loudspeakers at the time axis for both the 500 ms SOA (light gray) and 200 ms SOA (dark gray) condition.

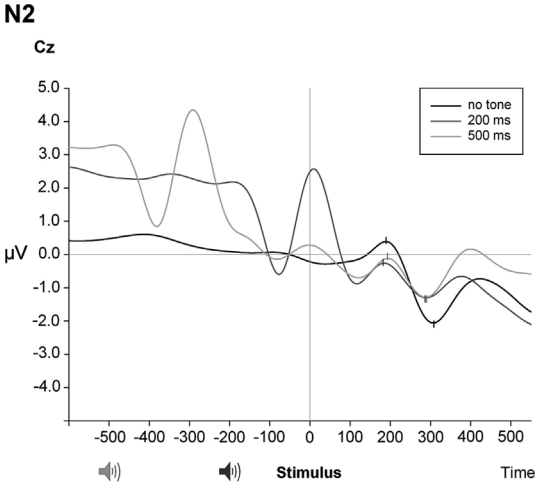

Figure 3. The N2 at Cz. Black lines reflect the no accessory signal condition, dark gray lines reflect the 200 ms SOA condition, and light gray lines mirror the 500 ms SOA condition. The means of automatically detected positive and negative peaks are labeled by dots in ERP curves. Onsets of tones are marked by loudspeakers at the time axis for both the 500 ms SOA (light gray) and 200 ms SOA (dark gray) condition.

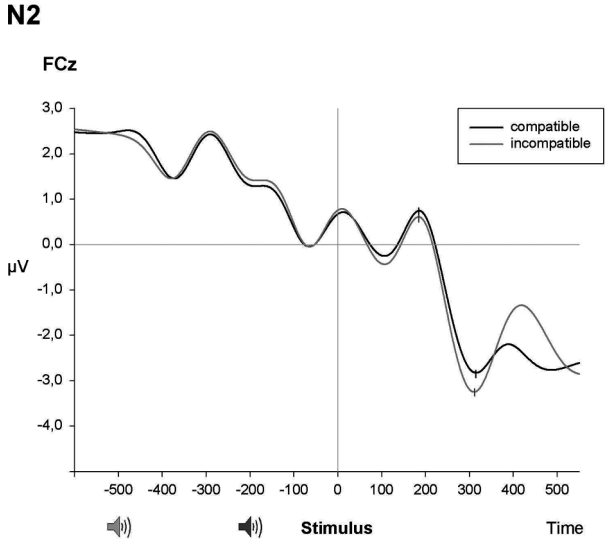

Figure 4. The N2 at FCz averaged over accessory stimulus conditions. The black line reflects the ERP curve in compatible trials, the gray line reflects incompatible trials. The means of automatically detected positive and negative peaks are labeled by dots in ERP curves. Onsets of tones are marked by loudspeakers at the time axis for both the 500 ms SOA (light gray) and 200 ms SOA (dark gray) condition.

from zero, $ts(15) > 6.2$, $ps < .001$, one-tailed. Paired t tests revealed enlarged incorrect activation for the 200 ms SOA condition as compared to the absence of accessory stimuli, $t(15) = 3.4$, $p < .01$, but showed no difference between the 500 ms SOA and the no accessory stimulus condition ($t < 1$). The N1 amplitude was significantly enhanced by an accessory stimulus at occipito-parietal electrode sites (O1, O2, PO7, and PO8; see Figure 2) $Fs(2, 30) > 3.9$, $MSEs < 5.7$, $ps < .05$. Compatibility conditions did not affect the N1 amplitude, $Fs < 1$.

A significantly reduced N2 amplitude occurred at Cz when an accessory tone was presented compared to no accessory signal trials, $F(2, 30) = 5.4$, $MSE = 4.7$, $p = .01$ (see Figure 3).

Incompatible trials evoked a larger N2 amplitude compared with compatible trials at FCz, $t(15) = 3.2$, $p < .05$ (see Figure 4). The two-way interaction Accessory stimulus condition × Compatibility was not significant, $Fs(2, 30) < 1.2$.

Discussion

The aim of the present study was to clarify whether the overall performance benefit and the increase of cognitive interference by accessory stimuli are due to processes causing conflict namely the facilitation of response preparation routes or to hampered cognitive control. The processes underlying both effects of accessory tones were investigated by means of electrophysiological measures. First of all, we replicated previously reported behavioral findings (Callejas et al., 2005; Fan et al., 2002; Fischer et al., 2010). Present ERP results indicate that the effects of accessory stimuli precede motor processes and are located before or during response selection because accessory tones resulted in an earlier onset of the stimulus-locked LRP compared to trials without accessory stimuli and did not affect the onset of response-locked LRPs (see also Hackley & Valle-Inclán, 1998). Moreover, the N1 amplitude, reflecting attentional allocation and early stimulus classification (Mangun & Hillyard, 1995), was amplified by accessory tones. These results are in line with the assumption that accessory tones affected perceptual processing of the Simon-task stimuli. Additionally, accessory tones reduced the N2 amplitude which can be seen as further evidence that accessory signals potentiated attentional allocation (for an overview, see Folstein & Van Petten, 2008). Taken together, in line with Fischer et al. (2010) we suggest that these results can be best interpreted within a dual-route framework. We assume that a potentiation of attentional allocation elicited by accessory tones boosts both processing routes. The facilitation of indirect route processes (instruction-based stimulus-response processing) speeds up responses to both compatible and incompatible trials, thereby speeding up performance in general. The potentiation of direct route processing (response priming based on task-irrelevant stimulus location) additionally benefits compatible assignments, but at the same time increases conflict in incompatible assignments. Moreover, accessory stimuli in the study at hand enhanced the incorrect LRP activation in incompatible trials. Early incorrect LRP activation in interference trials was proposed to result from direct route priming (De Jong et al., 1994; Stürmer et al.,

2002). Accessory stimuli seem to amplify response hand activation according to stimulus location. This support is notwithstanding limited because an increase of incorrect LRP activity was not observed when the tone preceded the visual target by 500 ms while behavioral effects did not differ between SOA conditions.

The present findings, however, stand in clear contrast to interpretations of enlarged interference effects as a result of hampered cognitive control by accessory stimuli. Fan and collaborates (2002) claimed that the size of the interference effect mirrors the efficiency of the executive control network. The increased interference effect in accessory signal trials was seen to reflect inhibition of the executive control network by arousal. In the study at hand, the conflict-related N2 in incompatible trials was not affected by accessory signals. Because this component is regarded as an ERP marker of reactive conflict control (Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003), we infer that control processes are not influenced by accessory tones. We also analyzed the sequence-dependent adaptation of the Simon effect as a measure of proactive cognitive control (Botvinick, 2007; Stürmer et al., 2002). Fischer et al. did not investigate whether accessory tones affect sequence-dependent adaptation when applied in the intertrial interval. We used a serial response task and applied accessory tones ahead of half of the trials and were, hence, able to investigate cognitive control processes crucial for intertrial conflict adaptation (Praamstra et al., 1999; Stürmer et al., 2007). The sequential modulation of the Simon effect in the present study was not reduced by accessory stimulation. This finding can be interpreted as a strong indication that accessory signals do not hamper adaptive conflict control as involved in sequence-dependent modulation of the Simon effect.

In order to test more directly whether the size of conflict in the preceding trial modulates the compatibility effect in the actual trial, accessory stimulation in the preceding trial was taken into account as well. It can be reasoned that enlarged conflict by accessory tones in the previous trial activates adaptation processes which increase the modulation of conflict in the subsequent trial. Present results, however, stand against this explanation, because accessory signals in the preceding trial did not affect the Simon effect in the current trial. Therefore, in spite of increasing conflict in a present trial, accessory tones do not influence subsequent processes of conflict adaptation. As far as we know, the accessory stimulus preceded the interference task stimulus at a fixed point in time in all studies up to now, including ours. Although the accessory stimulus did not contain information necessary for response selection it decreased the temporal uncertainty of target presentation. This increase of temporal expectation of target appearance can account for the general decrease of RTs by accessory stimuli (Doherty, Rao, Mesulam, & Nobre, 2005). The effect of reduced temporal uncertainty on interference effects, however, is still open. Although Fan et al. (2002) assumed that their accessory stimuli enhanced arousal and proposed an inhibitory relation between an arousal network and executive attention network, direct evidence is missing that arousal was effectively manipulated in their studies. On the basis of the present experimental design we cannot disentangle whether the effects of tones are due to increased arousal in an arousal network (Callejas et al., 2005; Fan et al., 2002) or whether the tones reduced the temporal uncertainty of target presentation and thereby potentiated attentional allocation. Further research is clearly needed to disentangle whether the potentiation of perceptual and visuomotor processes by accessory stimuli is based on the reduction of temporal uncertainty or on a potentiated state of arousal.

To conclude, in line with earlier findings accessory stimuli resulted in a general performance benefit and at the same time enhanced interference in the Simon task. By means of S-LRP onset and N1 results the effect of accessory stimulation could be ascribed to early perceptual processes of attentional allocation facilitating stimulus classification. The accessory signal considerably amplified the incorrect activation of the S-LRP to incompatible events, facilitating response priming related to direct route processing. There were, by contrast, no signs that conflict control was affected by accessory tones. The present findings can be interpreted on the basis of a dual-route framework, assuming that the perceptual facilitation elicited by accessory stimuli boosts both processing routes. The amplification of indirect route processes speeds up responses to both compatible and incompatible trials, thereby resulting in an overall performance benefit. Facilitation of the direct response preparation route additionally speeds up responses to compatible trials, while increasing conflict in incompatible trials. The enhanced interference effect with accessory auditory stimulation is, therefore, due to a potentiation of conflict provoking processes but not to hampered conflict control.

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