

Mismatch and Conflict: Neurophysiological and Behavioral Evidence for Conflict Priming

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Abstract

■ Conflict-related cognitive processes are critical for adapting to sudden environmental changes that confront the individual with inconsistent or ambiguous information. Thus, these processes play a crucial role to cope with daily life. Generally, conflicts tend to accumulate especially in complex and threatening situations. Therefore, the question arises how conflict-related cognitive processes are modulated by the close succession of conflicts. In the present study, we investigated the effect of interactions between different types of conflict on performance as well as on electrophysiological parameters. A task-irrelevant auditory stimulus and a task-relevant visual stimulus were presented successively. The auditory stimulus con-

sisted of a standard or deviant tone, followed by a congruent or incongruent Stroop stimulus. After standard prestimuli, performance deteriorated for incongruent compared to congruent Stroop stimuli, which were accompanied by a widespread negativity for incongruent versus congruent stimuli in the event-related potentials (ERPs). However, after deviant prestimuli, performance was better for incongruent than for congruent Stroop stimuli and an additional early negativity in the ERP emerged with a fronto-central maximum. Our data show that deviant auditory prestimuli facilitate specifically the processing of stimulus-related conflict, providing evidence for a conflict-priming effect. ■

INTRODUCTION

Goal-directed behavior requires an adaptive cognitive control system for monitoring performance and environmental changes in order to adjust behavior appropriately. To compare actual performance with internal goals, continuous assessment of environmental changes, ongoing actions, and the outcome of these actions is critical. Electrophysiological and functional neuroimaging studies point to the importance of the medial frontal cortex and other prefrontal structures in detecting and monitoring conflicts that increase the risk to miss internal goals (Ridderinkhof, Ullsperger, Crone, & Nieuwenhuis, 2004). A number of functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) studies identified areas activated when tasks require conflict detection and resolution. The anterior cingulate cortex, the dorsolateral prefrontal cortex, and other predominantly prefrontal brain structures are consistently involved (Ridderinkhof et al., 2004; Ullsperger & von Cramon, 2004; Botvinick, Braver, Barch, Carter, & Cohen, 2001). Electrophysiological studies have determined event-related brain potential (ERP) correlates in response to conflicts and the coherent risk of unfavorable outcome. Various frontal negativities—such as N2-like potentials (Falkenstein,

Hoormann, & Hohnsbein, 1999; Kopp, Rist, & Mattler, 1996; Gehring, Gratton, Coles, & Donchin, 1992), error (-related) negativity (Ne or ERN) (Gehring, Coles, Meyer, & Donchin, 1993; Falkenstein, Hohnsbein, Hoormann, & Blanke, 1990), and feedback-related negativity (FRN) (Holroyd & Coles, 2002; Ruchow, Grothe, Spitzer, & Kiefer, 2002) which is elicited by error feedback—appear to reflect such processes of monitoring conflict or unfavorable developments in general. In line with this concept, the Stroop task, as widely used experimental paradigm to induce conflict (Stroop, 1935), is reported to evoke a negativity after incongruent/conflicting versus congruent/nonconflicting stimuli (Hanslmayr et al., 2008; Mager et al., 2007; Liotti, Woldorff, Perez, & Mayberg, 2000; West & Alain, 1999; Rebai, Bernard, & Lannou, 1997). The principle of the Stroop task is the handling of two types of conflicting information, namely, meaning and color of the written word. Response latencies and error rates generally increase in the incongruent condition, and this delay has been termed the Stroop interference effect. Together with corresponding PET and fMRI findings (Zysset, Muller, Lohmann, & von Cramon, 2001; Leung, Skudlarski, Gatenby, Peterson, & Gore, 2000; Taylor, Kornblum, Lauber, Minoshima, & Koeppel, 1997; Carter, Mintun, & Cohen, 1995; Pardo, Pardo, Janer, & Raichle, 1990), the available ERP data support the hypothesis that the negativity in the incongruent condition of the Stroop task correlates with increased conflict-related activity in the prefrontal cortex

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(Markela-Lerenc et al., 2004; Liotti et al., 2000). In other conflict tasks, such as the flanker task, a similar negativity has also been observed (Bartholow et al., 2005; Kopp et al., 1996).

Another brain activity related to conflict on a conceptual level is the neural and hemodynamic response to stimulus deviance. Task-irrelevant changes in a stream of repetitive auditory stimulation evoke the mismatch negativity (MMN) (Näätänen, Gaillard, & Mantysalo, 1978). This ERP is produced by the violation of regularities, even those of an abstract nature, in the auditory stream pattern (Näätänen, Tervaniemi, Sussman, Paavilainen, & Winkler, 2001). The MMN is generated by a temporo-frontal network that includes subregions of the temporal auditory cortex (Jaaskelainen et al., 2004; Rosburg, Haueisen, & Kreitschmann-Andermahr, 2004; Muller, Juptner, Jentzen, & Muller, 2002; Alain, Woods, & Knight, 1998; Hari et al., 1984). However, there is increasing evidence that prefrontal structures also contribute to the generation of the MMN (Marco-Pallares, Grau, & Ruffini, 2005; Jemel, Achenbach, Muller, Ropcke, & Oades, 2002; Waberski et al., 2001; Alho, Woods, Algazi, Knight, & Näätänen, 1994; Giard, Perrin, Pernier, & Bouchet, 1990). Mismatch processing and conflict processing exhibit some similarities: Conflict and mismatch perception have an impact on performance outcome. Both have to be detected first and should then lead to control implementation to support goal-directed behavior. In the case of conflict, the processing of two different stimulus features or feature-related motor responses competes with each other. Likewise, a deviant auditory stimulus in a row of standard auditory stimuli implicates a process of comparison that detects mismatch between the deviant auditory input and a sensory-memory trace (standard stimulus) that matches the internal expectancy of the subject. Thus, the observed activity in the prefrontal cortex in the case of auditory deviance could reflect a comparison process leading to a mismatch or a conflict at the level of stimulus representations. Although the terms conflict and mismatch cannot be used interchangeably, both implicate a process of comparison and mean an increased risk that the subject might fail to reach a goal. In line with this notion, Yeung, Cohen, and Botvinick (2004) have stated that, despite important differences, the conflict and mismatch accounts are part of the same class of theories of performance monitoring.

In summary, an increase of negative activity (ERP) in the prefrontal cortex is a consistent correlate of different types of conflict regardless of stimulus modality. An important question is whether and how the different aspects of conflict interact. For example, it is not clear whether the successive appearance of different types of conflict deteriorates performance because processing resources are already depleted by the first conflict or rather leads to a priming effect that facilitates conflict processing. A previous study indicated that two simultaneous conflicts (flanker and Simon-type spatial conflict) both activating the prefrontal–cingulate network

did not produce the expected enhanced interference (Fan, Flombaum, McCandliss, Thomas, & Posner, 2003). Among several explanations, the authors assumed that anatomical overlap between tasks was only partial.

In the present study, we investigated the possible interaction between different types of stimulus-related conflict on both the performance and electrophysiological levels. It is important to note that here the term conflict is used on a more conceptual level addressing processing of ambiguous, deviant, or inconsistent stimuli while excluding conflict between motor responses. Therefore, two paradigms generating two different types of conflict, auditory mismatch and visual Stroop conflict, were coupled. A task-irrelevant auditory stimulus and a task-relevant visual stimulus were presented successively. The auditory stimulus consisted of a standard or a deviant tone followed by a congruent or incongruent Stroop stimulus. In line with the concept described above, both conflict stimuli are known to cause interference regarding reaction time and errors on the behavioral level as well as negative prefrontal ERP components on the neurophysiological level.

Thus, our cross-modal paradigm enabled us to study how standard and deviant auditory stimuli interact with the processing of subsequent congruent (no conflict) and incongruent (conflict) visual stimuli. Response-related conflict was avoided by decoupling the response from stimulus attributes: The conceptual conflict between the two dimensions of a Stroop stimulus within a matching process was separated from the response preparation and execution process. Both processes are confounded in the traditional Stroop task. This adapted Stroop task has recently been shown to induce a negativity related to stimulus conflict (Mager et al., 2007). For the main task, visual stimuli were used in order to avoid direct sensory interactions of successive auditory stimuli. Moreover, the two stimuli differed in modality and semantics which make stimulus-related priming effects (Mayr, Niedeggen, Buchner, & Pietrowsky, 2003) impossible. Accordingly, we employed a paradigm adapted to the auditory–visual distraction paradigm used by Escera, Yago, and Alho (2001).

A general prediction was that mismatch by deviant auditory stimuli modulates the subsequent Stroop task (performance and ERPs) differentially depending on whether the underlying visual Stroop stimulus represents a conflict or not. It was expected that deviant auditory stimuli deteriorate performance (more errors, increased reaction time [RT]) if the subsequent Stroop stimulus is congruent probably due to an attentional distraction process, as has been reported in similar paradigms that imply no conflict (Escera et al., 2001). The outcome of the sequence of both mismatch and conflict was less explicit and was a rationale for the study. Two predictions appear possible: One is that performance outcome would be further impaired because the distraction caused by auditory mismatch may limit the prefrontal resources for processing of the subsequent visual conflict. Alternatively, a priming

effect may occur, in that the first deviance-related mismatch may prepare the conflict-related brain structures for more efficient conflict processing and resolution of the subsequent visual conflict.

Thus, the neurophysiological prediction assuming a priming process by a deviant auditory stimulus was that the negativity related to the Stroop conflict should appear earlier or more strongly, reflecting faster or more pronounced conflict detection due to the preparation of the related neuronal structures by the preceding auditory mismatch. On the other hand, if the tradeoff hypothesis is correct, we expected a delayed or smaller negativity in incongruent Stroop trials after deviant auditory stimuli.

METHODS

Subjects

Seventeen healthy subjects between 25 and 32 years of age (mean age = 27.3 years, $SD = 4.1$) participated in the study. Subjects had a relatively high educational status with at least 9 years of school education and 4 years of professional training. All 17 subjects had right-hand preference.

Subjects had no history of current or past neurological or psychiatric illness and took no medication. All subjects had normal or corrected visual acuity. Subjects gave their written informed consent to participate. The study complied with the principles of the Declaration of Helsinki and was approved by the local Ethics Committee of the University of Basel, Switzerland.

Modified Stroop Task

Each test run began with a task-irrelevant standard (500 Hz plus superimposed harmonics; 0.8 probability) or deviant auditory stimulus (either 450 Hz or 550 Hz plus superimposed harmonics; 0.2 probability) lasting 100 msec, followed (300 msec after tone onset) by a single, congruent or incongruent, visual word stimulus lasting 300 msec. Four-word stimuli (i.e., the German words “gelb,” “grün,” “blau,” and “rot” corresponding to the English words yellow, green, blue, and red) were used. The words were printed in one of the four colors (i.e., yellow, green, blue, or red). Overall, 50% of stimuli were congruent (i.e., identical color and word meaning) and 50% were incongruent. Both conditions were equally distributed with respect to the preceding auditory condition. Stimuli were generated by a personal computer using the STIM software package (NeuroScan) and were projected on a black screen at a distance of 1 m from the subjects. In the present study, both dimensions (color and word meaning) were task-relevant, and thus, the generation of neutral stimuli as required for other versions of the Stroop task was not deemed necessary.

The order of presentation was pseudorandomized, that is, no more than three identical colors or words

and not more than four stimuli of identical condition (congruent/incongruent) were presented consecutively. For all types of stimulus pairs (standard tone + congruent Stroop stimulus; standard tone + incongruent Stroop stimulus; deviant tone + congruent Stroop stimulus; deviant tone + incongruent Stroop stimulus), the preceding pairs were balanced with respect to Stroop congruency to prevent a bias by trial sequence. The interstimulus interval varied randomly between 2050 and 2150 msec. In total, 4 blocks of 120 stimuli were presented. Participants were instructed to press one of two keys on the response pad, which was placed in front of them on a table. The subjects were asked to decide as quickly and accurately as possible whether the color in which the word was printed matched (left button, index finger) or did not match (right button, index finger) its meaning; they were told to ignore the tones. Instructions were presented on the screen and were also given orally by the experimenter before test initiation. All subjects completed eight practice trials prior to the test trials.

Neurophysiological Recording

Electroencephalographic (EEG) activity was recorded from 21 Ag/AgCl electrodes using a 32-channel cap (Easy-Cap) based on the 10–20 system (F3, F4, C3, C4, T3, T4, T5, T6, P3, P4, Nz, Fz, FCz, Cz, CPz, Pz, Oz, A1, A2, O1, O2). The recording bandwidth was 0.3 to 70 Hz. Data were sampled at 256 Hz using a BrainAmp amplifier (Brain Products, Munich). Off-line data analysis was performed using the software BrainVision Analyzer 1.03 (Brain Products). During recording, all electrodes were referenced to Cz; for data analysis, they were re-referenced to the linked mastoids (mean of M1 and M2). Vertical and horizontal eye movements were monitored from electrodes placed laterally to both eyes and above and below the left eye. Averaging and artifact rejection were performed off-line. Only correctly responded trials were included in EEG analysis. Continuous data were epoched around the word stimulus onset. Each epoch was of 1500 msec duration, including a 200-msec baseline period. The 200 msec preceding the tone were used as the baseline. Within each test block, epochs were mathematically corrected for eye-movement artifacts by using the Gratton and Coles method (Gratton, Coles, & Donchin, 1983). Subsequently, epochs exceeding $\pm 75 \mu V$ at any electrode were rejected. ERPs were averaged for each subject and for congruent and incongruent trials (correct trials only) after either standard tones or deviant tones. Waveforms were digitally filtered with a band pass of 0.3–15 Hz.

Statistical Analyses

For statistical analysis, SPSS 15.0 (SPSS, Chicago, IL) software was used. Behavioral performance (reaction time, accuracy) data were analyzed by two-way analysis of

variance (ANOVA) for repeated measures with factors auditory condition (two levels: standard vs. deviant tone) and Stroop condition (two levels: congruent vs. incongruent). ERPs were analyzed in different steps. Based on the finding that negativities were maximal at central electrodes, statistical analyses were restricted to the central derivation line. In order to test the hypothesis that non-matching auditory prestimuli would change the latency and/or amplitude of the negativity after incongruent Stroop stimuli, we segmented the relevant time period between 150 and 600 msec after the Stroop stimulus into six time segments (150–225, 225–300, 300–375, 375–450, 450–525, 525–600 msec). In a first step, a four-way ANOVA for repeated measures on all factors was conducted with the factors time segment (6 levels: see above), Stroop condition (2 levels: congruent vs. incongruent), auditory condition (2 levels: standard vs. deviant), and anterior–posterior electrode position (5 levels: Fz, FCz, Cz, CPz, Pz). Based on the finding that the anterior–posterior position exhibited an ordinal influence in the significant four-way interaction term ($p < .0001$), data of the anterior–posterior locations were pooled and further analyzed by a three-way ANOVA for repeated measures. All p values derived from ANOVAs were based on Greenhouse–Geisser corrected degrees of freedom, but the original degrees of freedom are reported. In case of a significant main or interaction effect, subsequent post hoc analyses were performed by means of linear contrasts with alpha correction for multiple comparisons (Curran–Everett, 2000). The threshold for alpha errors was set at $p < .05$. Means \pm SEM values are presented.

RESULTS

Behavioral Performance

Reaction Time

Figure 1A illustrates the RTs after presentation of non-conflicting (congruent) and conflicting (incongruent) visual Stroop stimuli. RTs for each Stroop condition are presented separately depending on the preceding auditory stimulus that was either a standard or a deviant tone.

Overall, the factors Stroop condition [$F(1, 16) = 1.19$, $p = .29$] and auditory condition [$F(1, 16) = 0.72$, $p = .41$] showed no significant effect. Instead, as suggested by Figure 1A, the Stroop condition effect depended on the precedent auditory condition. In fact, there was a strong interaction between Stroop condition and auditory condition [$F(1, 16) = 63.02$, $p < .0001$]. Post hoc analyses (linear contrasts) revealed that after standard auditory stimuli, RTs were slower to incongruent (731 msec) than to congruent Stroop stimuli [690 msec; $F(1, 16) = 44.89$, $p < .0001$], which is the expected effect. In contrast, after deviant auditory stimuli, subjects responded faster to incongruent Stroop stimuli (693 msec) than to congruent ones [721 msec; $F(1, 16) = 20.49$, $p < .0003$]. Furthermore, responses to congruent Stroop stimuli were

generally delayed after deviant compared to standard tones [$F(1, 16) = 24.97$, $p < .0001$], whereas responses to incongruent Stroop stimuli were accelerated after deviant compared to standard tones [$F(1, 16) = 38.81$, $p < .0001$].

Accuracy

As shown in Figure 1B, accuracy was lower in the incongruent compared to the congruent Stroop condition. Analysis of summed errors and misses yielded a main effect for the factor Stroop condition [congruent 0.42% vs. incongruent 3.1%; $F(1, 16) = 16.31$, $p < .002$]. Moreover, an effect was demonstrated for the factor “auditory condition” indicating better accuracy after deviant (1.25%) compared to standard (2.27%) tones [$F(1, 16) = 7.66$, $p < .02$]. An interaction between auditory condition and Stroop condition was missed [$F(1, 16) = 3.01$, $p < .11$].

Event-related Potentials

Figure 2 shows ERPs in response to auditory–visual stimulus pairs. Auditory standard stimuli (dotted line at

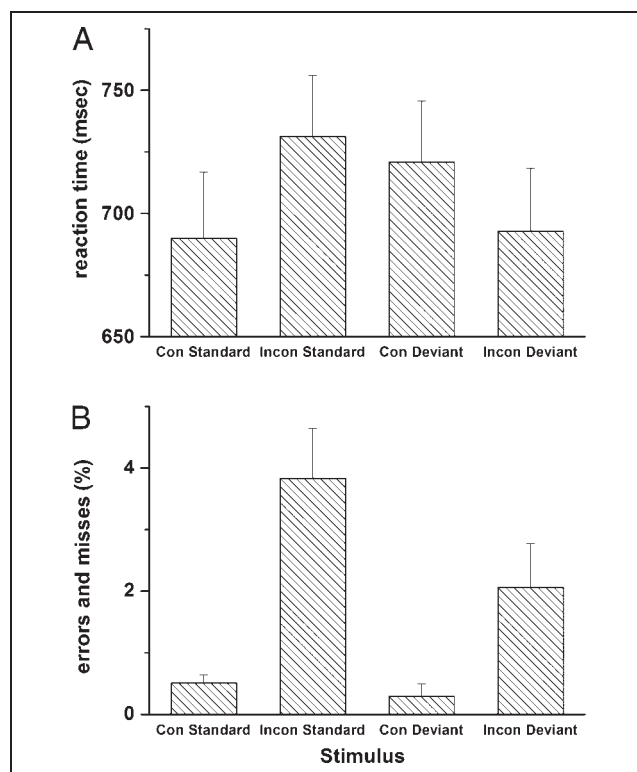


Figure 1. Performance parameters: (A) Reaction time for subjects after standard or deviant auditory stimuli followed by congruent (con) or incongruent (incon) Stroop-word presentations. (B) Number of summed errors and misses for subjects after standard or deviant auditory stimuli followed by congruent (con) or incongruent (incon) Stroop-word presentations. Vertical bars denote standard errors of the mean.

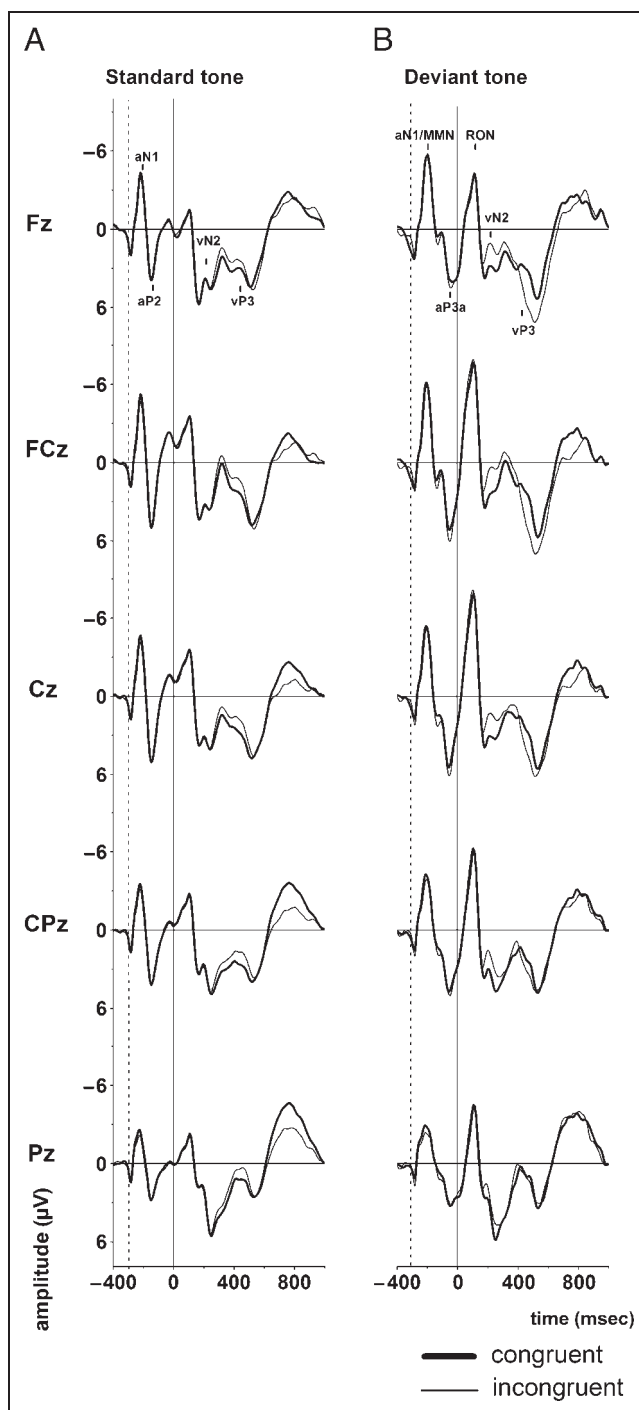


Figure 2. Grand averages of stimulus-locked ERPs are shown after standard (A) or deviant (B) tones (vertical dotted line, -300 msec) that are followed by congruent or incongruent visual Stroop-word presentations (vertical solid line, 0 msec; a = auditory; v = visual).

-300 msec) produced a typical N1–P2 complex (Figure 2A), whereas deviant auditory stimuli (Figure 2B) elicited a broader and heightened negativity in the 100 – 160 msec range, including the N1 component and the MMN. Analysis revealed a significantly delayed N1 latency in response to deviant tones (FCz; mean = 112 msec) compared to frequent tones (FCz; mean = 87 msec), indicating the de-

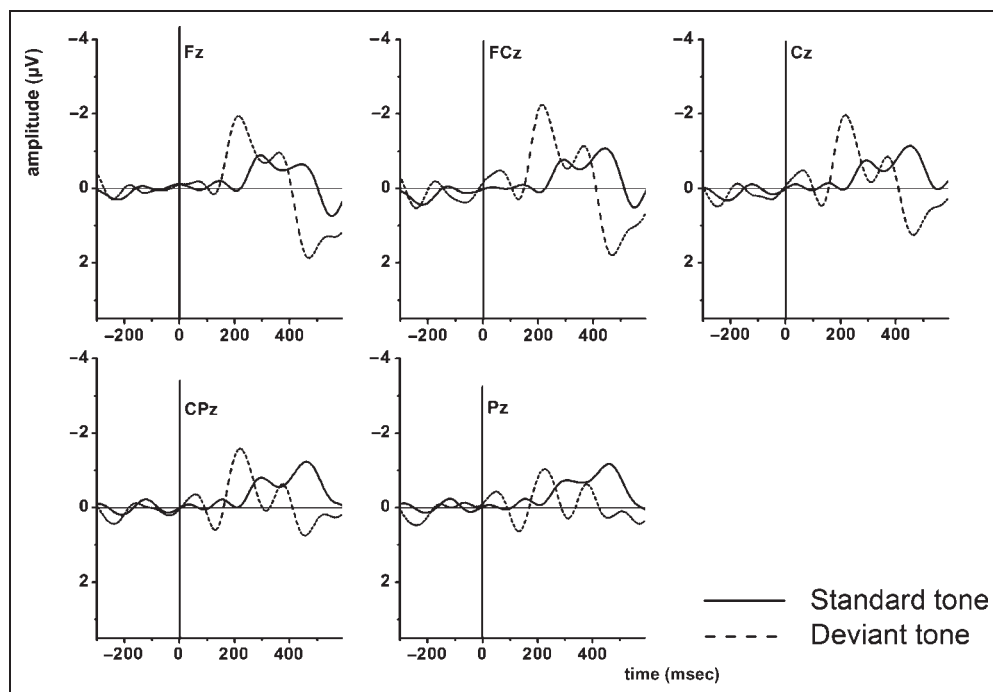
velopment of a MMN [$F(1, 16) = 6.44, p < .05$]. Subsequently, a P3a component as orienting (230 – 350 msec) and a reorienting negativity (RON) (350 – 500 msec) developed in the deviant auditory condition. The Stroop stimuli (straight line; Figure 2) evoked a visual N1–N2 complex that was followed by an early and late P3 component (P350, P550) as described in detail in a previous study (Mager et al., 2007).

In both auditory conditions, conflicting (incongruent) visual stimuli evoked a negativity compared to the non-conflicting (congruent) Stroop condition. However, the negativity appeared to occur earlier when Stroop stimuli followed an auditory mismatch (deviant tone; Figure 2B). In the absence of an auditory mismatch (standard tone; Figure 2A), the (Stroop) conflict-related negativity emerged later in the range between 275 and 525 msec. This late negativity was also demonstrated in other studies using Stroop paradigms without precedent auditory stimuli (Mager et al., 2007; Leung et al., 2000; West & Alain, 1999; Rebai et al., 1997).

The ANOVA with the factors Stroop condition, auditory condition, time segment, and electrode position revealed an interaction between Stroop condition, auditory condition, and time segment [$F(5, 80) = 7.04, p < .0001$], suggesting that generally stimulus-conflict (Stroop conflict)-related negativity was found at different times depending on the auditory condition. Furthermore, there was a four-way interaction between Stroop condition, auditory condition, time segment, and electrode position [$F(20, 320) = 4.62, p < .0001$]. This interaction shows that the negativity related to Stroop incongruence emerged not only at different times but also at different electrode positions depending on the auditory condition. Post hoc analysis showed that after standard tones, incongruent Stroop stimuli evoked a significant negativity in the time segments between 300 and 525 msec (all three segments $p < .05$), as also shown previously (Mager et al., 2007), whereas after deviant tones, a significant negativity developed and decayed earlier in the time segments between 150 and 375 msec (all three segments $p < .05$). After standard tones, the conflict-related negative shift in the time segment between 300 and 525 msec was less pronounced at frontal leads [Fz: mean = -0.45 μV , $F(1, 320) = 28.1, p < .0003$; FCz: mean = -0.69 μV , $F(1, 320) = 65.55, p < .0001$] compared to more dorsal leads [CPz: mean = -1.00 μV , $F(1, 320) = 136.06, p < .0001$; Pz: mean = -0.81 μV , $F(1, 320) = 89.45, p < .0001$]. In contrast, after deviant tones, the conflict-related negative shift in the time segment between 150 and 375 msec developed more pronounced at frontal leads [Fz: mean = -1.66 μV , $F(1, 320) = 377.5, p < .00001$; FCz: mean = -1.82 μV , $F(1, 320) = 453.5, p < .00001$] compared to more dorsal leads [CPz: mean = -1.01 μV , $F(1, 320) = 140.9, p < .00001$; Pz: mean = -0.68 μV , $F(1, 320) = 63.85, p < .00001$].

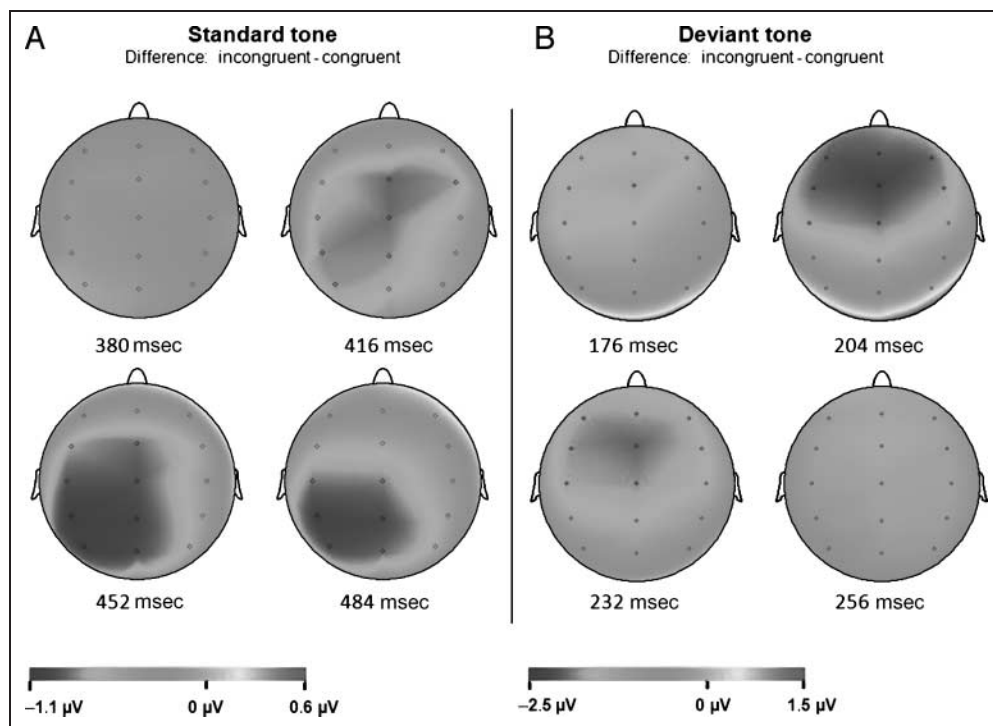
To illustrate stimulus conflict (Stroop incongruency), related potential change difference curves (incongruent

Figure 3. Averaged ERP difference waveforms (i.e., incongruent waveform minus congruent waveform) illustrate the appearance of an early negativity with a fronto-central amplitude maximum in trials after deviant tones compared to the more widely distributed “delayed” negativity after trials with standard tones.



minus congruent responses) were calculated separately for each auditory condition. The resulting curves are presented in Figure 3 and show the earlier Stroop-conflict-related potential changes and the altered topographical distribution after deviant auditory stimuli. The corresponding scalp maps indicate the distribution of the incongruency-related negativities in either auditory condition (Figure 4).

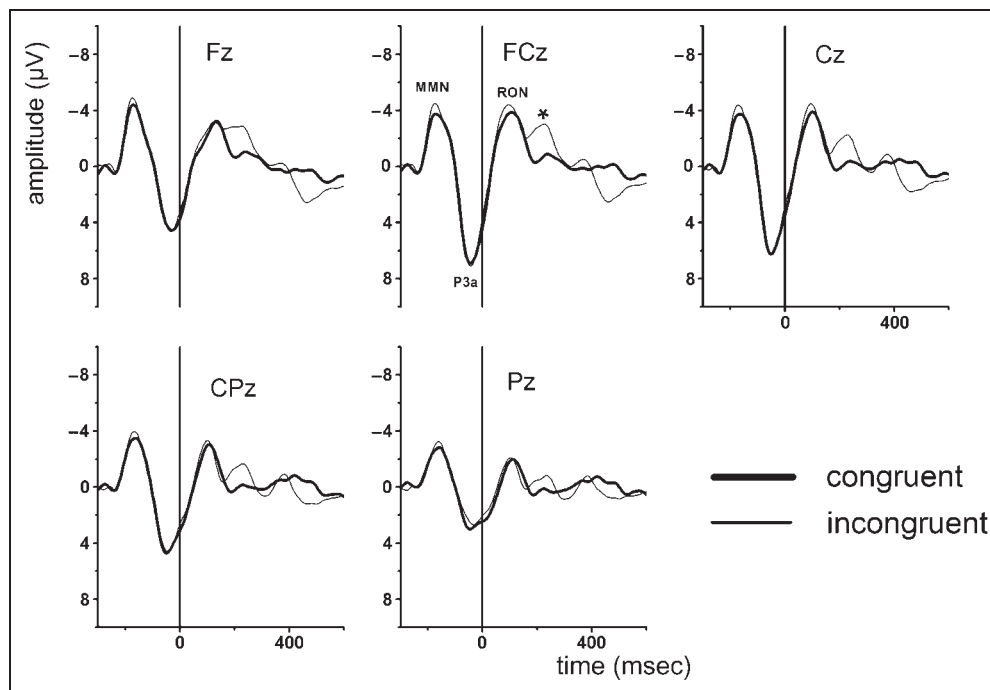
Figure 4. Scalp maps of the ERP difference waveforms (i.e., incongruent waveform minus congruent waveform) showing the maximal conflict-/interference-related negativity after standard (A) compared to deviant (B) tones (see also Figure 3).



Analysis of Difference Waveforms

As shown in Figure 2B, two auditory mismatch-related components (decaying aP3a and developing RON) interfered with the onset of the responses to the visual Stroop stimuli (straight line at 0 msec). To estimate the amount of interference and to determine MMN, aP3a and RON deviant minus standard difference curves were

Figure 5. Averaged ERP difference waveforms (i.e., deviant waveform minus standard waveform) show the MMN, P3a, and RON components separately for congruent (thick line) and incongruent (thin line) Stroop-word presentations. Note the additional negative component (*) subsequent to RON in the incongruent Stroop condition that is nearly absent in the congruent condition.



calculated as shown in Figure 5. As expected, peak latencies and amplitudes of the MMN, P3a, and RON components were not altered by the Stroop condition ($p > .2$). However, subsequent to the RON, an additional negativity emerged in the range between 150 and 300 msec in the incongruent Stroop condition, showing a maximum amplitude at FCz (*) that was nearly absent in the congruent Stroop condition. A comparison of the peak amplitudes in the incongruent and congruent Stroop condition (150–300 msec) revealed a significant effect for anterior–posterior location [$F(4, 64) = 5.68, p < .007$]. The peak amplitude difference was about $-2.66 \mu\text{V}$ at FCz ($p < .007$) compared to $-0.44 \mu\text{V}$ at Pz ($p = .44$). The incongruency-related negative shift at FCz was clearly distinct from that at the more dorsal lead Pz (linear contrasts, $p < .005$), supporting the view of a more frontal distribution.

DISCUSSION

Performance and ERP components associated with mismatch and conflict processing were monitored using a cross-modal paradigm with pairs of task-irrelevant auditory and subsequent task-relevant visual Stroop stimuli in a response task. A general prediction was that mismatch by deviant auditory stimuli modulates the subsequent Stroop task differentially depending on whether the visual stimulus represents a conflict or not. Indeed, a main finding was that auditory deviance did not have a unique effect on the processing of Stroop stimuli: After standard auditory stimuli, RT to incongruent Stroop stimuli was delayed compared to that after congruent

Stroop stimuli. This finding is in line with our previous study (Mager et al., 2007). However, after deviant auditory stimuli, RT to incongruent Stroop stimuli was faster than to congruent Stroop stimuli. Obviously, deviant auditory stimuli specifically improved processing of subsequent conflicting (incongruent) Stroop stimuli and impaired processing of nonconflicting (congruent) stimuli. The fact that the error rate was lower after deviant than standard prestimuli indicates that speed–accuracy tradeoff is not the reason for the observed interaction.

On the electrophysiological level, an interaction between auditory prestimuli and Stroop stimuli was also found: The ERPs showed the expected sequence of MMN, P3a, and RON (Figure 5) after auditory deviants compared to standards. After onset of the Stroop stimulus, a negativity is generally elicited for incongruent compared to congruent Stroop stimuli. However, this negativity has different characteristics depending on the preceding auditory stimulus. After standard auditory stimuli, it appears late and distributes widely over fronto-central to posterior midline areas (Mager et al., 2007). In contrast, after deviant auditory stimuli, it appears as a more phasic early negativity with a more fronto-central midline distribution (Figure 2 and Figure 3). In fact, in the traditional deviant minus standard difference waveforms (Figure 5), the negativity emerges as an additional (fronto-central) negative component. This pattern of results can be explained in two ways: Deviant auditory prestimuli may lead to a more synchronized firing of neural assemblies so that the early fronto-central subcomponent after incongruent visual stimuli, which is also present after standard stimuli, is enhanced and sharpened. Alternatively, deviant auditory prestimuli may trigger an additional early fronto-central

negativity. In any case, it appears that deviant auditory prestimuli enable an improved processing of subsequent visual stimuli with incongruent stimulus features. On the neurophysiological level, this improvement is associated with the development of a phasic fronto-central negativity, which may play a role in this cross-modal priming effect. An alternative explanation of the behavioral results is that deviant auditory prestimuli do not prime the processing of conflicting visual stimuli but rather the response which is related to “conflict.” However, this account cannot easily explain the enhanced or additional negativity after incongruent visual stimuli.

Basically, such a priming effect could have a high functional impact. Mismatch in auditory perception is a common cue to indicate upcoming dangerous events or changes in the environment (Tiitinen, May, Reinikainen, & Näätänen, 1994). It is evident that, in such situations, the risk increases that the subject is confronted with conflicts of any kind in the next seconds. Therefore, after perceptual auditory mismatch, it would be advantageous for an individual to transiently improve the efficiency to detect and process ongoing conflicts. The present behavioral and electrophysiological data provide evidence for enhanced cognitive function (conflict processing) after mismatch. Supporting this view, pure processing competition in a sense that auditory mismatch draws attentional resources away from the Stroop task may explain the deteriorated performance in non-conflict trials (Escera et al., 2001) but does not account for the observed performance improvement in conflict trials. We hypothesize that our data reflect conflict priming. If priming is viewed as activation of neuronal clusters, the first cluster might be activated by the auditory mismatch, and surrounding clusters (interconnected due to similar function) might become more activated. Thus, when the subsequent Stroop conflict occurs, conflict-related clusters might be already partly activated, resulting in the observed facilitated conflict processing such as the development of the fronto-central negativity. Of course, in the present study, the spatial resolution of the ERPs is not sufficient to assign a clear locus to the deviance-/conflict-related negativities and to name the neuronal assemblies underlying the auditory priming process. However, some recent fMRI findings addressing responses to auditory deviance or visual conflict point at shared neuronal structures: Various studies attempting to demonstrate generators of the MMN have repeatedly found evidence for frontal subcomponents (Marco-Pallares et al., 2005; Jemel et al., 2002; Waberski et al., 2001; Alho et al., 1994; Giard et al., 1990), even when the exact localization and function of such MMN subcomponents is still a matter of debate and so far not definitely proved (Deouell, 2007). This evidence implicates mainly the inferior frontal cortex and possibly also the medial frontal cortex. Interestingly, the only available fMRI studies investigating Stroop stimulus interference in the absence of response conflict, and thus, matching our paradigm,

reveal the activation of prefrontal structures such as the lateral prefrontal cortex and regions along the inferior frontal sulcus (Zysset, Schroeter, Neumann, & Yves von Cramon, 2006; Zysset et al., 2001). Contrasting congruent versus incongruent conditions, the authors found the strongest activation along the banks of the inferior frontal sulcus. Therefore, one might speculate that these regions contribute to the observed priming effect. The comparability of our data with other fMRI studies using the more traditional Stroop paradigm is restricted because here additional confounding processes are involved.

It remains to be shown whether the observed priming works only with auditory deviants that are known to differ from visual deviants in various aspects, which is also reflected in the ERPs (Berti & Schroger, 2001). Hence, it would be interesting to know in what way the priming effect would occur in case of visual deviants or emotional cues as prestimuli. Using a double conflict task, Fan et al. (2003) found no clear evidence for improvement or deterioration of conflict processing; while the RTs suggested faster processing for double incongruence, the error rates were higher for double incongruence. A further important issue that should be addressed in subsequent studies is the influence of the stimulus onset asynchrony between prestimuli and imperative stimuli on the expected behavioral and ERP parameters.

Our data show that deviant auditory prestimuli facilitate the processing of stimulus-related conflict. Further studies are needed to determine whether this finding might reflect a more general neurocognitive mechanism to transiently improve higher cognitive functions on demand.

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