

Rhythm perception: Speeding up or slowing down affects different subcomponents of the ERP P3 complex

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Abstract

The aim of this study was to investigate, by measuring the event related potential (ERP) P3 complex, whether the perception of small accelerations differs from that of small decelerations. Participants had to decide whether the last beat of a short sequence was presented ‘too early’ or ‘too late’. Target beats were accelerated or decelerated with 0%, 2%, 5%, or 10%. Individuals differed in their capability to detect small tempo changes. We found that good responders were able to identify all tempo changes whereas poor responders were only able to identify large (10%) tempo changes. In addition, we found that tempo changes affected two subcomponents of the ERP P3 in good performers. Accelerations increased a *late-P3 amplitude* whereas decelerations increased an *early-P3 amplitude*. These results imply the principle possibility to measure differential P3 effects within one task. This is important for acquiring more refined knowledge concerning different subcomponents of the ERP P3 complex and the cognitive processes by which they are elicited.

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1. Introduction

1.1. Rationale of the study

The perception of complex auditory information, like music and speech, requires the processing of structured information over time. Thus, gaining knowledge about how temporal manipulations affect the way we process auditory information should be of interest to the fields of music and language perception. The general aim of this study was to investigate how we perceive small tempo changes within a rhythm. During a rhythm perception task we measured both behavioral responses and the P3 complex of the event related potentials (ERPs). More specifically, we asked whether the perception of accelerations differs from the perception of decelerations.

While this question might not be easily resolved by means of behavioral research methods, one could expect that tempo accelerations might affect different subcomponents of the ERP P3 than decelerations, thus expressing two, perceptually differently processed, phenomena. In addition, we asked whether ERPs elicited by small tempo changes would be different for participants that were good at detecting tempo changes (determined by their behavioral responses) compared to those who have more difficulties with the task at hand.

1.2. Background

Earlier studies on the perception of temporal information revealed a robust phenomenon known as the ‘time order error’ (Allan and Gibbon, 1994; Schab and Crowder, 1988): When two durations (i.e., the intervals between consecutive stimuli) are presented in succession and the task of the participant is to judge whether the second duration is shorter or longer than the first, there often is a systematic bias. This bias varies as a function of the length of the first duration used: when this duration is shorter than 500 ms, listeners are more likely to

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respond that the second duration is even shorter than the first duration even when this duration is of equal, or slightly longer, length (Nakajima et al., 2004). The opposite is true when the first duration is longer than 700 ms: listeners are biased towards judging the second duration to be longer. An explanation for this phenomenon, proposed by Woodrow (1951), is that the perceptual duration of the first-presented duration “gravitates” towards a standard somewhere between 500 and 700 ms. When the durations have a length between 500 and 700 ms there is no bias, thus being referred to as the indifference interval (Fraisse, 1984; Franěk et al., 2000; Vos and Ellerman, 1989).

In a previous behavioral study on the perception of tempo change, Vos et al. (1997) observed a similar indifference interval. During a forced directional response paradigm, 10-tone sequences – with base durations of 250, 500, or 1000 ms – were presented with a tempo change introduced after the sixth or seventh tone. When the base tempo was faster than 500 ms, subjects were biased towards acceleration responses; when the tempo was above 700 ms, subjects were biased towards deceleration responses. If the base tempo of a tone sequence was between 500 and 700 ms, no bias in tempo change detection was observed. Similar findings have been obtained in other studies (McAuley and Kidd, 1998; Penel et al., 2001). The results of these studies – directed at the influence of base tempo on the detection of a temporal change in tone sequences – are consistent with the results obtained with single intervals.

This vast body of behavioral research strongly suggests that within the indifference interval (i.e., a base tempo between 500 and 700 ms), which mirrors the preferred tempo for many musical pieces, the detection of both accelerations and decelerations is equally difficult. Thus, many researchers have referred to tempo change, whether accelerated or decelerated, as being a rather uniform phenomenon—at least with respect to this indifference interval.

1.3. ERP measurements

Although many behavioral studies have been directed at the perception of tempo changes (for an overview, see Desain and Windsor, 2000), only few studies measuring Event Related Potentials (ERPs) have addressed this research topic (Pfeuty et al., 2003). ERPs are small voltage fluctuations in the EEG (electroencephalogram) resulting from, and time-locked to, sensory, cognitive, or motor-events (Coenen, 1995).

In the present study, we measured ERPs during a rhythm perception task. ERPs offer an excellent tool for studying perceptual processes because of their high temporal resolution. Whereas behaviorally obtained ratings only provide a measure of the end product of the processes involved, that is, the perceptual interpretation of a rhythmic pattern, ERPs enable a close examination of the time-course of the various processes involved in musical expectancy (Regnault et al., 2001).

1.4. The ERP P3 complex

One of the most commonly studied components in auditory ERP research that is related to the processing of expected

versus unexpected stimuli, is the P3 complex: a large positive complex around 300 ms after onset of either an unexpected, or a meaningful, stimulus (Katayama and Polich, 1999; Picton, 1992; Polich, 1996; Pritchard, 1981). The P3 complex appears to have multiple underlying generators with activation in the temporal and parietal lobes (Bledowski et al., 2004; Kiss et al., 1989). In addition, the thalamus (Horovitz et al., 2002) and hippocampus (Halgren et al., 1998; McCarthy et al., 1989; Tarkka et al., 1995) have also been found to contribute to P3 generation. This P3 complex is most commonly elicited by target stimuli in a simple discrimination task, the so-called ‘oddball paradigm’ (Donchin and Coles, 1988; Polich and Kok, 1995). The (auditory) oddball paradigm consists of infrequently occurring target stimuli embedded in a train of frequently occurring background stimuli. Although the P3 complex seems a rather uniform and robust wave, amplitudes, latencies, and scalp distributions of its subcomponents can vary widely depending on the task at hand (Gonsalvez and Polich, 2002). The P3 complex has been shown to be sensitive to a wide array of variables such as unexpectedness, probability, and salience of the targets (Croft et al., 2003). Many researchers showed that the P3 complex can be divided into separate subcomponents, for example a P3a and a P3b.

The early-P3a, or novelty P3, with its latency around 250–350 ms exhibits an anterior/frontal scalp distribution and precedes the P3b (Comerchero and Polich, 1999). The P3a is ordinarily evoked by several types of non-task-related stimuli, like infrequent stimuli and physically novel stimuli (Katayama and Polich, 1999; Polich and Kok, 1995). The P3a has therefore been described as an indicator of automated, bottom-up related aspects of attention (Escera et al., 1998; Debener et al., 2002), but has also been related to aspects of stimulus evaluation within active tasks (Hohnsbein et al., 1995).

The longer-latency P3b, with a latency around 300–600 ms, exhibits a more posterior scalp distribution (Comerchero and Polich, 1999) and is commonly elicited within active tasks. The P3b is thought to be related to salient, task-relevant events capturing attention and seems to reflect voluntary, top-down related aspects of attention (Debener et al., 2002). It has also been related to aspects of response selection (Hohnsbein et al., 1995).

1.5. The ERP P3 complex in music and rhythm research

The P3 complex has also been studied within the field of music research (Besson and Faita, 1995; Janata, 2001; Trainor et al., 2002). For example, a late-P3 has been observed in reaction to ‘wrong’ notes at the end of a melody (Besson and Faita, 1995). Thus, Besson and Faita (1995) concluded that the P3 complex serves as a good electrophysiological marker of (violation of) musical congruency. In addition, in an earlier rhythm perception study, we observed a late-P3 in reaction to omitted beats (Jongsma et al., 2005). In addition, several studies employing musical stimuli also revealed a more centrally orientated early-P3 (about 250 ms) (Jongsma et al., 2004a; Trainor et al., 2002). Again, violations of the musical congruency affected the P3 complex. Thus, different subcomponents of the P3 complex seem

to be sensitive to the violation of musical congruencies in such a way that the larger the violation, the larger the amplitude of the P3.

Since both an early-P3 and a late-P3 subcomponent have been found to be sensitive towards the violation of a rhythmical congruency (Jongsma et al., 2005, 2004a), the domain of rhythm perception research provides elegant stimulus material to study different subcomponents of the P3 complex elicited within the same, active task and towards target stimuli with similar task demands. Such a rhythm perception task could thus shed more light on cognitive aspects of P3 generation.

1.6. The current experiment

So far, quantitative behavioral measurements have not been able to separate perceptual phenomena underlying the detection of accelerations versus decelerations within the indifference interval. Within this interval, the percentage of correct responses is determined by the amount of tempo change and not by the direction of the tempo change (Fraisse, 1984; Franěk et al., 2000; Vos and Ellerman, 1989). However, within this indifference interval, people are commonly able to indicate not only that there is a tempo change, but also the direction of this tempo change. Therefore, in this study we aimed to distinguish these two phenomena – detecting acceleration versus detecting deceleration – by means of ERP research.

We measured ERPs, together with behavioral responses, within a forced directional response paradigm (Vos et al., 1997). Participants had to decide whether or not the last beat (the target beat) of a short, five-beat, sequence was presented

either ‘too early’ or ‘too late’. Target beats were accelerated or decelerated with 0%, 2%, 5%, or 10%, to establish whether detecting tempo change is indeed a uniform phenomenon or whether there are distinct differences between the detection of an acceleration compared to the detection of a deceleration.

1.7. Hypotheses

We hypothesized that all task related target beats will give rise to a distinct P3 complex. In addition, tempo change will violate rhythmical congruency, which will affect the P3 complex.

Others have reported that a late-P3 component is elicited when a target beat is presented ‘too early’ (Besson and Faita, 1995). However, when target beats occur ‘too late’ a P3 is already elicited at the time at which the target is expected, giving rise to distinct OEPs, or Omission Evoked Potentials (Jongsma et al., 2005). We thus hypothesize that accelerated target beats will give rise to a late-P3 subcomponent, whereas decelerations will elicit an early-P3 subcomponent.

Moreover, we expect a larger effect size with larger tempo changes: the larger the accelerations, the larger the late-P3 component amplitudes will be and the more correct responses will be obtained. Likewise, we expect that larger early-P3 component amplitudes will be measured and more correct responses will be obtained with large decelerations as compared to small decelerations.

Finally, we expect that participants that perform with high accuracy on this task (i.e., those who are able to correctly identify whether the tempo is accelerated or decelerated) will

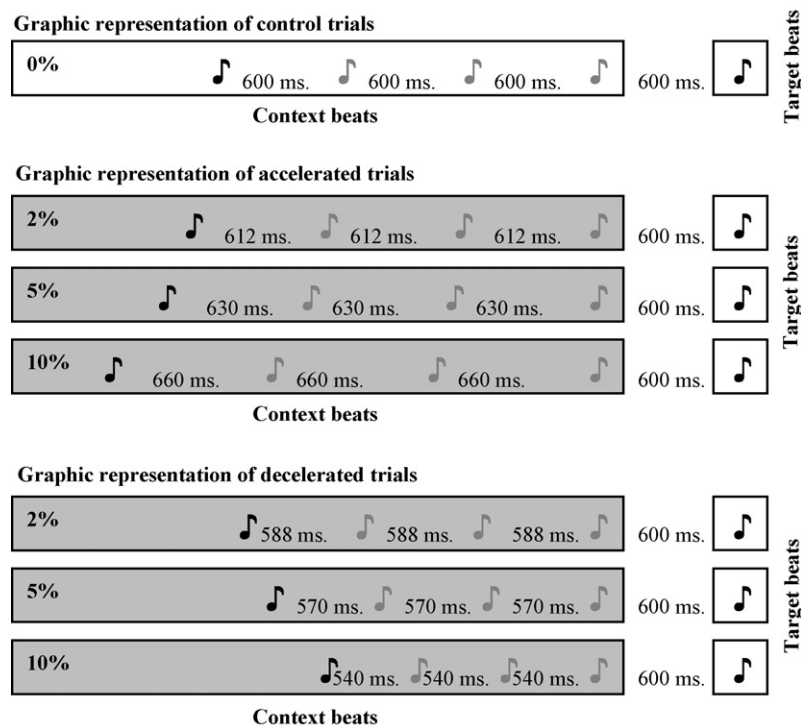


Fig. 1. Diagram of the stimulus material. Target beats were presented 600 ms after four preceding context beats. Target beats were either control beats (top panel), accelerated (middle panel), or decelerated (bottom panel). A total of 560 trials was presented in a random order.

show more pronounced increments of the P3 component amplitudes in comparison to participants that perform less well.

2. Method

2.1. Experimental design

A diagram of the seven stimulus categories is presented in Fig. 1. Each trial consisted of a five-beat sequence. The first and last beat of the sequence were accentuated (i.e., louder); the last inter-stimulus interval (ISI) was always 600 ms. The beats were short ‘high woodblock’ hits (1 ms attack, 10 ms decay to 6 dB below peak level) presented at 81 dB for the first and last (accented) beat and 71 dB for the three intermediate beats (Jongsma et al., 2004a).

ERPs were elicited by presenting target beats that were either accelerated or decelerated in comparison to four preceding beats. The amount of tempo change was 2%, 5%, or 10%. A seventh stimulus category, the control category, containing no tempo change was also presented (0%). A visual cue appeared about 750 ms after each trial, indicating that participants had to answer whether the target beat had occurred ‘too early’ or ‘too late’ by pressing one of two buttons. All stimulus categories were presented 80 times. A total of 560 trials were presented in a random order.

2.2. Participants

Twenty-three right-handed healthy undergraduates of the Radboud University Nijmegen participated in the experiment. The participants used no medication, had no history of neurological or psychiatric problems and they all reported normal hearing and (corrected to) normal vision. Participants were asked not to drink coffee or alcohol and to refrain from smoking prior to the experiment. The participants were paid €18 or received course credit points for their participation and signed a written informed consent and a small questionnaire asking about their music experience (i.e., years of music education and instrument).

Participants were tested individually. They were instructed to take a comfortable posture and to make as little movements as possible and to blink their eyes only during the inter-trial interval. Eight practice trials were presented. The auditory stimuli were presented to the participants in an electrically shielded, sound attenuating and dimly lit cubicle (inside dimensions: 2 m × 2.2 m × 2 m). The participants were seated in a chair in front of a table with a button box with two buttons – labeled ‘too early’ and ‘too late’ – on it. Labeling was counterbalanced across participants. A computer screen was located 1 m in front of the subjects. The auditory stimuli were presented by means of a speaker placed behind the chair. Participants received a verbal instruction about the task, which was to judge whether the last target beat of a sequence was ‘too early’ or ‘too late’ in comparison with the first four beats of the sequence.

2.3. EEG recordings

EEG was registered with tin electrodes fixed in an elastic electrode cap (Electrocap International) according to the 10–20 electrode system (American Encephalographic Society, 1994). EEG recordings from midline sites (Fz, Cz, and Pz) were used for data analyses. Linked mastoids served as a reference and a ground electrode was placed on the forehead. Horizontal EOG recordings were made from the outer canthi of the left and right eye; vertical EOG recordings were done from electrodes placed infra and supra orbital to the left eye. EMG was registered by two electrodes placed on the muscles in the wrist. Electrode impedance of all cortical electrodes was less than 3 k Ω and impedance for the EOG and EMG electrodes was less than 10 k Ω . EEG and EOG were filtered between 0.016 and 100 Hz and sampled at 500 Hz.

2.4. Data analysis

Offline, the data were digitally filtered between 1 and 30 Hz (slope: 24 dB). Epochs (100 before target presentation till 750 ms after target presentation)

were baseline corrected (–100 ms till 0 ms). Epochs containing EOG artifacts (about 10–20% per individual) were automatically removed. The data from one participant were excluded from further analysis because of excessive artifacts.

Based on their performance during the test, participants were divided in two groups: good responders ($n = 11$) with more than 65% correct answers, and poor responders ($n = 11$) with less than 65% correct answers (based on answers taken from 2%, 5%, and 10% tempo-change categories only).

A one-tailed *t*-test was performed on the years of music experience, to test the hypothesis that good performers have more music experience than poor performers.

A grand average ERP of all target beats from the 0% tempo-change condition was constructed. The P3 complex of this grand average consisted of two clear subcomponents: an early-P3 with a peak amplitude at 250 ms that appeared to be maximal over Cz, and a late-P3 at 400 ms with a maximum over Pz. See also Fig. 2.

Individual P3 subcomponents at midline sites were determined for each tempo change condition by their average value within a specified 40 ms window: early-P3: 230–270 ms; late-P3: 380–420 ms (Jongsma et al., 2006).

For each P3 subcomponent, a one-between group and three-within subjects: Direction (two levels; acceleration, deceleration); Amount (four levels; 0%, 2%, 5%, 10%); Electrode site (three levels; Fz, Cz, and Pz)—general linear model (GLM) multivariate test was performed. Since both the early-P3 and late-P3 component showed two-way and/or three-way interaction effects with both Direction and Electrode Site, one-between group and one-within subjects (Amount) GLMs were performed for accelerated and decelerated trials separately, for Fz, Cz, and Pz electrodes. Post-hoc analyses were performed whenever an interaction effect was observed.

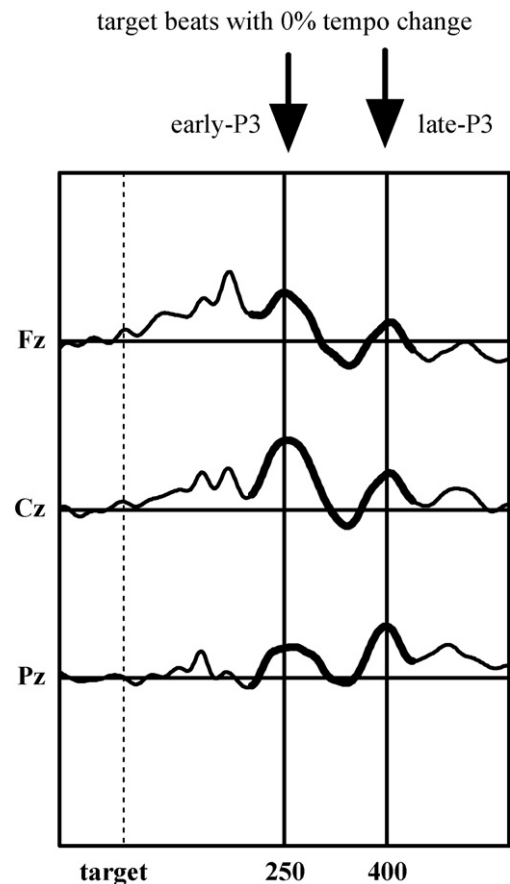


Fig. 2. Component definition based on grand average AEPs at Fz, Cz, and Pz of good performers (solid lines; $n = 11$) and poor performers (dotted lines; $n = 11$), for 0% tempo change (control beats). The early-P3 (maximal at Cz) and late-P3 (maximal at Pz) determination are marked with vertical lines.

3. Results

3.1. Behavioral responses

Two groups were constructed, based on the participants' performance. Good responders were able to identify all quantities of tempo change (2%, 5%, and 10%) above chance level (as on control trials, containing 0% tempo change) whereas poor responders were only able to identify 10% tempo changes significantly above the level of control trials. No effects concerning the direction of the tempo change (acceleration versus deceleration) were observed with respect to response accuracy.

3.2. Music experience

Information on years of musical training was missing for two participants. A one-tailed *t*-test on the data from the remaining participants only revealed a trend towards significance ($p = .09$), which was probably due to the large variance. There was a tendency that the group of good performers had more music experience than the group of poor performers, as expressed in years of music education (good responders: 3.8 ± 0.91 ; poor responders: 2.1 ± 0.89 , means \pm S.E.M.).

3.3. ERP component amplitudes

Fig. 3 shows the grand average ERPs (per trial type) at midline sites. Table 1 summarizes all significant *F* and *p* values of the initial one-between group, three-within subjects, ANOVA. An early-P3 showed main effects of Electrode site and Direction. In addition, two-way interaction effects of Electrode site with Group, Direction, and Amount were observed, and of direction with amount. Finally, there was a significant three-way Electrode site \times Direction \times Amount interaction effect (for *F* and *p* values see Table 1). A late-P3 showed main effects of Group, Electrode Site, Direction, and Amount. In addition, two-way interaction effects of Direction with Electrode site and Amount were observed (for *F* and *p* values see Table 1).

Since both an early-P3 and late-P3 component showed two-way and/or three-way interaction effects with Direction and Electrode site, Tables 2a and 2b summarizes all significant *F* and *p* values of the subsequent one-between group, one-within subjects ANOVAs, analyzing results of accelerated and decelerated trials separately for Fz, Cz, and Pz.

3.3.1. Effects of accelerations

Fig. 4a shows the early-P3 and late-P3 subcomponent amplitudes for accelerated trials. Both an early-P3 and a late-P3

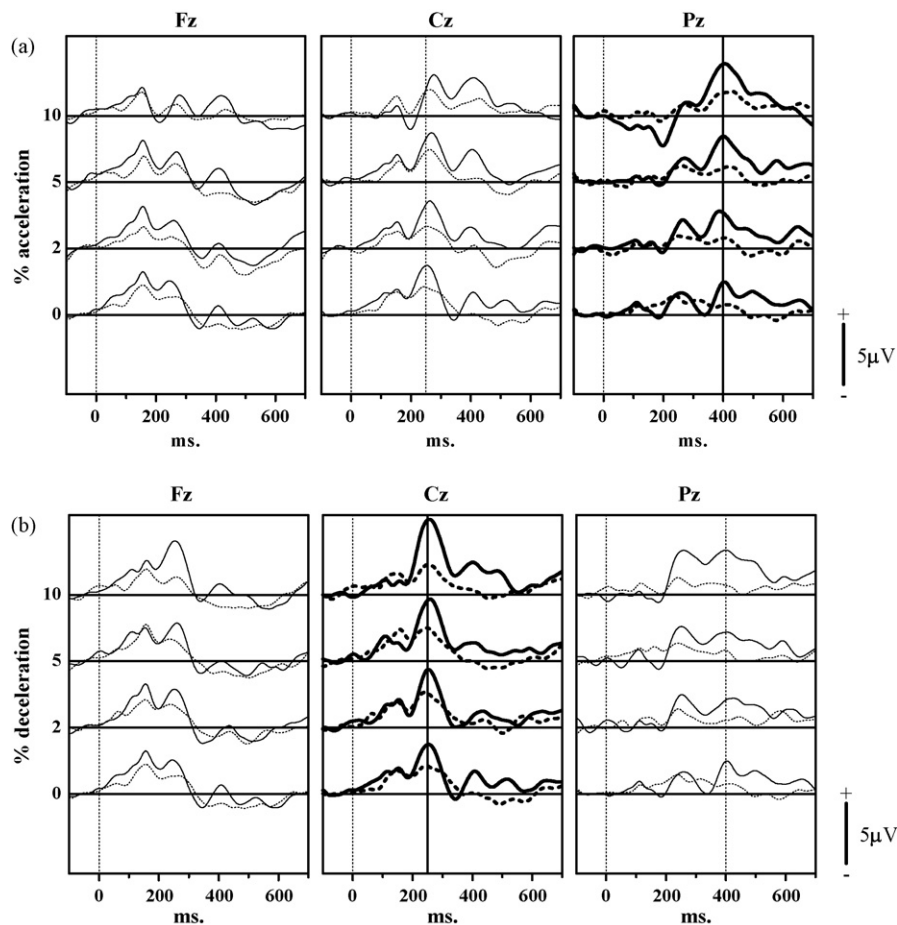


Fig. 3. Grand average AEPs at Fz, Cz, and Pz of good performers (solid lines; $n = 11$) and poor performers (dotted lines; $n = 11$), for both accelerated trials (a) and decelerated trials (b), for each level of tempo change. The early-P3 (at Cz) and late-P3 (at Pz) are marked with vertical lines.

Table 1
ANOVA P3 subcomponent amplitudes

ANOVA ERP component amplitudes			
One-between subjects		(good vs. poor responders)	
Three-within subjects		Electrode site (Fz, Cz, Pz)	
		Direction (acceleration, deceleration)	
		Amount (0%, 2%, 5% 10% tempo change)	
	d.f.	F	p
Early-P3			
Electrode site	(2, 19)	19.09	<.0001
Direction	(1, 20)	19.25	<.0001
Electrode site × Group	(2, 19)	5.16	<.05
Electrode site × Direction	(2, 19)	24.94	<.0001
Electrode site × Amount	(6, 15)	2.83	<.05
Direction × Amount	(3, 18)	6.5	<.01
Electrode site × Direction × Amount	(6, 15)	2.89	<.05
Late-P3			
Group	(1, 20)	4.48	<.05
Electrode site	(2, 19)	18.91	<.0001
Direction	(1, 20)	14.06	<.001
Amount	(3,18)	4.25	<.05
Electrode site × Direction	(2, 19)	7.9	<.01
Direction × Amount	(3, 18)	4.52	<.05

appeared that were sensitive to the amount of acceleration (all $p < .05$, see Table 2a) such that an early-P3 diminished at Fz, Cz, and Pz for both groups and a late-P3 increased at Fz and Cz for both groups with more pronounced accelerations. However, the most distinctive increase was observed at Pz (where a late-P3 appeared to be maximal), but only within the group of good performers.

3.3.2. Effects of decelerations

Fig. 4b shows the ERP early-P3 and late-P3 subcomponent amplitudes for decelerated trials. The early-P3 showed a main effect of Amount at Cz (where the early-P3 appeared to be maximal) and a Group × Amount interaction effect at Fz and Cz (all $p < .05$, see Table 2b). Post-hoc analyses at Fz and Cz for separate groups revealed significant effects for Amount

Table 2a
Post-hoc analyses (one-between subjects, one-within subjects: Amount) on accelerated trials

Effect	Acceleration (p)			Post-hoc
	Group	Amount	Interaction	
Early-P3				
Fz		<.05		
Cz		<.05		
Pz		<.05		
Effect	Accelerate (p)			Post-hoc
	Group	Amount	Interaction	
Late-P3				
Fz		<.05		
Cz		<.05		
Pz		<.05	<.05	Good performers amount effect $p < .05$

Table 2b
Post-hoc analyses (one-between subjects, one-within subjects: Amount) on decelerated trials

Effect	Deceleration (p)			Post-hoc
	Group	Amount	Interaction	
Early-P3				
Fz			<.05	Good performers amount effect $p < .05$
Cz		<.05	<.05	Good performers amount effect $p < .05$
Pz				
Effect	Decelerate			Post-hoc
	Group	Amount	Interaction	
Late-3				
Fz				
Cz				
Pz				

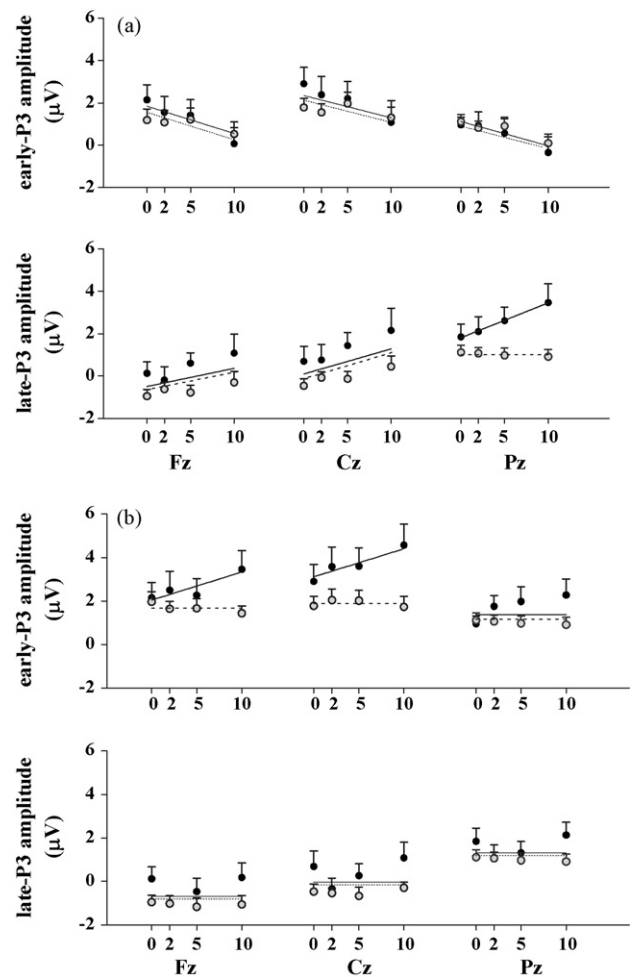


Fig. 4. The early-P3 and late-P3 component amplitudes of good performers (linear regression, solid lines; $n = 11$) and poor performers (linear regression, dotted lines; $n = 11$) for both accelerated trials (a) and decelerated trials (b) at midline sites (Fz, Cz, and Pz). The x-axis shows the percentage of tempo change. The y-axes show the P3 amplitudes (in μV).

within the group of good responders ($p < .05$), such that the early-P3 increased with increasing quantities of tempo decelerations. There was no significant effect of Amount in the group of poor performers. Effects of deceleration on the late-P3 were observed in neither group.

4. Discussion

The general aim of this study was to investigate whether small accelerations are processed differently than small decelerations by measuring the ERP P3 complex during a rhythm perception task. We also assessed whether ERPs to small tempo changes would be different for participants that were good at detecting tempo changes, determined by their behavioral responses, compared to participants that had more difficulties with the task at hand.

In response to accelerated trials, the ERP early-P3 amplitude slightly decreased. However, a more marked increase was observed of the late-P3 subcomponent amplitude over the parietal site with increasing amounts of accelerations within the group of good performers. In response to decelerated trials, however, the early-P3 component amplitude over the frontal and central site increased with increasing amounts of decelerations within the group of good performers.

4.1. Behavioral responses

We found that good responders were able to identify even the smallest amount of tempo change (2%), whereas poor responders were only able to identify the largest (10%) tempo changes above chance level. As expected, the percentage of correct answers was only affected by the amount of tempo change, regardless of direction, thus confirming an earlier study of Vos et al. (1997).

Woodrow (1951) reported that, when presenting single intervals, a difference of at least 6–10% (when intervals ranged from 200 to 2000 ms) was required in order for the participants to be able to detect a deviation from a standard. When presenting sequences (containing multiple intervals), participants have been found to be more sensitive to changes. For example, in a similar study, Pfeuty et al. (2003) observed that 3–5% differences could be detected when presenting five tones at a standard interval of 600 ms. This is in agreement with our results with respect to our group of good performers.

4.2. Individual performance

Although there had not been an explicit recruitment of participants differing in music experience, analyses of the results showed that individual participants differed greatly in their capability to detect small tempo changes. Besides being able to detect smaller tempo changes (i.e., 2%), the effects of different amounts of tempo change on the early and late subcomponents of the ERP P3 were more distinct within the group of good performers. Thus, the detection of small tempo changes does not seem to be a fully automated process, in which case both groups should show the same results. More

likely, the early-P3 and late-P3 reflect aspects of information processing that are closely linked to the generation of the consecutive (correct) response.

In a similar study, Pfeuty et al. (2003) found that their participants could also be separated into two groups with different ERP results. One group displayed an increase in CNV (contingent negative variation; a negative shift preceding the ERP) whereas another group showed a decrease in CNV. Although measuring the CNV was beyond the scope of the current study, a decrease in CNV has been generally linked to an increase in the P3 component (Korunka et al., 1993). In addition, the group showing a decrease in CNV displayed a better behavioral performance than did the other group. This is similar to our observations that good, but not poor, performers showed a marked P3 effect on a tempo change detection task together with a better behavioral performance.

Interestingly, our group of good performers also seemed to have had more musical training, although this effect although this effect failed to reach statistical significance. Comparable effects of musical training have been reported by others. For example, using a pitch detection task, Russeler et al. (2001) found a more pronounced effect for musicians compared to untrained participants. In line with this, Pantev et al. (2001) reported superior processing of piano tones in musicians. Koelsch et al. (2002) found an ERP effect to slightly impure chords – presented among perfect major chords – in professional violinists but not in nonmusicians. Besson et al. (1994) reported that musicians are faster than nonmusicians in detecting incongruous notes. Trainor et al. (2002) reported larger P3 amplitudes in musicians than in nonmusicians in a harmonic, musical task. In previous studies, we also found differences between musicians and nonmusicians, suggesting that an increase in musical experience is accompanied by a more refined rhythm perception (Jongsma et al., 2004a) and less latency variability of ERP responses to auditory patterns (Jongsma et al., 2004b). Others, however, did not observe ERP differences between musicians and non-musicians (Regnault et al., 2001; Koelsch et al., 2000).

4.3. The perception of accelerations

In response to accelerated trials, an early-P3 component amplitude slightly decreased with amount. This result is surprising given the generally accepted association of the P3a with orienting to a novel and unexpected stimulus (Simons et al., 2001). Thus, P3a would have been expected to increase in amplitude with acceleration of the tempo, and the premature appearance of the beat. In contrast, a late-P3 component amplitude markedly increased, and especially so within the group of good performers. This late-P3 component might be similar to the classic P3b, which reflects voluntary, top-down related aspects of attention (Debener et al., 2002). The P3b is commonly elicited within active discrimination tasks and has a maximum amplitude over the central/parietal areas (Comerchero and Polich, 1999). This is in line with our late-P3 findings.

A P3b like component, which was maximal over Pz and which had a latency of 400 ms, also emerged in a previous study

on rhythm processing in reaction to unexpectedly omitted beats (Jongsma et al., 2005). This is in line with results from previous ERP experiments. For example, Besson and Faita (1995) reported that ‘wrong’ notes at the end of a melody elicit a late positive component comparable to a P3b. They concluded that this component serves as a good electrophysiological marker of (the violation of) musical congruency. Therefore, we conclude that when a beat arrives unexpectedly ‘too early’ in time, the increased late-P3 component apparently reflects a similar detection, namely, that the target beat is ‘unexpected’ or ‘wrong’ (i.e., too early), providing feedback to the system in order to generate a correct response.

4.4. The perception of decelerations

In contrast, within the group of good performers, decelerated trials markedly increased an early-P3 component with no changes in the late-P3 component. The latter is surprising given the generally accepted association the P3b to evaluation and updating memory on a task-relevant stimulus. Thus, the P3b would have been expected to increase in amplitude when the expected stimulus was missing because of deceleration. Whereas the P3b is thought to be related to voluntary, top-down related aspects of attention, the P3a is usually described as an indicator of involuntary aspects of attention allocation (Debener et al., 2002). Although the classic P3b is elicited within active conditions and the classic P3a is obtained under passive conditions, these two components are commonly elicited within different tasks. One approach to measure these two subcomponents within one task is the 3-stimulus oddball. In a 3-stimulus variant of the oddball paradigm an additional infrequent non-target stimulus is inserted into the sequence of infrequent target and frequent standard stimuli. Infrequent non-target stimuli elicit a P3a-like component whereas infrequent target stimuli elicit a P3b-like component (Comerchero and Polich, 1999), although more recent research found no difference in P3 latency and topography between target and non-target infrequent stimuli (Katayama and Polich, 1999). Others reported the elicitation of both early-P3 and late-P3 components in choice reaction tasks (Hohnsbein et al., 1995). In addition, several studies employing musical stimuli in active tasks also found an early-P3. In a previous study (Jongsma et al., 2004a), violations of a (musical) congruency affected an early-P3 component. Trainor et al. (2002) also observed a P3a-like component in a musical task. Thus, besides the late-P3, the early-P3 too seems to be sensitive to the violation of musical, either harmonic or rhythmical, congruencies in such a way that the larger the violation, the larger the amplitude of the P3a. This is in line with our results with respect to decelerated trials.

Apparently, detecting a target beat that is presented ‘too late’ relies on different aspects of information processing than detecting a target beat that is presented ‘too early’. Moreover, this detection occurs earlier in time (since the early-P3 peaks at about 250 ms after the target is presented) than the detection of an acceleration (the late-P3 peaks about 400 ms after the target is presented).

4.5. Conclusion and possible theoretical implications

In all, we found that tempo changes affected an early and a late subcomponent of the ERP P3 in participants that were able to detect very small tempo changes. Accelerations were mainly characterized by an increase in the late-P3 subcomponent over parietal sites whereas decelerations were characterized by an increase in the early-P3 subcomponent over fronto-central sites.

This early-P3/late-P3 difference might be understood within the entrained dynamic attending approach that models attention as an internal oscillatory periodicity (Large and Palmer, 2002; Large and Kolen, 1992). Such an internal oscillator can predict when attention in the future will be maximal. Oscillators are activated and/or increased by each incoming event (Large and Palmer, 2002; Large and Kolen, 1992). In case a target beat arrives too early (i.e., is accelerated), attention is not yet maximal, which leads to a ‘surprise effect’ (Donchin, 1981) that gives rise to an increase in a late-P3, similar to the classical P3b amplitude, thus enabling the system to generate a correct response. See also Fig. 5a.

In contrast, when a target beat arrives too late (i.e., is decelerated), attention is already maximal, and the delayed target can be anticipated. The larger the delay, the larger the rhythmical incongruency, and the larger the amplitude of the early-P3 will be. Alternatively, when a target delays, the delay is already detected and attention is directed away from the auditory sequence. Then, the actual emergence of the target

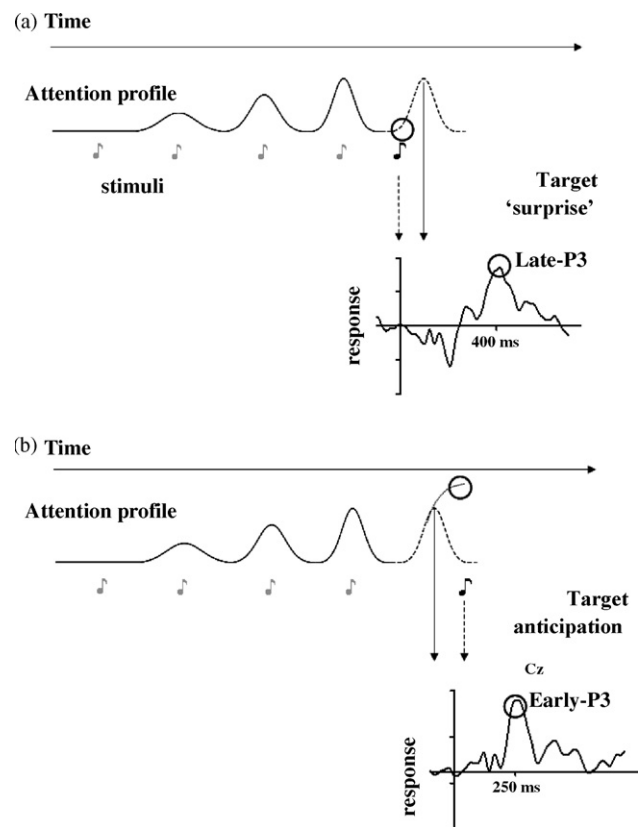


Fig. 5. A possible theoretical explanation for the observed early-P3 and late-P3 effects for, respectively, accelerated trials (a) and decelerated trials (b). The attention profile represents the amount of attention that fluctuates over time.

demands involuntary attention switching to it, thus eliciting a P3a-like component (Barcelo et al., 2006). This might explain why the detection of a decelerated target beat has an earlier expression (namely 250 ms) than an accelerated target beat (namely 400 ms) see also Fig. 5b.

Regardless of the validity of this proposed model, being able to measure differential subcomponents of the ERP P3 complex within one task, to targets with similar task demands, may lead to more refined empirical and theoretical knowledge concerning subcomponents of the ERP P3 complex.

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