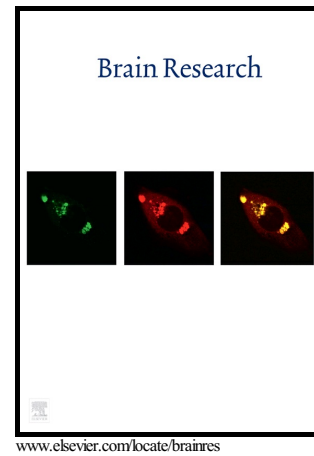


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cue processing in auditory distraction

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Abstract

The human cognitive system has various functions to enhance performance in tasks requiring responses to stimuli. When potentially occurring stimuli are known, we can establish selective attention sets and ignore task-irrelevant events while attending task-relevant ones. When the stimulation is temporally structured, we can rely on constant temporal relationships between stimulus events to prepare for the task-relevant moments. Most distraction paradigms feature task-irrelevant events which are followed by task-relevant ones within a constant interval, and distraction is induced by randomly replacing some of the standard task-irrelevant events. The constant time interval transforms irrelevant events to task-supportive temporal cues, which are integrated into the task-behavior by the participants. The present study investigated whether distracters could be utilized as temporal cues to support task-related processing in a continuous auditory stimulation paradigm. A continuous tone featuring short and long gaps, and pitch glides was presented. Participants performed a gap duration discrimination task, while ignoring glides. Glides could be presented frequently or rarely. In the informative condition, 80% of the glides predicted the presentation time of the forthcoming gap (400 ms), while in the uninformative condition, the occurrence of gaps and glides was independent. Rare glides elicited an enhanced N1, mismatch negativity, and P3 event-related potentials in both informative and uninformative conditions. In informative conditions glides were followed by a contingent negative variation; and rare informative glides elicited an N2b, suggesting that despite triggering distraction-related processes, distracters could be integrated into the task-behavior, and could be utilized as task-supportive cues.

Keywords: attention, distraction, foreperiod, cueing, predictability

1. Introduction

When performing tasks requiring overt or covert reactions to stimulation events, the predictability of the stimulation can often be exploited to streamline processing. If we know what types of stimulus events may occur, we can establish *selective attention sets*, which makes it possible to prepare for task-relevant sensory events while ignoring task-irrelevant ones (e. g. Parmentier, 2014). We can also make use of cues that predict *when* task-relevant events can occur, and prepare for their processing at a given moment in time (Holender and Bertelson, 1965). Numerous studies have shown that selective attention sets can be disrupted by rare, unpredictably occurring, or conspicuous stimulus events (distracters). In the present study, using the method of event-related potentials (ERPs), we investigated whether such distracters can nonetheless be utilized as temporal cues to support task-related processing in a continuous auditory stimulation paradigm.

Variants of the oddball paradigm especially suitable for investigating distraction-related processing have been introduced by Schröger and Wolff (1998b) and Escera, Alho, Winkler and Näätänen (1998). In these *distraction paradigms*, a discrete stimulus sequence is presented, and participants perform a discrimination task related to one aspect of the stimulation. Distraction is induced by infrequently, unpredictably changing a task-irrelevant aspect of the stimulation. In the paradigm introduced by Schröger and Wolff (1998b), participants perform a duration discrimination task in a sequence of short and long tones, in which (the task-irrelevant) tone pitch is occasionally changed (distracter trials). In the paradigm introduced by Escera et al. (1998), participants perform odd/even discrimination for visually presented numbers. Each number is preceded by a task-irrelevant sound, and distraction is induced by occasionally replacing the (task-irrelevant) sound with a different sound. The rationale of these arrangements is that behavioral and ERP response-differences between distracter and non-distracter trials reflect processes related solely to distraction because participants perform the same task on both types of trials.

Variations of these initial paradigms (see e.g.; Berti and Schröger, 2003; Escera et al., 1998; Escera et al., 2000; Escera, Yago and Alho, 2001; Polo et al., 2003; Roeber, Berti and Schröger, 2003; Roeber, Widmann and Schröger, 2003; Schröger and Wolff, 1998a, 1998b)

showed a consistent pattern of results. Response times in distracter trials were longer than in non-distracter trials, and more mistakes were made. In the ERPs (Escera et al., 2000; Escera and Corral, 2007) the distracter-minus-non-distracter difference waveforms showed an enhanced N1 and mismatch negativity (MMN) between 100-250 ms following the onset of the distracting stimulus event, followed by a P3a in the 250-400 ms interval; and finally a negative waveform termed reorienting negativity (RON) could be observed between 400 and 600 ms. These ERPs are usually described in a three-stage model of distraction. The deviant-related N1 enhancement and MMN are generally thought to reflect processes related to auditory change detection (e.g. Näätänen, 1982; Näätänen et al., 2007). P3a is thought to reflect an involuntary selective attention set change, that is, distraction (Friedman, Cycowicz and Gaeta, 2001; Polich, 2007). Finally, RON may reflect processes involved in the restoration of the task-optimal attention set after the distracting event (Berti, 2008; Schröger and Wolff, 1998a; Sussman, Winkler and Schröger, 2003).

To better understand information processing in these paradigms, it is useful to point out that all of these paradigms feature two types of *stimulation events* which differ in terms of their task-relevancy: 1) One type of event is task-relevant in the sense that the occurrence of the event provides the information necessary to select the correct response. For example, in the paradigm introduced by Escera et al. (1998), the onset of the number is the task-relevant event. In the paradigm introduced by Schröger and Wolff (1998b), the task-relevant event occurs at the time point of the short tone offset, at which the tone either stops or continues. 2) The second type of event is task-irrelevant in the sense that it does not convey information regarding the response to be given, but nonetheless, it is a well-detectable transient change in the stimulation which allows the temporal structuring of the stimulation. In the Schröger and Wolff (1998b) paradigm, this event is the tone onset, whereas in the paradigm introduced by Escera et al. (1998) such events are the tone-onsets and -offsets.

These task-irrelevant events may play an important role in distraction paradigms, because these events can be used as *temporal cues* to predict the onset of the task-relevant events, especially if they precede the task-irrelevant events by a constant interval (foreperiod effect, see e. g. Capizzi, Correa and Sanabria, 2013; Holender and Bertelson, 1975; Leynes, Allen and Marsh, 1998). Indeed, this is the case for all the studies referred to above: in these studies,

irrelevant and relevant events were presented with constant temporal separation, typically in the range of 100-200 ms (e.g. Wetzell, Widmann and Schröger, 2012; Berti and Schröger, 2001; Schröger and Wolff, 1998a, 1998b), but even as high as 600 ms in some experiments (Ruhnau et al., 2010). Because of this, it seems reasonable to assume that task-irrelevant events play a “supportive” role in performing the task by allowing temporal preparation for the forthcoming task-relevant event.

There is substantial evidence for the supportive, temporal cueing function of the irrelevant events in these paradigms. In some arrangements, task-irrelevant events cannot be disregarded at all: in a duration discrimination task (Schröger and Wolff, 1998b) the stimulus onset is a crucial reference point, and therefore even small deviations – for example, otherwise hardly noticeable (1%) pitch changes – occurring at the onset result in robust distraction effects (Berti, Roeber and Schröger, 2004). Recent behavioral studies, in which the separation of task-relevant and – irrelevant events was manipulated, as well as whether the irrelevant event was followed by a relevant one on each trial, showed that the distraction-related response time delay was reduced when the foreperiod was not constant and the irrelevant event was unreliable (50% or less) in signaling the forthcoming task-relevant event (Berti, 2013; Jankowiak and Berti, 2007; Li, Parmentier and Zhang, 2013; Parmentier, 2014; Parmentier, Elsley and Ljungberg, 2010; Wetzell, Widmann and Schröger, 2012). These results suggest that in distraction paradigms, participants actually use the “task-irrelevant” events as temporal cues to enhance their task performance, that is, these events are not disregarded at all, but are incorporated in the task-behavior of the participants.

One may even argue that “distraction”-effects observed in these paradigms actually reflect the disruption of the regular task-behavior: That is, despite having the same between-event relationship as for the standard stimulation, distracters may not enable the same preparatory activity for the task-relevant event. The goal of the present study was to investigate whether it was at all possible to exploit a regular temporal relationship between a task-irrelevant *distracter* and a task-relevant event, that is, whether distracting events could be utilized as temporal cues to support task performance.

In contrast with previous studies, in which the discrete, trial-based stimulation protocol established a standard between-event relationship and occasionally changed the identity of the cue event on a low proportion of trials, we used a continuous stimulation protocol in which the identity of the cue events was not varied at all, and distraction was induced by manipulating the presentation frequency (the probability of presenting an event within a given time interval). We administered a continuous stimulation paradigm (Horváth and Winkler, 2010), in which 4-5 minutes long, continuous tones are presented, which feature occasional gaps and frequency glides (rapid – 10 ms long – transitions from one pitch to another). In the present study, the task-relevant events were the gaps: participants performed a gap discrimination task: they indicated by key presses whether a long (100 ms) or short (10 ms) gap was presented (note that due to the short gap duration, the gap onset is too close to the task-relevant moment to be useful in any preparation). The glides were task-irrelevant.

Similarly to discrete paradigms, in which distraction is induced by introducing rare task-irrelevant stimulus variations, in the present study, the probability of the glides was manipulated to induce distraction: glides occurred frequently or rarely in separate conditions, and based on previous studies (Horváth and Winkler, 2010; Horváth, 2014b) it was assumed that rare glides lead to distraction. Note that although numerous studies compare responses elicited by rare and frequent stimuli presented within the same condition to assess the effects of distraction, these effects (as detailed above) are mainly brought about by the difference in presentation frequency, and not by the difference in tone identity (see e.g. Horváth, Winkler and Bendixen, 2008; but see also Horváth, 2014b, and Horváth, in press).

The temporal cue function of the glides was manipulated by randomly inserting glides and gaps independently in one condition, while creating an 80% reliable, predictive temporal glide-gap arrangement in another (glides preceded gaps by 400 ms, see Fig 1). 80% predictability was chosen because this level of reliability seems to be sufficient to compel participants to exploit cues (Posner et al., 1980; in the context of the distraction paradigm: Horváth and Bendixen, 2012). 400 ms separation was chosen, because this would allow efficient preparation (Holender and Bertelson, 1965), while allowing the observation of the relevant ERPs (see below). The orthogonal combination of the two manipulations resulted in four conditions: an informative frequent glide, an informative rare glide, an uninformative frequent glide, and an uninformative

rare glide condition. In this design, ERPs related solely to distraction would be observable in the uninformative rare-minus-frequent waveforms as described above, whereas solely cue utilization-related ERP effects would be observable in the frequent informative-minus-uninformative difference waveforms, and the main question of interest is whether interactions between these “pure” effects would occur in the informative rare glide condition.

In this paradigm, the utilization of temporal cues may be manifested in the ERPs in various ways: First, participants may form a selective attention set allowing the enhanced detection of the cue, which may be manifested as the enhancement of the N1 waveform (e.g. Hillyard et al., 1973; Kauramäki, Jääskeläinen & Sams, 2007; Lange, 2013), which may include contributions from the processing negativity (PN) or negative difference (Nd; Alho et al., 1986; Alho, 1992; Mueller et al., 2008) signaling that an attentional trace for the cue was established (Näätänen, 1982). Second, rare temporal cue events may also elicit an N2b (Alho et al., 1986; Folstein and Van Petten, 2008; Näätänen and Gaillard, 1983; Näätänen et al., 2007; Ritter, 1979, 1982, 1992), signaling that the event was registered as being task-relevant. Third, preparatory activity for the task-relevant event is likely to be manifested in a contingent negative variation following the cue (CNV; Dien et al., 2004; Donchin et al. 1975; Leynes, Allen and Marsh, 1998; Liu et al., 2013; McCallum, 1988; Mento, 2013; Smith, Barry and Steiner, 2013; Tecce, 1972; van Rijn et al., 2011; Verleger et al., 2012; Walter et al., 1964), even if the following, target event is omitted in 15-25% of the cases (Bauer, 1993; Walter et al., 1964).

Interestingly, some studies also hint at the possibility that the P3a, which is generally regarded as a reflection of distraction, may be sensitive to cue predictability and cue utilization. Wetzel, Schröger and Widmann (2013) compared a condition with a constant (100 ms) foreperiod between task-irrelevant and -relevant events, and a condition in which the foreperiod varied between 0, 50, 100, 150 and 200 ms. Although individual P3a assessments did not show a between-condition amplitude difference, the group average ERP waveforms seem to show a P3a amplitude increase for constant foreperiods (Wetzel et al., 2013, p. 926, Fig.3; and also a negative shift, potentially a CNV). A further hint for the potential effect of predictability on the P3a amplitude comes from the continuous stimulation distraction paradigm (Horváth and Winkler, 2010). In the study by Horváth and Winkler (2010) although glides occurred unpredictably, the glide-gap separation was 150 ms for 50% of the glides, therefore, participants may have used the

glides as a temporal cue for the forthcoming, task-relevant gap. In this arrangement glides elicited a P3a. When glides and gaps were interspersed independently, and therefore the glides could not be used as cues, the glides did not elicit a P3a (Horváth, 2014a). Although fully independent and coupled glide-gap presentation protocols were not compared directly, these results also hint at the possibility that P3a may be enhanced by the temporal predictive value of the distracter with respect to the task-relevant stimulus event. In a variant of the paradigm introduced by Schröger and Wolff (1998b), Hölig and Berti (2010) made the distracting events explicitly task-relevant: for the distracters participants had to discriminate the distracter pitch (high or low), instead of its duration. Such distracters elicited an N2b and an enhanced P3a in comparison to the condition when distracter events did not require such a task-change, which may indicate that P3a, at least in part, is involved in task-switching or task-set activation (Berti, 2008; Hölig and Berti, 2010, for similar suggestions see Dien, Spencer and Donchin, 2004; Barcelo et al, 2006; Horváth, Winkler and Bendixen, 2008).

In the present study, we hypothesized that in the informative conditions glide-related ERPs will feature an enhanced N1 (possibly involving PN or Nd) due to the establishment of a selective attention set for the glide, and that the glide will be followed by a CNV reflecting preparation for the forthcoming gap. It was further hypothesized that the rare-minus-frequent glide difference waveforms would show the characteristic distraction waveform: an enhanced N1, as well as MMN and P3a. Importantly, we hypothesized that the cue value of the glides would modulate the rare-minus-frequent glide difference waveforms: informative glides would lead to the emergence of an N2b, and the enhancement of the P3a in the difference waveform. Conversely, if cue utilization would be interrupted by distraction, the CNV would be elicited with lower amplitude in the informative rare glides condition than in the informative frequent glide condition.

2. Results

2.1 Behavioral results

Although the present study was not designed for the investigation of the gap-related behavioral and electrophysiological responses, a liberal trial-selection procedure still made it possible to assess distraction- and cue function-related effects manifested in the accuracy and reaction time data. To make meaningful and unbiased between-condition comparisons, we selected glide-gap pairs with a similar temporal structure: we selected gaps which were preceded by a glide in 300-500 ms and were not followed by any glides in 1 s. The 300-500 ms interval was used for the following reason: In the informative conditions, 80% of the glides were followed by a gap in 400 ms. In the uninformative conditions, however, this 400 ms glide-gap separation is extremely rare because of the independent presentation of glides and gaps. To include a reasonable number of trials with close to 400 ms separations, gaps with 300-500 ms glide-gap intervals were selected. The 1 s glide-free interval following the gap was chosen to make sure that no interference from glides presented during the response interval contaminated the data. Even with the liberal trial selection, two participants did not have trials with responses, that is, they failed to respond to gaps in the selected trials in the rare uninformative condition. For this reason they were not included in the following accuracy and reaction time analyses.

To assess gap-related accuracy, correct response rates were calculated. The 2×2 ANOVA of the correct response rates showed no significant main effect of Glide Frequency ($F(1, 11) = .38$, $p = .55$, $\eta^2_G = .002$) or Cue Function ($F(1, 11) = .04$, $p = .848$, $\eta^2_G < .001$). The Glide Frequency \times Cue Function interaction was not significant ($F(1, 11) = 3.74$, $p = .08$, $\eta^2_G = .004$) either. Participants performed the task in average with 88.9% ($SD = 9.4$) correct response rate.

Gap discrimination performance was assessed in a 2×2 ANOVA of the d' -s. Although a tendency of Glide Frequency \times Cue Function interaction effect ($F(1, 11) = 4.14$, $p = .067$; $\eta^2_G = .023$) was found, the main effect of Glide Frequency ($F(1, 11) = .029$, $p = .86$, $\eta^2_G < .001$) and Cue Function ($F(1, 11) = .164$, $p = .69$, $\eta^2_G = .004$) were not significant. The mean gap duration discrimination sensitivity was 2.62 ($SD = .88$) in the sample.

For the reaction times, a significant Cue Function main effect was found ($F(1, 11) = 9.19$, $p = .011$, $\eta^2_G = .125$), showing that informative foreperiods allowed faster responses than uninformative ones. The average response time was 526.76 ms ($SD = 70.92$) in the informative and 591.02 ms ($SD = 99.98$) in the uninformative conditions. Neither Glide Frequency main effect ($F(1, 11) = .11$, $p = .75$, $\eta^2_G < .001$), nor the Glide Frequency \times Cue Function interaction ($F(1, 11) = .12$, $p = .735$, $\eta^2_G < .001$) was significant.

Due to the nature of the task, participants may also inadvertently respond to glides and not only to gaps. The tendency to respond to task-irrelevant glides was assessed by selecting sequences where a response to a gap was preceding a glide at least in 100 ms, and where these glides were not followed by any other event (glide or gap) in 1 s. Then, the ratio of keypresses to such glides in 1 s was calculated. Using this method, we ensured that the keypress is actually a response to the glide and not a late reaction to a previously presented gap. The number of keypresses to such glides was rare (in average between 0% and 18%), suggesting that participants did understand the task properly, and followed the instructions.

2.2 ERPs

Individual ERPs were on average calculated from 109 epochs (range: 79 to 130; $SD = 14.4$) from the frequent informative condition, 64 (range: 50 to 83; $SD = 9.33$) from frequent uninformative condition, 54 (range: 30 to 73; $SD = 11.47$) for the rare informative condition, and 56 (range: 38 to 77; $SD = 11.02$) for the rare uninformative condition.

The group-average ERPs and the corresponding difference waveforms are presented in Fig. 2. Glides elicited a clear N1, which was peaking at 107 ms in the frequent uninformative condition at Fz. The rare-minus-frequent glide difference waveform in the uninformative condition showed a fronto-centrally negative deflection (labeled as N1/MMN, because this may include both change-detection-related waveforms), peaking at FCz at 129 ms, with its polarity inverted on the mastoids. In the informative condition, an additional negativity following the N1/MMN was observable peaking slightly later (158 ms) at FCz. This peak showed no polarity-inversion at the mastoids. These negative deflections were followed by a centro-parietally

distributed positive waveform peaking at 346 ms at the Pz electrode, which was present in the uninformative condition as well. Due to its parietal distribution, we labeled this waveform P3 instead of P3a (which usually exhibits a fronto-central maximum).

The Glide Frequency \times Cue Function ANOVA of the amplitudes measured the N1 time range (97-117 ms), at Fz showed only a Frequency main effect: $F(1, 13) = 16.788$, $p = .001$, $\eta^2_G = .123$, indicating that rare glides elicited higher N1 amplitudes than frequent ones. Neither the Cue Function main effect ($F(1, 13) = .466$, $p = .507$, $\eta^2_G = .005$), nor the Glide Frequency \times Cue Function interaction ($F(1, 13) = 1.061$, $p = .321$, $\eta^2_G = .007$) was significant.

The Glide Frequency \times Cue Function ANOVA of the N1/MMN amplitudes (measured in the 119-139 ms interval at FCz) showed only a significant Glide Frequency main effect: $F(1, 13) = 41.009$, $p < .001$, $\eta^2_G = .27$, showing that rare glides elicited higher (more negative) N1/MMN amplitudes than frequent ones. Neither the main effect of Cue Function ($F(1, 13) = .457$, $p = .52$, $\eta^2_G = .006$) nor the Glide Frequency \times Cue Function interaction were significant ($F(1, 13) = 2.9$, $p = .11$, $\eta^2_G = .02$). The comparison of the N1/MMN topographies showed no Cue Function \times Electrode interaction ($F(3, 39) = .338$, $p = .80$, $\eta^2_G = .003$), that is, N1/MMN topographies were not significantly different in the informative and uninformative conditions.

The Glide Frequency \times Cue Function ANOVA of the amplitudes of the early negative waveform overlapping the MMN (measured at FCz in the 148-168 ms interval) showed a significant Glide Frequency main effect ($F(1, 13) = 24.08$, $p < .001$, $\eta^2_G = .075$), but the main effect of Cue Function failed to reach statistical significance ($F(1, 13) = 1.19$, $p = .296$, $\eta^2_G = .008$). In addition, a significant Glide Frequency \times Cue Function interaction was present ($F(1, 13) = 23.01$, $p < .001$, $\eta^2_G = .02$) indicating that the ERP was larger (more negative) in the informative than in the uninformative condition. The topographical comparison of the rare-minus-frequent glide difference waveforms showed a significant Cue Function \times Electrode interaction ($F(3, 39) = 9.2$, $p < .001$, $\eta^2_G = .077$), suggesting that the topographical distributions differed between the informative and uninformative conditions across electrodes, that is, this effect was not a modulation of the N1/MMN. Additionally, the difference of the two difference waveforms (i.e. the Glide Frequency \times Cue Function interaction effect) was explored in a 150-ms long window

(from 90 to 240 ms), to determine the latency of its (negative) maximum. The negativity peaked at Cz, at 162 ms (see topography in Fig 3).

Based on its topographical and latency characteristics, this cue function-related negativity might be labeled both as N2b and PN/Nd. Both waveforms are typically elicited by active attention (Alho et al., 1986; Alho, 1992; Mueller et al., 2008) to register task-relevant events (Ritter, 1992) and reflecting template matching processes (Alho, 1992; Näätänen, 1982; Näätänen et al., 2007; Ritter et al., 1992). However, since N2b is related more strongly to attended rare deviations (Patel and Azzam, 2005; Ritter et al., 1992) than PN/Nd, it is more likely that the overlapping negativity is an N2b effect to the attended task-irrelevant events, as it can be seen in the right panel of Fig. 2, elicited by rare informative glides.

The Glide Frequency \times Cue Function ANOVA of the P3 peak showed a significant Glide Frequency main effect: ($F(1, 13) = 27.783$, $p < .001$, $\eta^2_G = .148$). The main effect of Cue Function ($F(1, 13) = 2.96$, $p = .11$, $\eta^2_G = .05$) and the interaction were not significant ($F(1, 13) = .08$, $p = .783$, $\eta^2_G = .001$). The topographical comparison of the rare-minus-frequent glide difference amplitudes showed no Cue Function \times Electrode interaction at Fz, Cz, Pz, and Oz electrodes (after scaling: $F(3, 39) = .018$, $p = .908$, $\eta^2_G = .001$), that is, the P3 topographies were not significantly different in the two conditions. The informative-minus-uninformative difference waveforms are also presented in Fig 2, in the right panel. These difference waveforms show that the lack of the hypothesized P3 difference might be due to the overlap of CNV in the time window of P3, and Fig. 4 represents its topographical distribution.

3. Discussion

The goal of the present study was to investigate whether it was possible to exploit a regular temporal relationship between a task-irrelevant *distracter* event (a glide) and a task-relevant event (a gap) to prepare for the moment the task-relevant event (gap) was likely to occur. Distraction was induced by the manipulation of glide presentation frequency (rare vs. frequent), which resulted in a characteristic distraction ERP waveform: Rare glides elicited an early negative deflection (probably composed of an enhanced N1 and MMN) in comparison to frequent

glides, indicating that rare glides triggered automatic auditory change detection mechanisms. The N1/MMN was followed by a similar P3 in both informative and uninformative conditions. The manipulation of cue function (i. e. whether the glide allowed the prediction of the task-relevant moment) was also successful, as evidenced by the N2b elicited by the rare informative glides, and CNV elicited in both informative glide conditions. An N1 difference between informative and uninformative conditions, which would reflect the establishment of a selective attention set for the informative, but not for the uninformative glides, was, however, not observable.

The rareness-related early negativity (presumably the mixture of an enhanced N1 and MMN) reflects auditory change detection, potentially leading to the orientation of attention to the eliciting event (Näätänen, 1982; Näätänen et al., 2007). Importantly, this negative waveform was further modulated by the cue function of the glides: somewhat later, an N2b was observable in the informative rare-minus-frequent glide waveform but not in the uninformative one. This finding is in line with previous findings, which showed that N2b is elicited only by sounds which are rare in the terms of a sound-related task (Sams, Alho and Näätänen, 1983; Ritter et al., 1992). In the present context the presence of the N2b indicates that participants included the informative glides into their task-behavior, that is, they utilized the distracter glides as temporal cues. It is important to note, however, that we found no evidence that participants formed an attention set tuned for glides in the informative glide conditions, as no N1-enhancement was observed in the informative-uninformative glide contrast. That is, the inclusion of the glides into the task-behavior seems to be limited to a post-perceptual level: whereas the N1 reflecting the auditory processing of the glides was unaffected, the task-relevance was nonetheless reflected by the elicitation of the N2b, and the following CNV.

The hypothesized P3a enhancement in the informative condition was not observable and the measured waveform also showed a parietal distribution, therefore we labeled it more generally as P3. Beyond the trivial explanation (i.e. the predictability of the task-relevant moment has no effect on the P3), the lack of the expected effect has at least two further explanations. First, it is possible that the rare informative glides may have elicited ERPs which overlapped, and presumably cancelled the P3a-effect. Beside the N2b, the CNV observed in the informative conditions may have contributed to such an overlap. Since the CNV is a long lasting negative deflection, it might affect the later components in the time window of the foreperiod, including

the P3a related to the first event (Dien, Spencer and Donchin, 2004; Verleger et al., 2012; Wetzel, Schröger and Widmann, 2013). In the study of Wetzel, Schröger and Widmann (2013) P3a and CNV waveforms were also observable when the distracter was informative regarding the presentation probability and occurrence time of the target (300 ms following distracter, that is 300 ms foreperiod). In their study, similarly to our results, P3a amplitude did not differ significantly between informative and uninformative conditions either, although for informative distracters a P3a latency shortening was present and informative distracters elicited a late negative shift interpreted as CNV, but it did not overlap P3a. The lack of overlap of these two waveforms could be explained by the relatively early occurrence of P3a (between 220 and 300 ms) compared to CNV (between 330-400 ms) and the utilization of cross-modal stimulation (auditory distracters and visual targets). In the present study, however, CNV started around 300 ms, which coincided with the P3 time-range. There is also evidence that rare cue events are followed by enhanced CNVs in comparison to frequent cues (Bauer et al., 1992), suggesting that an enhanced CNV to rare informative glides could cancel a potentially significant P3a-increase which might explain both the null-effect and the parietal distribution of the component in the present study.

Second, one might also argue that participants were not motivated enough to rely on glides as cues and to extract the temporal information they provided because this would essentially transform the single-task into a – more difficult – dual-task situation (detect the glides as well as discriminate the gaps). Because cue utilization is voluntary, and cue utilization behavior was not measured on-line, participants could “opt-out” from using the cues without notice (as demonstrated by Horváth, 2013). However, this explanation is not convincing, because of the presence of the attention- and preparation-related negativities to rare informative glides (N2b, CNV), indicating that participants evaluated these as task-relevant events.

In line with the ERP data, the behavioral results also suggest that informative glides were utilized as cues allowing task-related preparation: although correct response rate and gap duration discrimination scores were not affected, participants responded significantly faster when an informative foreperiod was provided. It is important to note that data from two participants were excluded from the reaction time- and accuracy analysis, because they did not respond in the selected trials in the uninformative rare glide condition. Such response omission to task-relevant

stimuli following a distracting event has also been reported by Pacheco-Unguetti, Gelabert & Parmentier (2016), who interpreted it as a temporary suspension of cognitive activity after distraction.

The behavioral results basically fit into the literature using either discrete (e. g. Li, Parmentier and Zhang, 2013; Parmentier, 2014; Parmentier, Elsley and Ljungberg, 2010; Wetzel, Widmann and Schröger, 2012) or continuous (Horváth, 2014a; Horváth and Winkler, 2010) stimulation. In studies where temporal intervals between task-irrelevant and task-relevant events (in audio-visual paradigms: distracter tone onset and offset and the onset of visual target stimuli) were manipulated, the fixed foreperiod between rare distracters and targets had the potential to enhance behavioral performance (e. g. reduced reaction times or at least reduced distraction effect) on a second, task-relevant event in a 2-choice task, even though the task-irrelevant first event did not provide any specific information on the type of the succeeding second one (Holender and Bertelson, 1975; Parmentier, Elsley and Ljungberg, 2010; Wetzel, Widmann and Schröger, 2012, but see Li, Parmentier and Zhang, 2013), and implicit timing expectations improved reaction times and accuracy as well (Rimmele, Jolsvai and Sussmann, 2011). In the present study, participants also responded faster when the task-relevant event was preceded by an informative foreperiod, which is in correspondence with the studies cited above, suggesting that they exploited the temporal cue value of the glides.

Most of the studies cited above did not find any change in hit rates when a temporally informative foreperiod was present in discrete stimulation protocols (Li, Parmentier and Zhang, 2013; Wetzel, Schröger and Widmann, 2013; Wetzel, Widmann and Schröger, 2012, but see Parmentier, Elsley and Ljungberg, 2010), which is in line with the present findings. Using continuous stimulation, in Horváth and Winkler's (2010) study, gap detection rate was significantly reduced and participants got slower as well when only 50% of the glides were followed by a gap. However, when glides and gaps were presented in a fully independent manner, reaction times were not impacted (Horváth, 2014a), which suggests that randomly presented glides did not enhance readiness for response, while in case of 50% gap probability, participants might have treated task-irrelevant glides and succeeding gaps as a common unit and glides as potential cues. In the present study, the 80% gap presentation chance after glides in the informative condition let participants to form stronger associations between the two types of

stimuli and to mark glides as task-relevant events exploiting their cue value as reflected in ERPs (enhanced N2b, CNV) and in decreased reaction times to gaps. Correct response rates and d' -s were, however, not significantly impacted by glide presentation frequency. This difference to Horváth's (2014a) study might be explained by the task-difference between the two studies: while in Horváth's (2014a) experiment, the task was gap detection, which required fast simple responses, the present study, however, featured a discrimination task, in which the frequently presented glides without any information regarding the correct answer (i. e. the duration of the target) might have interfered with the discrimination process.

In summary, the present study showed that the constant foreperiod between task-irrelevant distracter and task-relevant target events allowed participants to exploit the temporal cue value of rare distracters and to support the temporal preparation for the task-relevant second event. This supportive effect was not manifested in an enhanced perceptual processing of the informative glides (as no cue function-related N1 differences were found), but it was manifested in ERPs reflecting post-perceptual processing: the characteristic rare-minus-frequent difference waveform featured an N2b in the informative condition, and informative glides were also followed by a CNV, suggesting preparational effects. The task-supporting effect was present behaviorally as well: the presence of informative glides enhanced participants' response-behavior to the gaps reflected by decreased reaction times, even though it did not increase accuracy. Our results basically fit the results of studies varying the temporal cue value of the distracter events not only in discrete (Hölig and Berti, 2010; Parmentier, Elsley and Ljungberg, 2010; Wetzel, Schröger and Widmann, 2013; Wetzel, Widmann and Schröger, 2012) but in continuous stimulation paradigms (Horváth, 2014a; Horváth and Winkler, 2010) as well. Finally, and most importantly, the present study supports the idea that both prediction- and distraction-based information processing are manifested in various distraction paradigms.

4. Methods

4.1 Participants

16 paid volunteers took part in the experiment but data of 2 participants were excluded from further analyses (one performed the task at chance level, i.e. accuracy between 46% and 58%; d' -s between -.2 and .4; and one had a high number of movement artifacts resulting in the rejection of about 85% of all epochs). The remaining 14 participants (mean age: 23, from 19 to 31 years, all right-handed, 12 women) reported normal hearing and normal or corrected-to normal vision. They received either modest financial compensation or course credit for participation. All participants gave written informed consent after the experimental procedures were explained to them.

4.2 Stimuli and procedure

During the experiment, participants listened to continuous tones (through headphones, Sennheiser HD 25-1, Wedemark, Germany) generated off-line with Csound 5.16 (www.csounds.com), with a sampling rate of 44.1 kHz. The tones consisted of three harmonics with equal amplitude: the fundamental, the second and third harmonics (the first harmonic was missing). The fundamental frequency was either 220 Hz (low) or 277 Hz (high). Tone intensity was 68 dB SPL (measured with an artificial head, HMS III.0, Head Acoustics, Germany). The tone featured two types of events: pitch changes with an exponential transition over a duration of 10 ms from low to high or back (*glides*), and short silent periods (*gaps*) breaking the continuous tone for 10 or 100 ms (with additional 10 ms linear fall and 10 ms linear rise times). Participants performed a gap discrimination task: they indicated by keypresses whether a long or short gap was presented, while ignoring frequency glides. The assignment of left and right keys to short and long gap durations was counterbalanced between participants. Participants were familiarized with the gap duration discrimination task in two 4-minute-long training blocks at the beginning of the experiment. These blocks did not feature any frequency glides in order to demonstrate the difference between long and short gaps (i.e. the pitch was constant in these blocks - in one it was high, in the other it was low). The probability of the two gap durations was 50 per cent each and

they followed each other in random order. The between-gap intervals (measured between the onsets of the amplitude decreases) was random: it contained a fixed, 1.3 s period and an additional time period randomly drawn from an exponential distribution characterized by a mean of 1.5 s. Glides were presented either frequently or rarely in different conditions. The glide-to-glide interval was chosen randomly from a uniform distribution of intervals between 4.0 and 16.0 s in rare glide blocks, and between 1.0 and 4.5 s in frequent glide blocks. (On average, frequent glide blocks featured 87 glides and 85 gaps, whereas rare glide blocks featured 23 glides and 85 gaps). Because glide and gap presentation times were independently generated, glides and gaps could occur temporally close to each other. To avoid glide-gap overlaps, for gap and glide events scheduled to occur within 150 ms, the starting point of a long gap was re-scheduled to a time point 150 ms earlier, whereas short gaps were re-scheduled to be presented 80 ms earlier. If the gap was scheduled to be preceded shortly by a glide, the gap was re-scheduled to be presented 80 ms later, irrespectively of its duration. In the uninformative conditions, no further manipulations were administered. In the informative condition, however, gaps immediately following glides were re-scheduled to exactly 400 ms following glide onset in 80% of the cases (randomly chosen), thereby creating an event sequence in which 80% of the glides were followed by a gap exactly by 400 ms. To be able to collect a similar number of ERP epochs in each condition, and for each glide presentation frequency (with timing parameters described below) without overlaps from other events, a simulation of the scheduling was run. Based on the results of this simulation, the informative glide condition was administered in 5 rare and 2 frequent glide blocks, the uninformative glide condition in 6 rare and 2 frequent glide blocks.

The experiment was conducted at the University of Leipzig. Participants were sitting in a comfortable chair in a sound-attenuated chamber. The experiment was run in two parts. The first part featured the informative condition blocks for seven participants, while seven others started with the uninformative condition blocks. The duration of an experimental block was approximately 4 minutes. Before each condition, a short (2 minutes long) practice block reflecting the structure of forthcoming experimental blocks was presented.

During each block a black fixation cross was presented on grey background on a screen in front of the participants. At the beginning of each block, the task instruction was displayed on the screen, and stimulation started when participants pressed a key. Data from the practice blocks

were not analyzed. Between the blocks short (1-2 min) pauses were available, and at about the half of the experiment, participants had the opportunity for a longer (5-15 min) break. At the end of each block, feedback about the accuracy was displayed on the screen.

4.3 EEG recording

The EEG was recorded with 512 Hz sampling rate with an Active Two (BioSemi B. V., Amsterdam, Netherlands) amplifier, from 64+2 active electrodes mounted on a headcap according to the 10% system (Nuwer et al., 1998). A further electrode was placed on the tip of the nose for off-line re-referencing. Horizontal electro-oculogram was measured by two electrodes placed to the outer canthi of the eyes, and vertical electro-oculogram was measured from electrodes attached above and below the left eye. Because of the malfunction of the electrode at Fp1 position this channel was discarded from the analyses.

The continuous EEG was referenced to the nose and was filtered offline, using a 30 Hz lowpass filter (Kaiser-windowed sinc finite impulse response filter, beta of 5.65, 929 coefficients; 2 Hz transition band width, stop-band attenuation at least 60 dB). 500 ms long glide-related epochs were extracted, including a 100 ms pre-glide interval. Only epochs corresponding to glides not preceded by any event in 600 ms and not followed by any event in 390 ms were retained for analysis. Epochs with a signal range exceeding 100 μ V on any channel were also discarded from the analyses. The remaining epochs categorized according to Cue Function (informative / uninformative) and Glide Frequency (frequent / rare) were averaged separately, that is, rare informative, frequent informative, rare uninformative and frequent uninformative glides were included in the analyses.

4.4 Statistical analyses

Only correct responses occurring within 120 to 1000 ms after the beginning of a gap were included in the reaction time analysis. Individuals were characterized by the median reaction time, because it better represents the typical response time than the mean due to the skewed individual reaction time distribution. d' sensitivity scores for gap discrimination were calculated according to the Signal Detection Theory (MacMillan and Creelman, 1991). Reaction times and

d' -s were analyzed in repeated measures ANOVAs including the factors Cue function (informative / uninformative) and Glide Frequency (rare / frequent).

The glide-related N1 latency and maximum was measured in the group-average uninformative frequent glide condition: it reached its maximum (negative) peak at Fz, at 107 ms. The N1/MMN deflection was identified in the rare-minus-frequent difference waveform of the uninformative condition: it peaked at 129 ms at FCz. For identifying informativeness-related negative ERP waveforms, and the P3a, however, the informative condition was chosen since these components should be elicited with maximal amplitudes in this condition. The negative peak overlapping the N1/MMN peaked at 158 ms at FCz in the informative rare-minus-frequent difference waveform; the P3 peaked at 346 ms at Pz. Finally, as an exploratory step, we calculated the difference of the frequent-minus-rare difference waves, to better characterize this negative difference. For all analyses individuals were characterized by the average amplitude measured in 20-ms windows centered on these peak latencies, at the electrodes, and the data were submitted to Cue Function \times Glide Frequency ANOVAs. To assess whether amplitude differences were caused by topographical differences between ERP waveforms or difference waveforms (and not by genuine amplitude modulations), the effects were compared in ERP \times Electrode (for N1/MMN and N2b: AFz, FCz, CPz, POz; for P3: Fz, Cz, Pz, Oz, respectively) ANOVAs, in which the amplitudes were vector-normalized as described by McCarthy and Wood (1985). In such analyses a significant interaction would mean that the shapes of the two ERP topographies differ, that is, that the manipulations result in the activation of different ERP generators as well. Statistical analysis was conducted in R (version 3.1.0, R Core Team, 2014). Generalized eta squared (η^2_G) effect sizes are also reported (Olejnik and Algina, 2003; Bakeman, 2005).

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Figure captions

Fig. 1: The schematic design of the experimental paradigm, including glides, short gaps and long gaps. The thick black line represents the continuous tone alternating between two pitches (non-target glides) and the short breaks mark the gaps (short and long targets). The difference between glide – gap time intervals and the predictive values in the informative and uninformative conditions are marked with dashed lines.

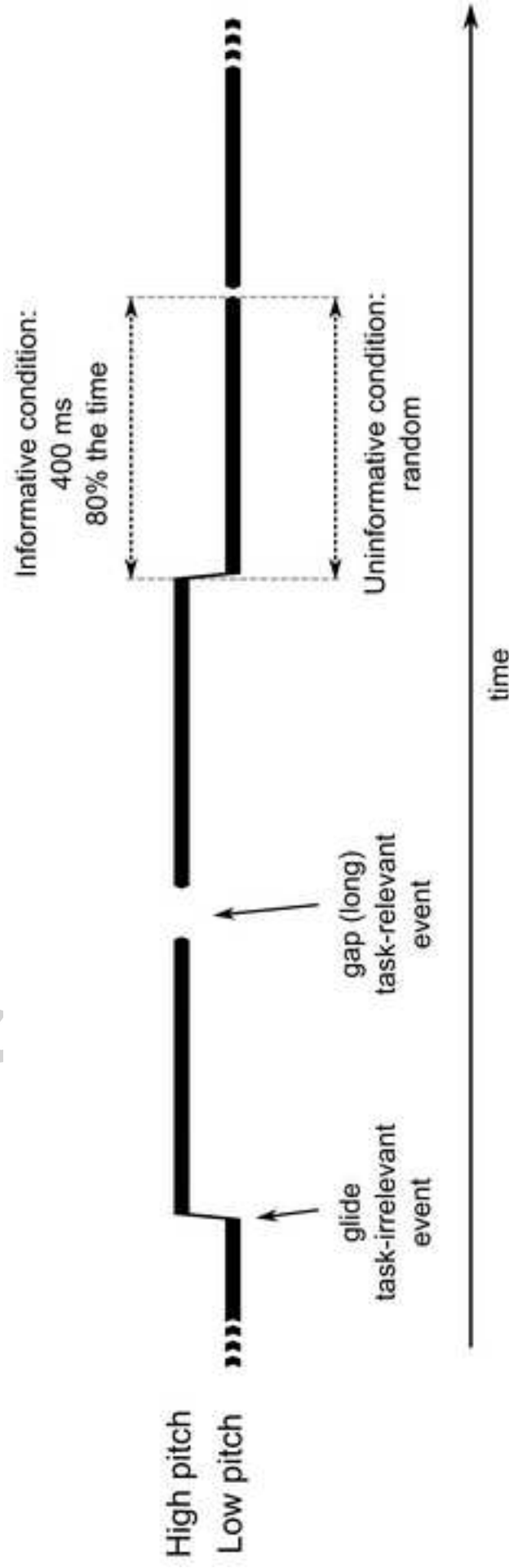
Fig. 2: Group-average (N=14) glide-related ERPs in the frequent informative, rare informative, frequent uninformative and rare uninformative conditions (left column) and the rare-minus-frequent difference waves measured at midline electrodes (FCz, Cz, CPz, Pz, POz) and at the averaged mastoids (M) in the informative and uninformative condition (middle column). The informative-minus-uninformative difference waveforms showing the effect of informative foreperiod are presented in the right column.

Fig. 3: Group-average (N=14) topographical distribution of the MMN, N2b and P3 waveforms in the uninformative (first row) and in the informative condition (second row). The MMN, N2b and P3 are based on rare-minus-frequent difference waveforms and the between-condition difference is plotted in the third row. Note that the scales differ in order to highlight differences and similarities in the shape of the distributions.

Fig. 4: Group-average (N=14) topographical distribution of CNV in the uninformative (first row) and in the informative condition (second row). Since CNV is basically elicited under informative foreperiod, the informative-minus-uninformative differences are relevant in this case.

Highlights

5. Distraction studies use event pairs separated by fixed time intervals (foreperiod).
6. The first (distracter) event is task-irrelevant, the second is task-relevant.
7. The fixed foreperiod allows the temporal prediction of the target event onset.
8. The temporal information content of the distracter was manipulated.
9. Informative distracters elicited ERPs reflecting cue information processing.



Figure

