Research Report

Perceptual and cognitive task difficulty has differential effects on auditory distraction

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ABSTRACT

When a task-irrelevant feature of an auditory stimulus varies at rare and unpredictable times, the processing of this change interferes with the processing of task-relevant stimulus information. The present study investigated whether this distraction effect is modulated by the difficulty of the auditory task. Event-related potentials (ERPs) and behavioral responses were recorded while subjects classified stimuli based on their temporal dimension. In one condition, the task was made more difficult by decreasing the perceptual discriminability (temporal distinctiveness) of the stimuli. In a second condition, the difficult task involved an increase in memory load: subjects were asked to assess the duration of the current compared to that of the previous stimulus. The occurrence of an infrequent task-irrelevant change in the pitch of the stimulus caused distraction in all task conditions. Following this change, performance deteriorated, and a distinct P3a component was visible in the ERP. Importantly, the extent of this distraction effect was significantly enhanced during the high memory load task, but not during the difficult perceptual task. It may be that the attentional resources afforded to the stimuli, rather than task difficulty, affected the extent of the distraction response. When the processing requirements of a task demand more highly focused attention for stimulus processing, the processing of the distracting information embedded within this stimulus may inadvertently also benefit from this attention.

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1. Introduction

Distraction can be defined as the involuntary switching of attention from the processing of task-relevant to the processing of task-irrelevant information. Distraction may thus be viewed as an obstacle to task execution. It may however also be viewed as an adaptation necessary for survival, forcing the individual to become aware of biologically relevant information regardless of current processing priorities. In the auditory domain, Näätänen (1992) purports that distraction is caused by certain highly relevant transient aspects of stimulation, most notably, an abrupt change in stimulus energy or a violation of acoustic regularity. Evidence for this comes from studies demonstrating that the occurrence of such task-irrelevant auditory events may lead to deterioration in performance on an ongoing task, whether this task is of a visual (Escera et al., 1998) or auditory (Schröger and Wolff, 1998) nature. Of course, not all transient aspects of stimulation will be successful in causing distraction; both stimulus (bottom-up) and psychological (top-down) factors may interact in determining if the task-irrelevant auditory event warrants further evaluation.

In order to uncover these factors, the auditory distraction literature has heavily relied on the analysis of event-related

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potentials (ERPs). This is because, in addition to the behavioral performance cost, the detection of and orientation to a task-irrelevant auditory change yields a distinct signature on the ERP. In particular, the P3a component has been viewed as an index that such an attention-switch has occurred (for a review, see Escera et al., 2000). Its peak, maximal at fronto-central sites on the scalp, is typically observed 250–300 ms following the occurrence of a distracting task-irrelevant stimulus. It is preceded in time by an enhanced N1 and/or a mismatch negativity (MMN) component, depending on the physical nature of the transient event. A small physical change in the regularity of the acoustic sequence will primarily elicit an MMN, peaking from 100–200 ms. The MMN is claimed to reflect the pre-conscious detection of this change (Näätänen, 1992). The MMN–P3a complex may be followed by a much later negativity, the reorientation negativity (RON), a component that possibly underlies the process of reorienting back to the task-related information following distraction (Schröger et al., 2000).

Current behavioral and ERP evidence suggests that distraction mediated through change detection may be modulated by various factors: the extent (size) of this change, such that larger physical difference between standard and deviant stimuli will result in enhanced distraction (Berti et al., 2004; Yago et al., 2001); the (un)predictability of acoustic change, such that predictable (e.g. visually cued) acoustic changes do not cause distraction (Sussman et al., 2003); the extent of channel separation between task-relevant and -irrelevant information, such that a small change occurring in the same spatial and temporal auditory channel as the task information results in greater distraction than when this auditory change arises in a more distinct visual channel (Schröger and Wolff, 1998); and the demands of the task. The present study aims at further clarifying the effect of task demands on attention-switching toward a task-irrelevant auditory change.

Attentional capacity is limited, and thus the more this capacity is consumed by the task-at-hand, the greater becomes the need for selective processing of task-relevant over task-irrelevant information. As such, a task-irrelevant auditory change may be less distracting during tasks making greater demands on the limited attentional resources. Studies of the effect of task demands on the MMN have nevertheless shown that the pre-conscious detection of task-irrelevant auditory changes, as indexed by MMN, is only minimally (and under certain circumstances) influenced by the nature and demands of the primary task (for a review, see Muller-Gass et al., 2006). On the other hand, the extent to which this detected change then captures attention, as indexed by the P3a, has been reported to be affected by task demands. Harmony et al. (2000) and Muller-Gass et al. (2006) reported a significant inverse relationship between the amplitude of P3a elicited by deviant stimuli presented in a to-be-ignored auditory sequence, and the difficulty of a visual task. These results propose that when subjects are involved in a more difficult visual task, a task-irrelevant auditory change captures attention to a lesser extent (see however Munka and Berti, 2006, for non-significant visual task effects on P3a).

The present study examines the effect of the difficulty of an auditory task on task-irrelevant auditory stimulus processing. It is possible to selectively attend to a channel defined by a certain auditory feature while disregarding a channel that contains auditory stimuli not sharing this feature (Cherry, 1953). Here however, the selection leading to further processing of task-relevant over task-irrelevant stimuli is less rapid than when task relevance is defined by modality because the spatial channel separation between stimuli is less distinct. Consequently, task-irrelevant stimuli occurring in the same modality may not be as readily ignored, and have shown to cause larger distraction effects than when presented in a different modality (Schröger and Wolff, 1998). For this reason, auditory task difficulty may have different effects on distraction than visual task difficulty. Indeed, the opposite finding was reported by Comerchero and Polich (1999), using an auditory sequence containing task-relevant (standard and target tones) and task-irrelevant (non-target tone) stimuli. A P3a component was elicited following the task-irrelevant stimulus in the condition in which the standard and target stimuli were difficult to discriminate, but was not apparent when their perceptual discriminability was made easier. Thus, in the more difficult auditory task, the increased attentional resources afforded to the processing of task-relevant stimuli also benefitted the intrusion (i.e. processing) of task-irrelevant stimuli. This study however failed to clearly establish a to-be-attended and a to-be-ignored channel, as both task-relevant target and -irrelevant non-target stimuli differed from the standard on the basis of pitch.

The effect of auditory task difficulty was also examined by Berti and Schröger (2003), using an auditory paradigm in which task-relevant and -irrelevant information is easily discerned based on a physical feature of the stimulus. In this paradigm, the subject’s task is to discriminate between equiprobable long and short duration auditory stimuli. At rare and unpredictable times, the pitch of the auditory stimulus is slightly changed but this is irrelevant to the duration discrimination task. The deviant stimulus captures attention, resulting in an increase in reaction time for the duration classification task, and eliciting a prominent P3a and RON. Berti and Schröger investigated the effects of task difficulty by manipulating memory load. In the easy low-load condition, subjects were asked to classify the duration of the current stimulus, while in the more difficult high-load condition, that of the previous stimulus. Both the P3a and RON elicited by the deviant stimulus were attenuated in the high-load relative to low-load condition. The RT delay observed following presentation of the deviant in the easy condition was also significantly reduced in the difficult task. The authors concluded that a more difficult auditory task, making additional demands on working memory, does not benefit task-irrelevant information processing but rather may inhibit it. However, it should be noted that the Berti and Schröger 1-backward task requires the subject to respond to the previous stimulus while simultaneously processing the current stimulus. This task thus involves a divided attention or an implicit dual-task situation. The manipulation of task difficulty in the Berti and Schröger study therefore affects overall (stimulus and response) processing demands. Nevertheless, the processing demands of the current stimulus were not manipulated.

The purpose of the present research is to examine distraction effects initiated by a task-irrelevant auditory change when the processing demands of the current stimulus...
are increased. An auditory duration discrimination task will be rendered more difficult through two different manipulations, involving different stages of information processing. In one condition, the task is made more difficult by increasing memory load (M-Difficult); in a second condition, by decreasing the perceptual discriminability of the stimuli (P-Difficult). In the M-Difficult task, subjects were asked to assess the duration of the current stimulus and compare it to that of the previous stimulus. In contrast to the Berti and Schröger task, this thus requires the distractor stimulus to be processed prior to the selection and initiation of the behavioral response. In the P-Difficult task, the temporal difference between the long and short duration stimuli was reduced. This latter manipulation hence implicates additional processing at the level of stimulus perception/identification rather than involving working memory. The present study should clarify whether distraction is affected by auditory task difficulty and if so, whether its effects occur independently of the way in which task difficulty is manipulated.

2. Results

2.1. Behavioral data

As illustrated in Fig. 1, both task condition and stimulus type (standard, deviant) had important effects on behavioral performance. A significant interaction of these factors was obtained from the analysis of hit rate, \( F(2,24)=4.6, p<0.03 \). A post-hoc analysis of this interaction showed that mean hit rate was modulated by task for both standard and deviant stimuli: hit rate was highest in the Easy task (\( M=0.95 \) and 0.91, respectively), significantly decreased in the P-Difficult condition (\( M=0.87 \) and 0.84, respectively), and significantly decreased again (compared to both Easy and P-Difficult conditions) in the M-Difficult condition (\( M=0.82 \) and 0.73, respectively). The post-hoc analysis further indicated that, for all task conditions, mean hit rate was also affected by the type of stimulus (although for the P-Difficult condition, this effect just failed to reach significant, \( p<0.07 \)); deviant stimuli were associated with reduced hit rates when compared to standard stimuli. The significant Task × Stimulus type interaction can be attributed to the extent of difference (slope) between standard and deviant hit rates, a so-called ordinal interaction. In order to clarify this effect, a further one-way ANOVA was performed on the hit rate difference (deviant minus standard) score. This difference score was significantly modulated by task, \( F(2,24)=4.6, p<0.03 \). Post-hoc analysis of this main effect demonstrated that the difference score was largest for the M-Difficult condition (\( M=−0.09 \)), and significantly smaller for the Easy and P-Difficult conditions (\( M=−0.04 \) and \( −0.03 \), respectively). No significant differences were however noted between the scores of these latter two conditions.

The pattern of results for RT mirrored that for hit rate. A significant Task × Stimulus type interaction was found, \( F(2,24)=4.9, p<0.02 \). Post-hoc testing on this interaction showed that the nature of the task modulated RT, whether the stimulus was a standard or a deviant. Consistent with the hit rate data, RT was lowest during the Easy task (\( M=592 \) and 615 ms, respectively), significantly increased during the P-Difficult task (\( M=642 \) and 666 ms, respectively), and significantly increased again (relative to both other conditions) during the M-Difficult task (\( M=662 \) and 703 ms, respectively). The post-hoc analysis also indicated that in all task conditions, the deviant stimulus yielded significantly prolonged RTs compared to the standard stimulus. As the interaction was again ordinal, an ANOVA was performed on the RT difference (deviant minus standard) scores. A significant main effect of task was found, \( F(2,24)=4.9, p<0.02 \). Subsequent post-hoc testing showed that the RT difference score was significantly larger during the M-Difficult task (\( M=41 \) ms) when compared to either the Easy or P-Difficult conditions (\( M=23 \) and 24 ms, respectively). RT prolongation was not significantly different for the latter two conditions.

2.2. ERP data

The effect of task demands on general auditory processing was assessed by examining the ERPs elicited by the standard stimulus (see Fig. 2). Although the N1 was visibly enhanced at
ERPs to Standard Stimuli

![Graph showing ERPs to Standard Stimuli](image)

Fig. 2 – Grand average ERPs elicited by the standard stimulus during all task conditions. An N1 enhancement is visible in the ERP elicited during the high load task (M-Difficult). Significant differences among conditions were present at fronto-central sites in the time window ranging from 200 to 460 ms following stimulus onset. Task effects were also found on the P3b at Pz.

ERPs to Deviant Stimuli

![Graph showing ERPs to Deviant Stimuli](image)

Fig. 3 – Grand average ERPs elicited by the deviant stimulus during all task conditions. A prominent P3a was elicited by the deviant stimulus during the task requiring increased memory load (M-Difficult task). This P3a was significantly larger than that obtained in the other task conditions.

fronto-central sites in the M-Difficult condition when compared to the other conditions, the effect of task on the intervals containing this deflection (from 100-140 ms) just failed to reach significance, ps < 0.11 (this task-related N1 enhancement was also present in the ERP to the deviant stimulus, see Fig. 3). Significant task differences started to emerge in the standard ERP as early as 200 ms following stimulus onset at fronto-central sites. An enhanced and sustained negativity was apparent in the standard ERP of the P-Difficult condition compared to that of the Easy and M-Difficult conditions, F(2, 24) = 3.5-32.2, for intervals from 200-460, ps < 0.05. The Post-hoc testing indicated a second task-
related effect on the standard ERP. During the intervals from 360–460 ms, the ERP elicited during the M-Difficult condition was significantly more positive than that of the other conditions, likely due to an early and/or larger P3b in this condition. Indeed, the P3b peak analysis at Pz indicated a significant main effect of task for both latency and amplitude of P3b, $F(2,24)=19.4$, $p<10^{-5}$ and $F(2,24)=5.0$, $p<0.02$, respectively. P3b peaked significantly earlier ($M=478$ ms) and was smaller in the Easy relative to both Difficult conditions. In turn, P3b peaked significantly earlier in the M-Difficult ($M=527$ ms) relative to the P-Difficult ($M=592$ ms) condition.

The grand average ERPs to the deviant stimulus are presented in Fig. 3. An early positivity, the P3a, is apparent at approximately 340 ms. The significant effect of task condition on the amplitude of P3a at frontal and central sites is clearly visible in this figure, $F(2,24)=11.4$, $p<10^{-3}$ and $F(2,24)=11.5$, $p<10^{-3}$, respectively. The amplitude of the P3a elicited in the M-Difficult condition was significantly enhanced relative to that elicited in the Easy and P-Difficult conditions, whereas the P3a in these latter conditions was not significantly different. There were no significant effects of task on the latency of P3a. When compared to the standard waveform, the P3b observed in the deviant waveform peaked about 30 ms later, $F(1,12)=5.4$, $p<0.04$; this effect did not however interact with task condition.

Task effects on early deviance-related processing were assessed in the difference waveforms, which are depicted in Fig. 4. As may be observed in this figure, two distinctive negative peaks are apparent at Fz in the time window extending from 110 to 240 ms following stimulus onset. The earlier peak, reaching maximum amplitude at approximately 130 ms, was largest at frontal sites, decreased at more posterior sites, and inverted in polarity at this latency at the mastoids. The later peak, with maximum amplitude at approximately 200 ms, showed a more fronto-central distribution, and appeared as a negativity at mastoid sites. At both frontal and mastoid sites, task demands did not significantly affect any of the intervals ranging from 0 to 240 ms, which included these two prominent deflections. Later positive and negative deflections are also visible in the difference wave. However, as the assumptions restricting the use of the difference waveform where not met, ERP components reflecting post-sensory processes were only quantified in the raw deviant waveform (For further elaboration, see discussion; Besle et al., 2004).
behavioral data pertaining to the two difficult tasks indicate that the M-Difficult task was also significantly more difficult to perform relative to the P-Difficult task. Additionally, the N1 elicited during the M-Difficult condition was larger (although non-significantly) than that obtained in the P-Difficult or Easy conditions. N1 amplitude is enhanced with stimulus processing demands, reflecting either the additional attentional capacity required for, or the increased arousal during a difficult task (for a review, see Nätänen and Picton, 1987). Together these data thus suggest that while the P-Difficult task was indeed more difficult to perform than the Easy task, the largest attentional demands were made during the M-Difficult condition.

Independently of task demands, the small task-irrelevant deviance was detected and captured attention, thereby interfering with task-related processing. Deviant stimuli were associated with longer RTs and lower hit rates on the classification task when compared to standard stimuli. Consistent with this, the ERPs elicited by the deviant stimuli included an early deviance-related negativity (DRN) followed by a distinct P3a component. The DRN appeared to consist of two negativities, probably the MMN and N2b, and was not affected by task demands. The MMN peaked around 130 ms, showed the classic fronto-central scalp distribution and polarity reversal at sites below the Sylvian fissure. The absence of task effects on the MMN has also been reported in other studies (Alho et al., 1992; Berti and Schröger, 2003; Muller-Gass et al., 2006), and lends support to the view that the pre-conscious detection of auditory change is strongly automatic. Although it should be noted that in the current paradigm, the MMN process is followed in close succession to (and therefore may be overlapped by) that of the N2b, a component related to attentive deviance processing.

Importantly, the task manipulation did however affect the extent of the attention switch toward the auditory change. Distraction effects were significantly more pronounced in the M-Difficult task, yet similar between the P-Difficult and Easy task. The response delays and additional errors occasioned by the change occurrence were approximately 23 ms and 4%, respectively, for the P-Difficult and Easy conditions, while those for the M-Difficult were 41 ms and 9%. Furthermore, the P3a elicited by the deviant stimulus was much more prominent in the M-Difficult compared to that evoked during the other conditions. In contrast, the time-course of the task-irrelevant processing was similar in all task conditions, as is apparent in the deviant ERP waveform: The P3a and a subsequent (around 400–450 ms) negativity, akin to the RON component, peaked at similar latencies during all tasks. Due to the differential task-related amplitude shifts in the deviant ERP, amplitude differences in the RON were difficult to assess. The RON (and frequently, the P3a) is evaluated in the difference wave, computed through a subtraction of the standard from the deviant ERPs. The difference waveform is computed in order to eliminate the processing that is common to the standard and deviant stimuli; the remaining activity can then be attributed to the processing of the auditory change rather than to the processing of the deviant stimulus per se. In the present study, the difference waveform was not utilized for the examination of task-irrelevant processing beyond sensory analysis (i.e. DRN components); instead P3a was evaluated in the raw deviant waveform. In order for the difference waveform to be useful for post-sensory (i.e. P3a and RON) analysis, it would have to be assumed that the processing of the distracting task-irrelevant information occurs in parallel, without changing the time-course of task-relevant processing, and thus would result in an additive effect on the deviant ERP. This is the case for the sensory analysis related to auditory change. However, subsequent to this, once the task-irrelevant change is detected, processing of this information seems to take priority (regardless of task demands), and task-relevant processing is delayed. Support for this comes from the P3b data: this component peaked significantly later in the deviant compared to standard waveform, presumably because the occurrence of the task-irrelevant change had to be first evaluated. Caution should thus be heeded in the use of difference waveforms particularly when the condition manipulation results in latency shifts of components. Such temporal variation will result in an amplitude variation in the difference waveform, at times appearing as an artificial modulation of a component, or even a spurious difference-related component (for additional discussion on the assumptions restricting the use of the difference wave see Picton et al., 2000; van Boxtel, 2004).

The present results concerning the effect of increased memory load (i.e. M-Difficult task) on auditory distraction appear to be at odds with those of Berti and Schröger, using a similar paradigm and stimuli. While they reported that distraction was significantly reduced (shorter RT delays and smaller P3a) during the high compared to low load task, our results demonstrate the opposite, an increase in the distraction effect during high working memory demands. The differences in these results could be due to the structure of the specific high memory load task. As mentioned previously, in the Berti and Schröger high load task, attention needs to be divided between the demands of motor response and stimulus processing during stimulus presentation. Fewer attentional resources may have thus been available for stimulus processing and this may have diminished the distracting impact of the deviant. Support for this alternative explanation comes from their electrophysiological data. The N1 elicited by both standard and deviant stimuli was smaller in the high relative to low load condition. N1 is typically reduced when stimuli are afforded less attention. By contrast, the N1 was larger during our high load memory condition, suggesting an increase of attention to the auditory stimulation in this condition. In this way, the Berti and Schröger results and the present results are complimentary: their data demonstrate that there is less distraction when the stimuli receive less attention (during...
their high memory load task), while ours show that there is more distraction when the stimuli receive more attention (during our high memory load task).

The present findings thus offer evidence that greater attention to the task-relevant stimulus (which also contains the distractor information) enhances the processing of all stimulus information, including the auditory change. A similar conclusion was made by Lavie (2005) for distraction effects occurring within the visual modality. That is, when target and distractor information are part of the same visual stimulus, additional attention to the target also results in unavoidable additional attention to the distractor. On this basis, Lavie suggests that a clear channel separation between target and distractor information is necessary in order to observe reduced distractor processing during high load tasks. Consistent with this, some studies manipulating visual task difficulty have provided ERP evidence that attention-switching to the task-irrelevant auditory change is mitigated during a difficult compared to an easy visual task (Harmony et al., 2000; Muller-Gass et al., 2006).

The present results thus lead to the proposal that channel separation has an interactive effect with task demands in determining the extent of auditory distraction. However, this interaction does not seem to involve a straightforward relationship with task difficulty, as determined on the basis of behavioral performance, but rather depends on the specific nature of the additional demands made by the task. If the distraction effect were modulated by task difficulty, then it should also have been enhanced in the P-Difficult relative to the Easy task, as a significantly poorer general performance was observed during the former. It is however plausible that the P-Difficult condition, albeit more difficult, did not make significantly greater demands on attentional capacity than the Easy condition. As suggested by Norman and Bobrow (1975), the processing limitations due to the quality of the input to the perceptual system (when, for example, perceptual discriminability is decreased) cannot be greatly compensated by engaging more attentional resources, whereas the subsequent operations performed on this input may utilize these resources. As such, the extent of auditory distraction is not dependent on task difficulty per se but rather on the attentional capacity consumed by the additional stimulus-related operations required by the task.

4. Experimental procedures

4.1. Subjects

Thirteen subjects (8 females) aged from 18 to 31 years (M = 22.5, S.D. = 3.5) were paid an honorarium for their participation. All subjects reported normal hearing, and had no history of neurological/psychiatric disorder. Written informed consent was obtained prior to the experimentation. The study was conducted in accordance with the Declaration of Helsinki.

4.2. Stimuli and procedure

During the EEG recording session, subjects were seated in a sound attenuated room. Auditory sequences composed of long (p = 0.5) and short (p = 0.5) duration stimuli were presented binaurally via insert earphones (EAR 3A). Subjects were instructed to classify each stimulus as belonging to one of two possible categories based on stimulus duration information. In separate conditions, the auditory classification task was varied in its level of difficulty. In the Easy condition, subjects were to classify stimuli as being of either long or short duration, by pressing the appropriate left or right arrow buttons on the keyboard. In this condition, the duration difference between the long (400 ms) and the short (100 ms) stimulus was large, and therefore the classification task was easy to perform. In the P-Difficult (i.e. Perceptual-Difficult) condition, task instructions were identical to those of the Easy condition, but the classification task was made more difficult by reducing the perceptual discriminability of the long (310 ms) and the short (190 ms) stimulus. In the M-Difficult (i.e. Memory-Difficult) condition, the long (400 ms) and the short (100 ms) stimulus were identical to those presented in the Easy condition, but task instructions were changed in order to increase memory load. In this condition, subjects were asked to indicate via button-press whether the currently presented stimulus was of same or different duration relative to that of the immediately preceding stimulus.

The paradigm employed in the present study was derived from that of Berti and Schröger (2003). On the majority of trials, the stimulus (long duration, p = 0.42; short, p = 0.42) was a 1000 Hz, 70 dB SPL tone, i.e. standard stimulus. On the remaining 16% of trials, the frequency of the stimulus was lowered to 950 Hz, i.e. deviant stimulus. This rare frequency change was however task-irrelevant, and subjects were instructed to disregard its occurrence in all task conditions. The stimulus onset asynchrony was fixed at 1800 ms, and the rise/fall time of the stimuli was 5 ms. The order of the presentation of the stimuli was pseudo-randomized. Deviants were separated by at least 3 standards in the train of stimuli.

Prior to the start of the experiment, the subject was trained in each of the classification tasks. During the experiment, two blocks of each of the three task conditions was presented, for a total of 664 stimuli per task condition. The response-to-key mapping alternated between the two same-task blocks for each subject, and the order of conditions was randomized across subjects.

4.3. EEG/ERP recording

EEG activity was recorded from 7 scalp channels (Fz, Cz, Pz, F3, F4, C3, C4) using tin electrodes attached to an electrode cap (Electro-Cap International Inc., Eaton, OH). Two additional channels were recorded from individual tin cup electrodes placed on the left and right mastoids (M1, M2). The nose served as a reference. A vertical EOG was recorded from electrodes placed at the infra- and supra-orbital ridges of the right eye. A horizontal EOG was recorded from electrodes placed at the outer canthus of each eye. The ground electrode was attached to the forehead. Inter-electrode impedances were below 5 kΩ.

The physiological signals were digitized continuously at a 256 Hz sampling rate. The high frequency filter was set at 30 Hz and the time constant at 2 s. Eye movement and blink artifact were corrected using an algorithm operating in the time and
frequency domain (Woestenburg et al., 1983). The continuous data were subsequently reconstructed into discrete trials of 1000 ms, which included a 100 ms pre-stimulus baseline period. Trials containing values greater than ±100 μV relative to the baseline on the EEG channels were excluded from further analyses. The single-subject ERPs were averaged separately for each stimulus type (standard, deviant) and each task condition (Easy, P-Difficult, M-Difficult), yielding 6 different average waveforms per subject. Only correct trials were included in the averages. Subsequently, ERPs were low-pass filtered using an inverse FFT algorithm with a 20 Hz high frequency cutoff.

4.4. Performance and physiological data analyses

Performance (hit rate, RT) on the classification task was determined separately for standard and deviant stimuli, for each task condition. A response occurring between 150 and 1000 ms from the offset of the short duration stimulus was classified as a “hit”. The mean RT was computed by averaging only those trials that included correctly classified stimuli.

For all ERP analyses, the average of the data points in the 100 ms pre-stimulus interval was used as a baseline. The latency window for peak detection was selected based on grand average waveforms. Task effects on general processing were examined by analyzing ERP waveforms elicited by standard stimuli, at Fz and Cz. The waveforms were divided into consecutive 20 ms intervals from 0–500 ms following stimulus onset. All data points within each interval were then averaged yielding a mean amplitude for each interval. Additionally, maximum peak amplitude detection methods were used to score the standard P3b at Pz.

Task effects on distractor (i.e. task-irrelevant deviant) processing were examined by quantifying P3a in the deviant waveform, at Fz and Cz. The reasons for assessing P3a in the deviant instead of difference waveform are outlined in the discussion. The time course of task-relevant processing during the distractor trials was investigated by comparing the latency of the deviant P3b to that of the standard P3b.

Early deviance-related activity (which included the MMN) was quantified in the difference waves; these were obtained by subtracting point-by-point the auditory standard ERP from the respective auditory deviant ERP, at Fz and M1. Mean amplitude values were computed for each 20 ms interval from 0–240 ms following stimulus onset.

Performance measures were subjected to two-way ANOVAs with repeated measures on type of stimulus (Standard, Deviant) and task (Easy, P-Difficult, M-Difficult). Physiological measures were analyzed via one-way repeated measures (task) ANOVAs. For effects with more than one degree of freedom, the original degrees of freedom are reported along with the corrected probability. The Tukey Honestly Significant Difference test was used as a post-hoc procedure following significant effects.

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