



Rhythmic context influences the auditory evoked potentials of musicians and nonmusicians

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Abstract

In this study, we investigated how rhythms are processed in the brain by measuring both behaviourally obtained ratings and auditory evoked potentials (AEPs) from the EEG.

We presented probe beats on seven positions within a test bar. Two bars of either a duple- or triple meter rhythm preceded probe beats. We hypothesised that sequential processing would lead to meter effects at the 1/3 and 1/2 bar positions, whereas hierarchical processing would lead to context effects on the 1/3, 1/2 and 2/3 bar positions.

We found that metric contexts affected behavioural ratings. This effect was more pronounced for rhythmic experts. In addition, both the AEP P3a and P3b component could be identified. Though metric context affected the P3a amplitudes, group effects were less clear.

We found that the AEP P3a component is sensitive to violation of temporal expectancies. In addition, behavioural data and P3a correlation coefficients (CCs) suggest that temporal patterns are processed sequentially in nonmusicians but are processed in a hierarchical way in rhythmic experts.

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1. Introduction

The general aim of this study was to investigate how the brain processes rhythmical information and how a mental representation of a rhythm leads to expectancies about events

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in the near future. This was investigated by means of evoked potentials and by means of behaviourally obtained ratings.

There are several theories concerning the processing of (musical) rhythms. An early paper concerned with rhythm processing is one by [Martin \(1972\)](#). In this paper, Martin proposes a distinction between sequential versus hierarchical coding of temporal sequences. Earlier psychological models concerned with temporal relationships represented relationships between elements as being sequential only. [Martin \(1972\)](#) however proposed that any real time sequence of events might possess a hierarchical internal structure. For example, on a first, sequential level, an underlying invariant, e.g. the beat, is determined. This beat induction is fundamental to the processing of temporal information. One level up, equal subdivisions between beats in either two (as with duple-meters) or in three (as with triple meters) often occur. On a higher level, these subdivisions themselves might be divided in two or three equal parts. In line, the pattern-based, or beat-based model of [Povel \(1981\)](#) also proposes that the first step in the perception of temporal sequences is beat-induction. On a higher level, periods within beats should be either empty; filled with events at equal intervals or filled with events at unequal intervals, provided the subdivision relate as 1:2. The statistical approach of expectancy implies involuntary but relatively long lasting expectancies that are acquired probabilistically: “one expects what is most probable” ([Palmer and Krumhansl, 1990](#)). By examining the rhythmic structure of existing musical pieces, expectancy profiles belonging to either a duple- or triple-meter can be estimated. More recent theories like the dynamic attending and the distributed expectancy approach have proposed a dynamic view of rhythm-induced expectancies. The entrained dynamic attending approach thus models attention as an internal oscillatory periodicity. This oscillator can thus predict the maximum expectancy, or when attention in the future is maximal. Oscillators are activated and/or increased by each incoming event. On a lower-order sequential level, the beat will activate such an oscillator. In addition, on a higher-order hierarchical level both beats and subdivisions between beats will activate multiple, possible coupled, oscillators ([Large and Kolen, 1992](#); [Large and Palmer, 2002](#)). The distributed expectancy approach ([Desain, 1992](#)) models expectancy also in a dynamic way. This theory however bases the mental organization of temporal patterns on time intervals instead of the events. Given a rhythmical sequence, complex expectancy profiles are generated with a maximum on the dominant time-interval and additional expectancies on multiples or subdivisions of this interval.

Though all of the above-mentioned theories differ dramatically in how they model rhythm-induced expectancies, they predict more or less similar expectancies given a certain short rhythm. Also, none of the above-mentioned theories proposes a difference in rhythm-induced expectancies between musicians or naïve listeners. We hypothesize that differences between musicians and nonmusicians will exist such that with an increase in musical experience, there will be an increase in hierarchical levels in which rhythmical sequences can be perceived. Thus, we propose that musical experience will lead to higher-order hierarchical coding of rhythmical patterns instead of a first-order sequential processing of temporal patterns. Since different order levels of rhythm processing lead to different expectancies, in this study we determined if rhythm-induced expectancies were different within rhythmically trained participants compared to musically untrained participants (MUPs).

Evoked potentials (EPs) are small voltage fluctuations resulting from sensory, cognitive, or motor evoked neural activity. These electrical changes are commonly obtained by

averaging EEG epochs time-locked to repeated events. EPs consist of components that are typically divided, based on their latency, into exogenous and endogenous components (Coenen, 1995; Näätänen, 1990). It is assumed that early components (<100 ms after stimulus onset) are primarily determined by the physical characteristics of the external stimulus (Blackwood and Muir, 1990), hence labelled the exogenous components. Cognitive aspects of information processing are well known to modulate the later occurring endogenous components (>100 ms after stimulus onset) (Blackwood and Muir, 1990; Gaillard, 1988). For example, it has long been known that expectancy modulates the endogenous EPs (for review, see Polich and Kok, 1995). When expectancy is violated, EPs typically show a large positive wave around 300 ms after onset of the unexpected stimulus, the so-called P300 or P3 (Castro and Diaz, 2001; Johnson and Donchin, 1980; Squires et al., 1977). In line, when expectancy is confirmed, the EP P3 amplitude will be smaller.

We constructed hypotheses about when a following event is maximally expected given a rhythmical sequence, based on either a first-order sequential or a higher-order hierarchical level. Though the above-mentioned theories do not propose that there might be a difference in rhythmical induced expectancies between musicians or naïve listeners, other researchers using EP measurements have reported that musicians show more refined detection of, e.g. pitch (Russeler et al., 2001) and impure chords (Koelsch et al., 2002). In line, we hypothesize that differences between musicians and nonmusicians will exist such that with an increase in musical experience, there will be an increase in hierarchical levels in which rhythmical sequences can be perceived. Since different levels of rhythm processing lead to different expectancies, EPs might be used to determine if expectancies are different within rhythmically trained participants compared to musically untrained participants. Behaviourally obtained ratings only provide a measure of the end product of the processes involved. Recording EPs however allows one to follow the time-course of the different processes involved in musical expectancy (Regnault et al., 2001). Additionally, EP measurements provide a very direct measure not sensitive to response-bias due to, for example group differences in skill (Gaillard, 1988).

In this study, we elicited EPs by presenting probe beats on either the 1/6, 1/4, 1/3, 1/2, 2/3, 3/4 or 5/6 position within a test-bar. Probe beats were preceded by two bars of either a duple- (2/4) or triple (3/4) meter context and a silent bar. Thus, seven different probe beats were presented in two different metric conditions (duple- and triple meter). A diagram of the presented stimulus material is depicted in Fig. 1. The silent bar was introduced to avoid cumulative effects of inhibition on AEP component amplitudes that occur when two or more stimuli are presented with relatively short inter-stimulus intervals (Cardenas et al., 1997; Fitzgerald and Picton, 1981). Thus, for each probe beat, the last three events (lasting more than a second) were identical in both conditions. This design led to the following hypotheses. Graphical representations of the H_0 and H_1 are depicted in Fig. 2a and b.

H₀. The temporal pattern is processed according to a sequential, i.e. first-order interpretation of the pattern. The probe beat in the test bar either continues the preceding, isochronous pattern (e.g. occurs after the same interval as the interval between beats and sub-beats in the preceding pattern) or is a discontinuation of the preceding isochronous pattern (i.e. occurs after a deviant interval as in the preceding pattern). Thus, within the duple-meter trials, only a high expectancy towards probe beats on the 1/2 bar position will arise. In the triple meter

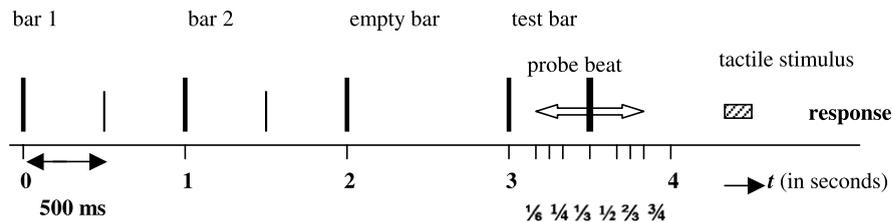
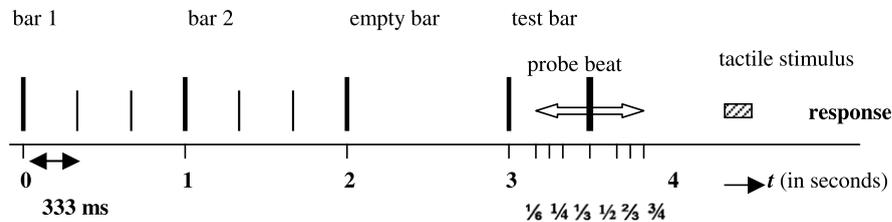
Duple meter context**Triple meter context**

Fig. 1. Shows a diagram of the presented stimulus material. Probe beats were presented on either the 1/6, 1/4, 1/3, 1/2, 2/3, 3/4 or 5/6 position within a test bar. Probe beats were preceded by two bars of either a duple meter context (top) or triple meter context (bottom). Bar length (1 s) was kept constant over conditions.

trials, a high expectancy towards probe beats on the 1/3 position in the test bar will arise. For these hypotheses, the amount of expectancy is depicted as a Gaussian curve for the duple meter context. For the triple meter context, the curve is skewed, since no probe beats can occur earlier than the beginning of the test bar, but can still occur at the end of the test bar. Thus, according to this hypothesis, a maximal effect of context will appear on the probe beats on the 1/3 position of the test bar (see Fig. 2a). Thus, the estimated, relative values of expectancies towards probe beats (according to their position of occurrence in the test bar) in the duple-meter context can be described as: $[1/2] > [1/3, 2/3] > [1/4, 3/4] > [1/6, 5/6]$, but in the triple meter context as: $[1/6] < [1/4] < [1/3] > [1/2] > [2/3] > [3/4] > [5/6]$.

H1. The temporal pattern is processed in accordance with an extra hierarchical level, taking into account the induced meter, i.e. beats are not only expected to continue the previously presented isochronous pattern, but are also expected to occur on subdivisions and multiples of the interval between beats and sub-beats. In this study, we have modelled expectancy according to this hypothesis as the sum of several Gaussian curves, one around each relevant maximum (Desain, 1992). Thus, within the duple meter trials not only a high expectancy arises on the 1/2 bar position, but also expectancies with respect to the 1/4 and 3/4 positions will arise. Similarly, in the triple-meter trials, expectancies on the 1/3 position, but also on the 2/3 position, and to a lesser extend on the 1/6, 1/2 and 5/6 positions will arise. The estimated relative values of expectancies towards probe beats in the duple-meter context can then be described as: $[1/2] > [1/4, 3/4] > [1/6, 1/3, 2/3, 5/6]$, but in the triple meter context as: $[1/3, 2/3] > [1/6, 1/2, 5/6] > [1/4, 3/4]$. According to this hypothesis, a maximal effect of context will appear on the probe beats on the 1/2 position of the test bar (see Fig. 2b).

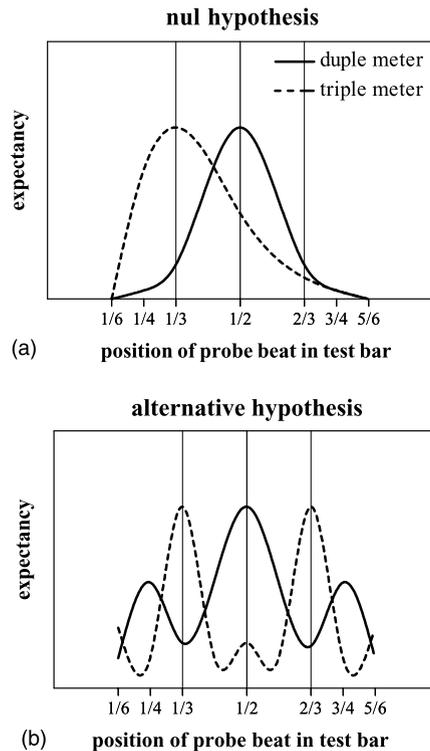


Fig. 2. Shows graphical representations of the hypotheses. (a) Shows the null hypotheses, (b) shows the alternative hypotheses. The *x*-axis shows the position of a presented probe beat within the final test bar. The *y*-axis show the estimated amount of expectancy. The solid lines depict expectancies evoked by a duple meter rhythm; the dotted lines depict expectancies evoked by a triple-meter rhythm.

2. Methods

2.1. Participants

Fifteen musically untrained participants without having formal music or dance education and sixteen rhythmically trained participants (RTPs), e.g. professional percussionists and bass guitar-players, participated in the experiment. One MUP and two RTPs were excluded because more than 50% of the trials were lost (due to, e.g. EOG and movement artefacts). RTPs ($n = 14$) had on average 15.2 ± 10.66 years of musical experience (mean \pm S.D.), and were aged 32.7 ± 12.87 (mean \pm S.D.). NTP ($n = 14$) were aged 22.6 ± 3.93 (mean \pm S.D.).

Only healthy participants, not using medication and without a neurological history, participated in the experiment. Participants signed a written informed consent. They all received a small fee or course credit points for their participation. The participants were not allowed to drink coffee, or to smoke cigarettes prior to the experiment. The participants sat comfortably in a chair during the experiment and were instructed to keep their eyes closed. They were asked to blink their eyes as little as possible during stimulus presentations. Finally, they were instructed to sit as still as possible.

2.2. EEG recordings

EEG was registered with tin electrodes mounted in an elastic electrode cap (Electrocap International). EEG was derived from Fz, Cz, Pz, Fp1, Fp2, F3, F4, F7, F8, C3, C4, T7, T8, P3, P4, P7, P8, O1 and O2, according to the 10–20 electrode system (Jasper, 1958). The left mastoid served as reference (Unrug et al., 1997). 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. Electrode impedance of all cortical electrodes was less than 3 k Ω and impedance was less than 5 k Ω for EOG electrodes. EEG and EOG were filtered between 0.016 and 100 Hz and sampled at 500 Hz. Recordings were off-line filtered with a steep low-pass filter of 30 Hz (198 dB).

2.3. Procedure

A diagram of the used paradigm is presented in Fig. 1. Auditory EPs (AEPs) were elicited by presenting probe beats on either the 1/6, 1/4, 1/3, 1/2, 2/3, 3/4 or 5/6 position within the test-bar. Two bars of either a duple- or triple meter context, followed by an empty bar, preceded probe beats. The test bar contained the first beat and a probe beat. Bar length was 1000 ms, inter-stimulus intervals (ISIs) between beats and sub-beats were 500 ms for duple- and 333.33 ms for triple-meter trials. The inter-trial intervals (ITI) were randomly varied between 2.5 and 3.5 s. After each trial, participants had to judge whether probe beats fitted good within the duple- or triple-meter context on a seven-point scale. In total 14 different trials were constructed: seven different probe beats presented in two different metric conditions (duple- and triple meter). All trials were presented 25 times and randomised within blocks of 14 trials. In total, 350 trials were presented.

Participants were tested in an electrically shielded, sound attenuated and dimly lit cubicle (inside dimensions: 2 m \times 2.2 m \times 2 m). The participants were seated in a comfortable chair. A speaker was placed in front of the participant and was used for presenting auditory stimuli. Participants had their hands placed on a keyboard with seven keys. Subjects were instructed to judge the last beat (e.g. the probe beat) of each trial. Five practice trials were presented before a session started. Duration of a test session was 50 min.

Judgements were made after a tactile warning stimulus given by a vibrator placed on the left wrist, thus allowing a delayed response (about 1.5 s. after the trial had ended), in order to avoid motoric artifacts in the EEG. The vibrator consisted of a small dc-motor (5 V) with an eccentrically placed weight on its axes, enclosed in an isolating encasing of PVC, thus ensuring isolation from the electronics to the participant. The signal to trigger the stimulator was generated as a midi-output, to ensure high timing accuracy.

Judgemental ratings varied from 1 (the last beat does not fit within the preceding rhythm at all) to 7 (the last beat fits perfect within the preceding rhythm). The responses were routed to the NeuroScan equipment to be captured along with the EEG data to be used for further processing.

The stimuli were generated by a general MIDI synthesizer (Yamaha MU-90) controlled by a Macintosh G4 running the POCO system (Honing, 1990; Desain and Honing, 1992) and an OMS Midi driver. The sound was presented via a Yamaha MS-20 active loudspeaker at 1 m

distance in front of the subject. The sound consisted of a short ‘high woodblock’ (General MIDI) percussion sound (1 ms attack, 10 ms decay to 6 dB below peak level) presented at a sound pressure level of 81 dB(A) for the beats and 71 dB(A) for the subdivisions at the subjects position. Markers embedded in the MIDI stream were caught by a second Macintosh G4 and routed to the NeuroScan equipment to be captured along with the EEG data to be used for further processing.

2.4. Statistical analysis

The EEG was visually checked off-line for EOG activity and other artefacts. AEPs generated by stimuli that were presented in the presence of artefacts were excluded from further analysis. The EEG fragments time-locked to probe beat onsets were averaged for each probe beat separately. For each probe beat position, a different baseline correction was performed. This is because AEPs elicited by beats preceding probe beats affected the AEPs of interest. The period used for baseline corrections started at stimulus onset of the beat preceding the probe beat until probe beat onset (e.g. for probe beats on the 1/6: –167 ms till 0 ms; at 1/4: –250 ms till 0 ms; 1/3: –333 ms till 0 ms; 1/2: –500 ms till 0 ms; 2/3: –667 ms till 0 ms, 3/4: –750 ms till 0 ms and 5/6: –834 ms till 0 ms). Separate averages for the seven trial types, in each metric condition, were determined for each individual. Visual inspection of the AEPs showed a distinct P3a component with maximal amplitudes over Cz and a distinct P3b component with maximal amplitudes over Pz. All AEP P3a and P3b component amplitudes at Fz, Cz and Pz and their common latencies were determined by picking maximum values within a priori specified windows at a specified channel (P3a: max. amplitude at Cz between 200 and 300 ms; P3b: maximum amplitude at Pz between 300 and 450 ms) of the individual AEPs.

On P3a and P3b amplitudes, a one-between (group), three-within (electrode position, metric context and position of probe beat) multivariate ANOVA analysis with repeated measures was performed. On P3a and P3b latencies, a one-between (group), two-within (metric context and position of probe beat) multivariate ANOVA analysis with repeated measures was performed.

Secondly, with respect to the P3a and P3b amplitudes, three-within (electrode position, metric context and position of probe beat) multivariate ANOVA tests with repeated measures were performed, to determine context effects for groups’ separately.

Finally post-hoc ANOVAs and *t*-tests, to determine context effects for separate leads and separate probe beats respectively, were performed.

In addition, and for descriptive purposes only, we determined for each individual participant correlation coefficients (CCs) of the P3a domain (e.g. all values in the window 200–400 ms after probe beat onset). CCs were calculated from signals derived from Cz where P3a appeared to be maximal. CCs were calculated between the P3a domains elicited in the duple meter context compared to all the P3a domains elicited in the triple meter context. Denoting the *N* samples of the P3a_{*n*} domain as P3a_{*n*}*i* (*i* = 1, . . . , *N*), the zero-delay inter-P3a correlation coefficient is obtained from:

$$CC_{n,m} = \sum_{i=1}^N (P3a_{n,i} - \overline{P3a_n}) / N_n \times (P3a_{m,i} - \overline{P3a_m}) / N_m,$$

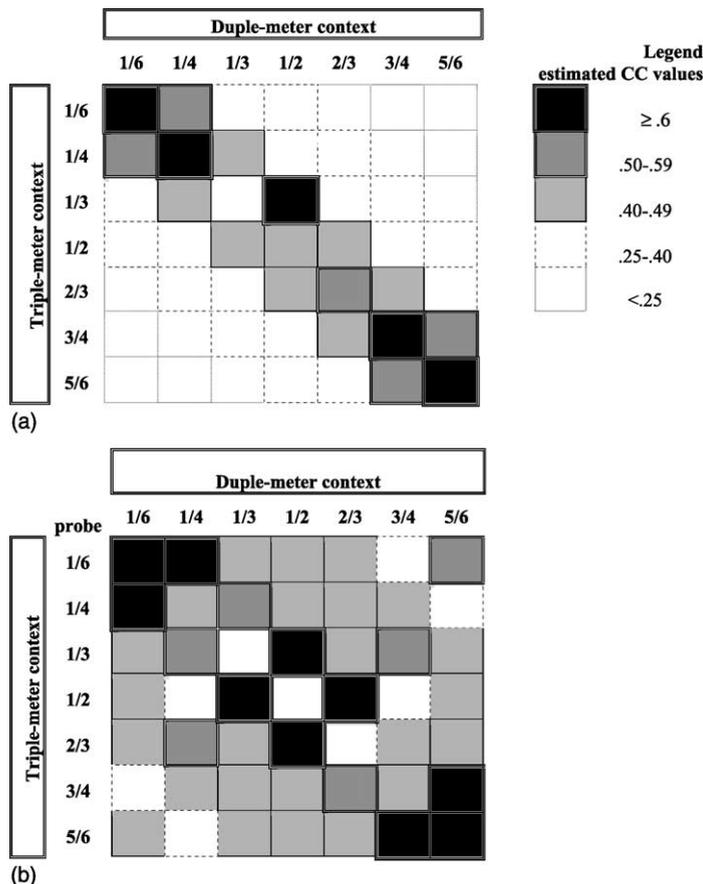


Fig. 3. Shows estimated correlation coefficients according to the null hypothesis (a) and alternative hypothesis (b). Black squares represent relatively high correlation coefficients; lighter squares represent relatively low correlation coefficients. Correlation coefficients are estimated on all probe beats (on 1/6, 1/4, 1/3, 1/2, 2/3, 3/4 or 5/6 position) between the duple- and triple-meter contexts.

where the normalization factor $N_n = \sqrt{\sum_i (P3a_{n,i} - \overline{P3a_n})^2}$, and the mean P3a signal $\overline{P3a_n} = \sum_{i=1}^N P3a_{ni} / N$. The CCs expresses the resemblance of the two P3a signals involved. $CC = 1$ is obtained for identical signals, $CC = -1$ for mutual inverted signals. The advantage of this method is that one single measure can express the amount of similarity or deviance between two signals, taking into account both amplitudes and latencies (Jongsma et al., 2000).

Fig. 3a and b depicts estimated correlation coefficients between the seven points on the two curves of the H₀ (3a) and H₁ (3b), respectively. Relatively high CCs between the p1/3 (the probe beat on the 1/3 position of the test bar) of the triple meter trials and the p1/2 of the duple meter trials would support our H₀. In line, relatively depressed CCs between

the p1/3 of the triple meter context with the p1/3 of the duple meter context (the maximal predicted difference) would also support our H_0 .

Relative high correlation coefficients between the p1/3 of the triple meter trials and the p1/2 of the duple meter trials, between the p2/3 in triple meter trials and the p1/2 in duple meter trials, between the p1/2 in triple meter trials and the p1/3 in duple meter trials and the p2/3 in duple meter trials with the p1/2 in triple meter trials, would support our H_1 . In addition, relative low CCs between the p1/2 in duple meter trials with the p1/2 in triple meter trials (the maximal predicted difference), together with overall higher CCs, would further support our H_1 .

3. Results

3.1. Behavioural results

Fig. 4a shows normalised ratings of MUPs and Fig. 4b shows normalised ratings of RTPs. With respect to the ratings a main context effect and main probe effect were observed. In addition, a context \times probe interaction effect and a context \times probe \times group interaction effect were observed (for F - and P -values, see Table 1). Post-hoc analyses revealed that for the MUPs context only affects probe beats presented at the 1/3 and 1/2 positions in the test bar (all $P < 0.05$). In the group of RTPs, context effects were found on probe beats presented at the 1/4, 1/3, 1/2 and 2/3 positions of the test-bar (all $P < 0.05$).

3.2. AEP results

Fig. 5a shows the grand average AEPs at midline sites of MUPs and Fig. 5b shows the grand average AEPs at midline sites of RTPs. Fig. 6a and b shows scalp distributions of the P3a for both MUPs (Fig. 6a) and RTPs (Fig. 6b). Fig. 6c and d shows scalp distributions of the P3b for both MUPs (Fig. 6c) and RTPs (Fig. 6d). Scalp distributions are given for all seven probe beats for both contexts.

Fig. 7a and b shows P3a amplitudes and latencies for MUPs and RTPs, respectively. Fig. 8a and b shows P3b amplitudes and latencies for MUPs and RTPs, respectively.

Table 1 summarizes all F - and P -values. With respect to AEP P3a component amplitude, main effects of electrode site (amplitudes were higher at Cz then at Fz and Pz), context (amplitudes were higher in the duple meter context) and probe beat (amplitudes increased with probe tone position) were observed. In addition, a context \times group interaction was observed.

A second ANOVA analysis revealed only main effects of electrode site (P3a amplitudes appeared to be higher at Cz then Pz and Fz), context (P3a amplitudes appeared to be higher in triple meter the duple meter context) and probe beat (P3a amplitudes decreased when position of the probe beat appeared later within the test bar) within the group of MUPs.

In the group of RTPs only a main effect of electrode site (P3a amplitudes appeared to be higher at Cz than Pz and Fz) was observed. In addition an interaction effect between electrode site, probe beat and context was observed. Post hoc two-within ANOVA analyses for each electrode site separately revealed interaction effects between context and probe

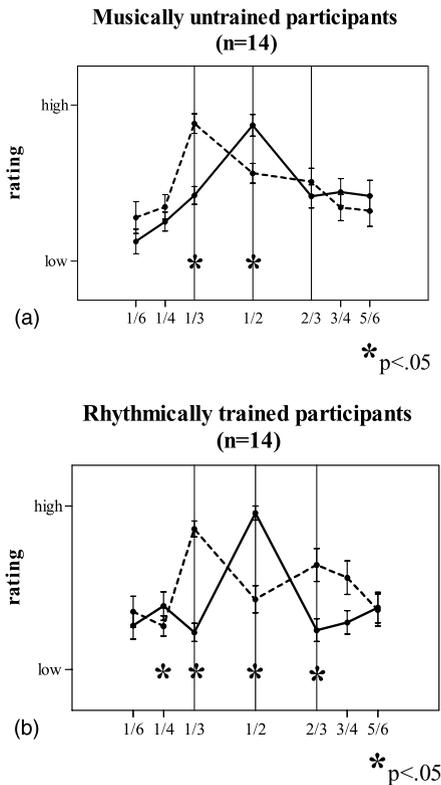


Fig. 4. Shows normalised behaviourally obtained judgemental ratings of both musically untrained participants (a) and rhythmically trained participants (b). The x-axis shows the position of a presented probe beat within the final test bar. The y-axis shows the normalised ratings (high = 1, low = 0). The solid lines depict ratings obtained in duple meter trials; the dotted lines depict ratings obtained in triple-meter trials. Significant context effects are marked (*).

beat at both Cz and Pz, such that P3a amplitudes were decreased at the 1/3 position within the triple meter context (Pz), the 1/2 position within the duple meter context (Cz) and the 1/6 position within the duple meter context (Pz).

With respect to AEP P3b component amplitude, a main effect of electrode site was observed (P3b appeared to be maximal at Pz). In addition, an electrode site \times probe beat interaction effect was observed. At Pz, P3b amplitudes decreased when the position of the probe beat within the test bar increased. With respect to group, no interaction effects were found.

With respect to the P3a latency, a main probe beat effect (latencies decreased when probe beat position increased) and a main group effect (RTPs had longer latencies than MUPs) were observed. No effects with respect to the P3b latency were found.

Table 1
Summarizes *F*- and *P*-values of ANOVA results for behaviourally obtained judgemental ratings, AEP P3 component amplitudes and latencies and the P3b component amplitudes and latencies

Behaviour	ANOVA results	<i>F</i> -values	<i>P</i> -values
Behavioural ratings	Context	$F(1, 26) = 4.81$	0.050
	Probe beat	$F(2, 54) = 8.84$	0.001
	Context \times probe beat	$F(3, 75) = 20.23$	0.001
	Context \times probe beat \times group	$F(3, 75) = 3.44$	0.050
AEPs	ANOVA I results	<i>F</i> -values	<i>P</i> -values
P3a amplitude	Electrode site	$F(2, 25) = 43.24$	0.001
	Context	$F(1, 26) = 5.18$	0.050
	Probe beat	$F(6, 21) = 2.69$	0.050
	Context \times group	$F(1, 26) = 3.98$	0.060
P3a latency	Probe beat	$F(6, 21) = 4.5$	0.010
	Group	$F(1, 26) = 8.40$	0.010
P3b amplitude	Electrode site	$F(2, 25) = 17.03$	0.001
	Electrode site \times probe beat	$F(12, 15) = 3.36$	0.050
P3b latency	–	–	–
MUPs	ANOVA II results	<i>F</i> -values	<i>P</i> -values
P3a amplitude	Electrode site	$F(2, 12) = 18.94$	0.001
	Context	$F(1, 13) = 7.13$	0.050
	Probe beat	$F(6, 8) = 6.18$	0.050
	Electrode site \times probe \times context	$F(12, 2) = 2.59$	n.s.
P3b amplitude	Electrode site	$F(2, 12) = 5.66$	0.050
RTPs	ANOVA II results	<i>F</i> -values	<i>P</i> -values
P3a amplitude	Electrode site	$F(2, 12) = 27.35$	0.001
	Context	$F(1, 13) = 0.07$	n.s.
	Probe beat	$F(6, 8) = 2.12$	n.s.
	Electrode site \times probe \times context	$F(12, 2) = 41.44$	0.050
P3b amplitude	Electrode site	$F(2, 12) = 12.31$	0.010
Post hoc analyses			
P3a amplitude			
Fz	Probe beat		0.010
Cz	Context \times probe		0.010
Pz	Context \times probe		0.010

3.3. Correlation coefficients of the endogenous AEPs

Fig. 3 shows estimated correlation coefficients according to the null hypothesis (Fig. 3a) and alternative hypothesis (Fig. 3b). Black squares represent relatively high correlation coefficients; lighter squares represent relatively low correlation coefficients. Correlation coefficients are estimated on all probe beats (on 1/6, 1/4, 1/3, 1/2, 2/3, 3/4 or 5/6 position) between the duple- and triple-meter context.

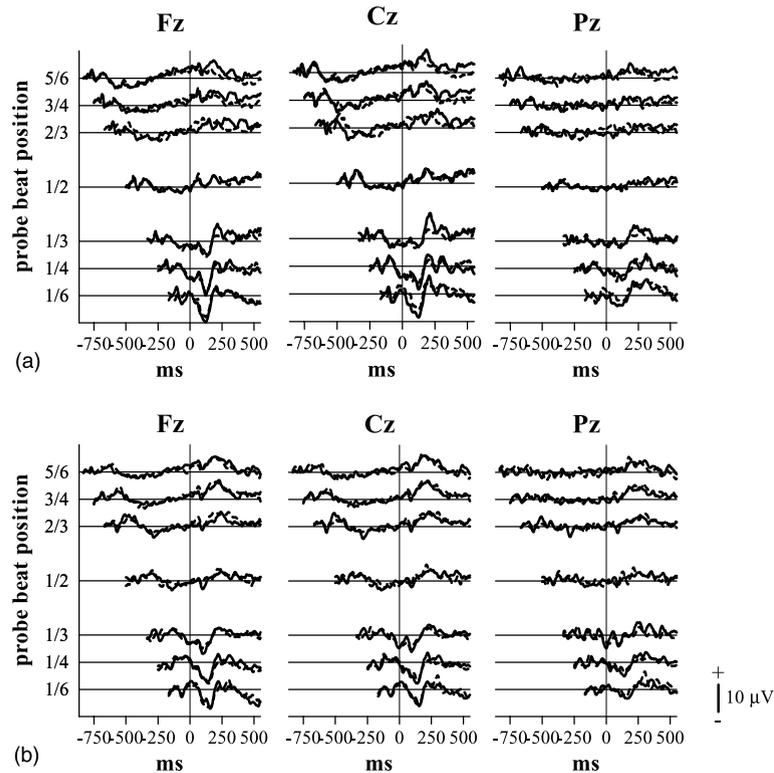


Fig. 5. Shows grand average AEPs ($n = 14$) at Fz, Cz and Pz of both musically untrained participants (a) and rhythmically trained participants (b). The x -axis shows time (ms) in relation to probe beat onset (at 0). Probe beat onset is marked with a black rectangle. The y -axis shows the amplitudes (in μV) and position of probe beat within the test bar. The solid lines depict AEPs elicited in duple-meter trials; the dotted lines depict AEPs elicited in triple-meter trials.

Fig. 9a shows calculated, averaged CCs for MUPs and Fig. 9b for RTPs. We found that CCs of MUPs could be compared fairly well with the CCs as predicted by the H_0 hypotheses. That is, in general fairly low CCs were observed. Though we did observe the predicted lower CCs for AEPs elicited by both probe beats at the 1/2 bar position between the duple- and triple meter context and for both probe beats at the 1/3 bar position between the duple- and triple meter context (the maximal predicted difference), we did not observe the predicted higher CCs for both probe beat at the 1/2 bar position in the duple meter context with the probe beat at the 1/3 bar in the triple meter context.

In contrast, CCs of RTPs could be better compared with CCs as predicted by the H_1 hypotheses. That is, in general higher CCs than in the MUPs were observed. High CCs occurred between AEPs elicited by probe beat at the 1/3 bar within the triple meter context and the probe beat at the 1/2 bar position within the duple meter context and between the probe beat at the 2/3 bar within the triple meter context and the probe beat at the 1/2 bar position within the duple meter context. In line, a decreased CC appeared between

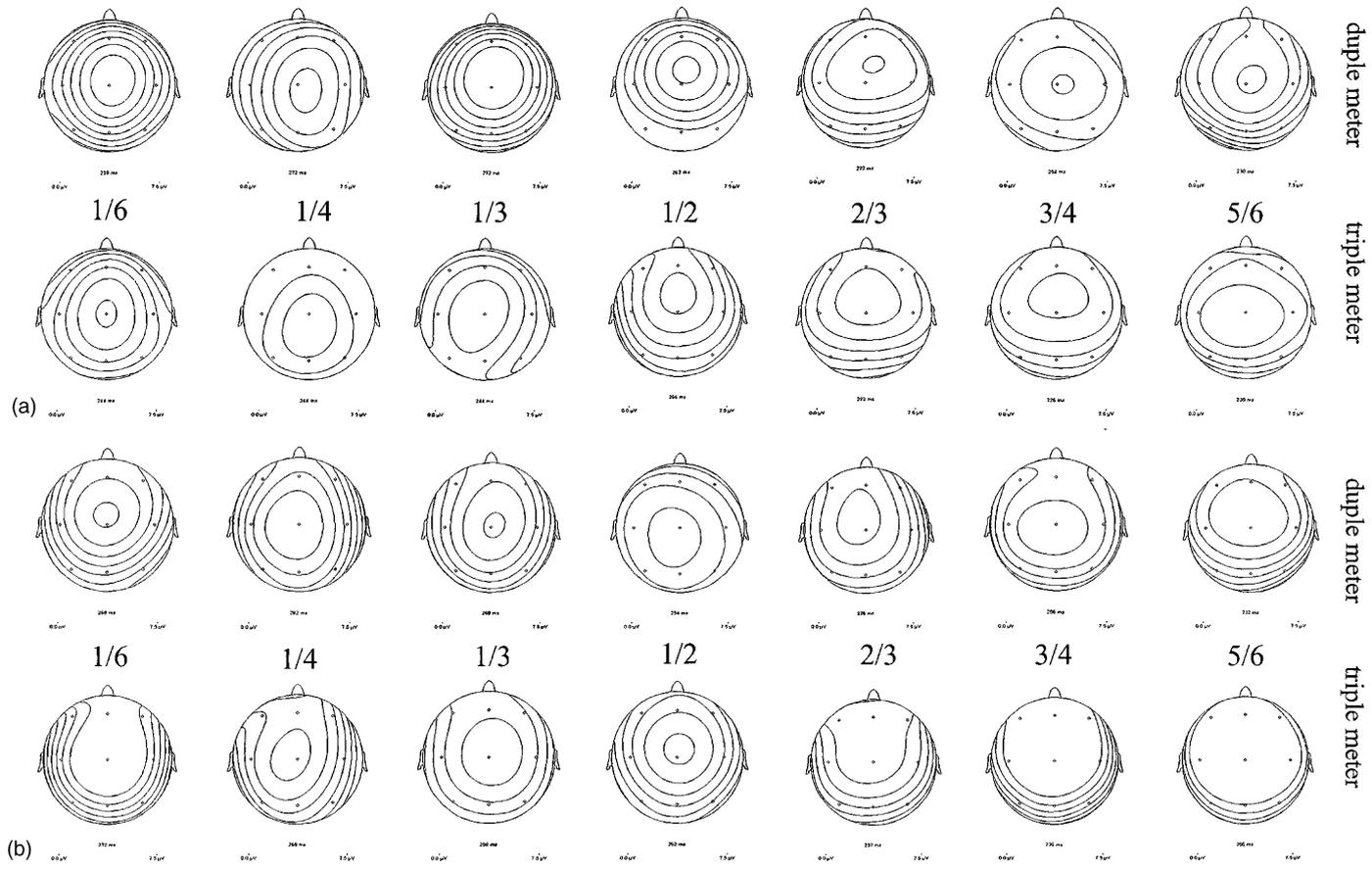


Fig. 6. (a and b) Shows scalp distributions of the AEP P3a component for both musically untrained participants (a) and rhythmically trained participants (b). (c and d) Shows scalp distributions of the P3b component for both musically untrained participants (c) and rhythmically trained participants (d). Scalp distributions are given for all seven probe beats for both context.

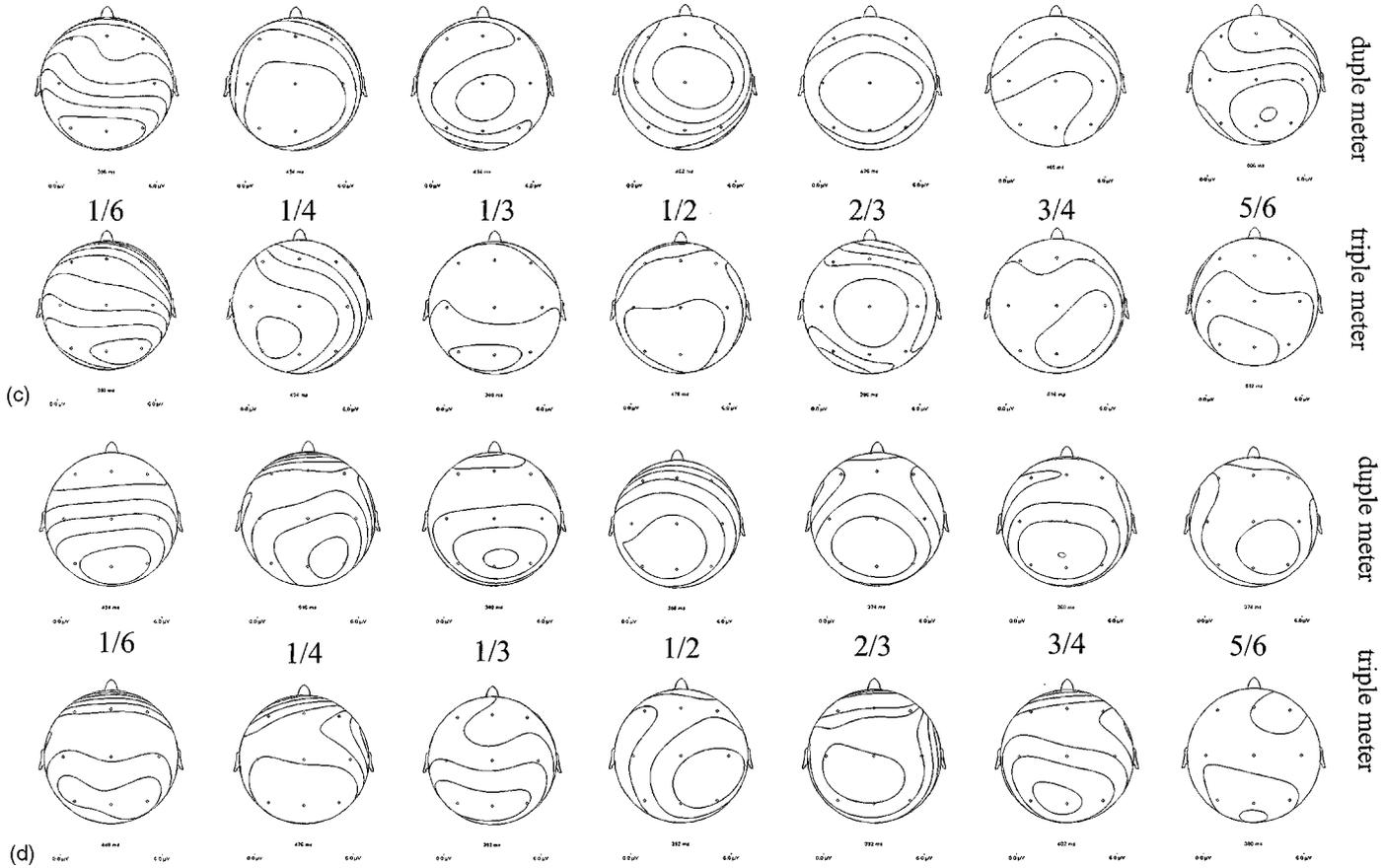


Fig. 6. (Continued).

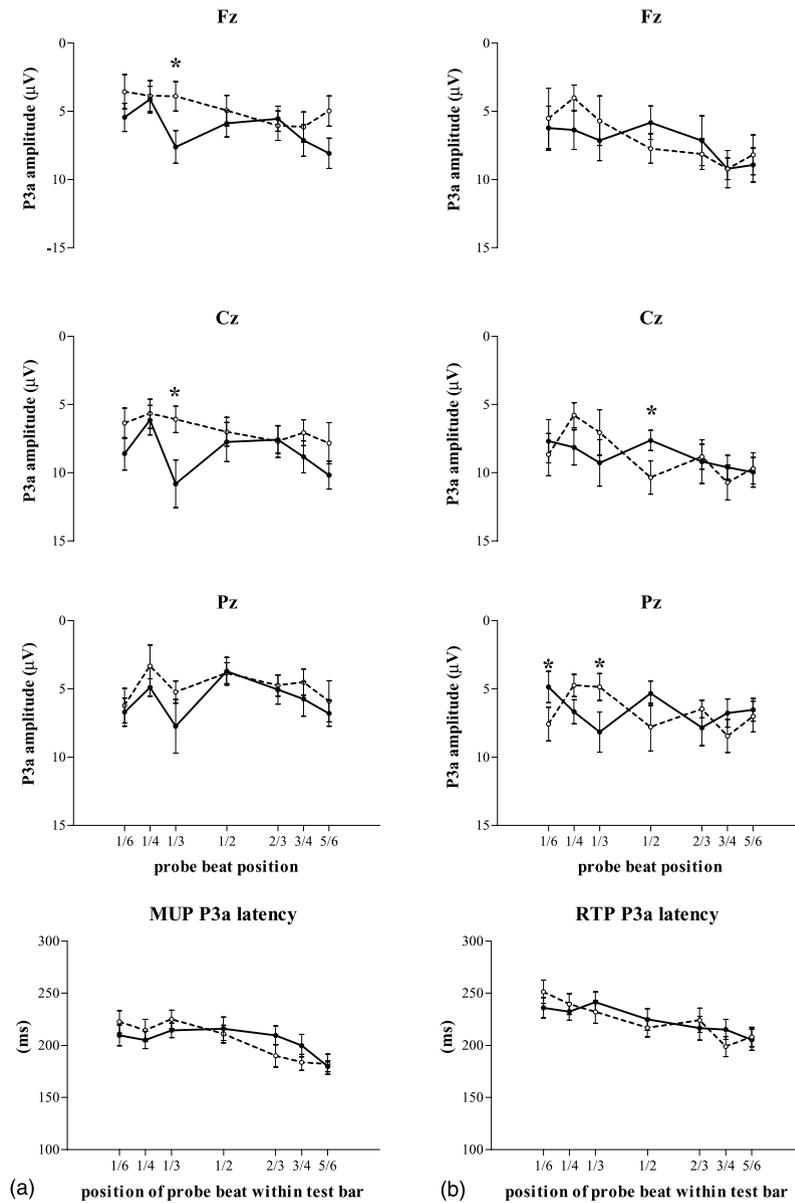


Fig. 7. Shows the P3a component amplitudes and latencies of both musically untrained participants (a) and rhythmically trained participants (b) at Fz, Cz and Pz. The x-axes show the position of a presented probe beat within the final test bar. The y-axes show the P3a amplitudes (μV) and latencies (ms), respectively. The solid lines depict expectancies evoked in duple meter trials; the dotted lines depict expectancies evoked in triple-meter trials. Significant context effects are marked (*).

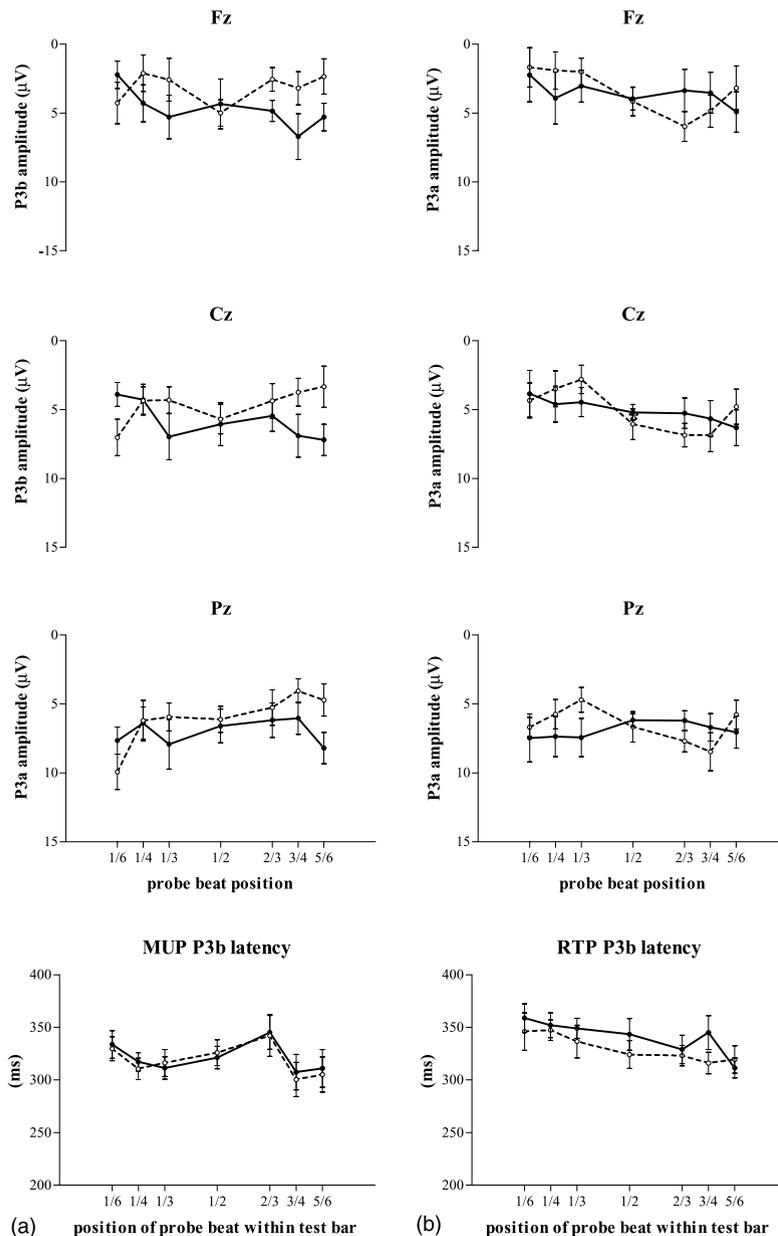


Fig. 8. Shows the P3b component amplitudes and latencies of both musically untrained participants (a) and rhythmically trained participants (b) at Fz, Cz and Pz. The x-axes show the position of a presented probe beat within the final test bar. The y-axes show the P3b amplitudes (μV) and latencies (ms), respectively. The solid lines depict expectancies evoked in duple meter trials; the dotted lines depict expectancies evoked in triple-meter trials. Significant context effects are marked (*).

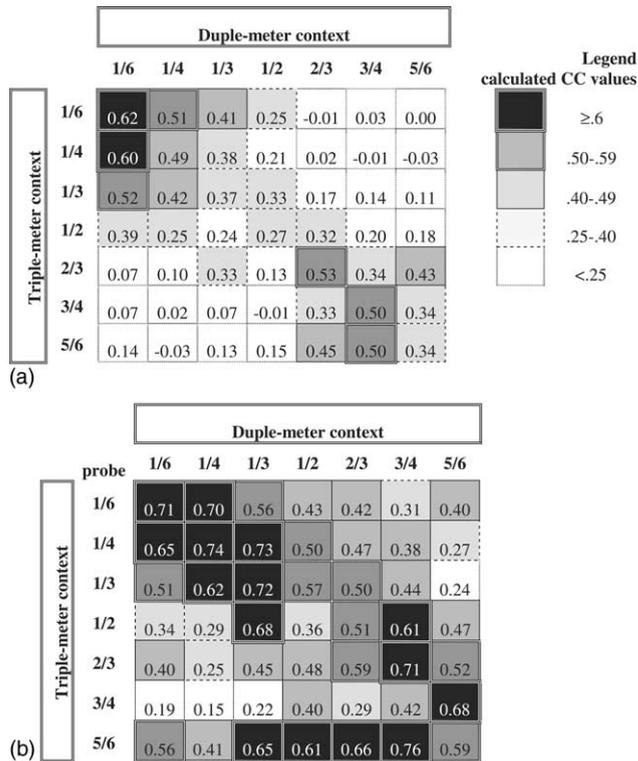


Fig. 9. (a) Shows calculated, averaged correlation coefficients for musically untrained participants and (b) for rhythmically trained participants. Black squares represent relatively high correlation coefficients; lighter squares represent relatively low correlation coefficients.

AEPs elicited by probe beat at the 1/2 bar position within the triple meter context and probe beat at the 1/2 bar position within the duple meter context (the maximal predicted difference).

4. Discussion

In this study behavioural results and CCs of the P3a signal obtained from musically untrained participants could best be described by our H_0 hypothesis, suggesting a sequential processing of rhythmical patterns within this group. In contrast, results obtained from rhythmically trained participants could best be described by our alternative hypothesis suggesting that specific training leads to a higher-order, hierarchical representation of rhythmical patterns related to the induced meter. Though, P3a and P3b results were less conclusive, rhythmical context clearly affected the P3a, and especially so within the group of rhythmically trained participants. Interestingly, P3b appeared to be less sensitive to changes in rhythmic context.

4.1. Behavioural ratings

With respect to behaviourally obtained ratings, musically untrained participants judged probe beats following two bars of either a simple duple- or triple-meter rhythm according to a classification based on the dominant interval length between beats and sub-beats of the preceding pattern (i.e. ISI 500 and 333.33 ms for duple- and triple-meter trial, respectively). That is, probe beats occurring at the half bar position in the test bar following the duple meter rhythms and probe beats occurring at the one-third position following the triple meter rhythms were judged as being a good fit. Other probe beats were judged to fit the pattern less well the more they differed from these preferred positions. These results can be best described by our H_0 hypotheses; the temporal pattern is processed sequentially; beats in the test bar are maximally expected after the dominant time interval presented in bar 1 and 2 (see also Fig. 2a).

The group of rhythmically trained participants judged probe beats, following two bars of either a simple duple- or triple-meter rhythm, according to a hierarchical classification. That is, probe beats not only occurring at the half bar position in the test bar following the duple meter rhythms were judged as being a good fit, but also (on a second level) probe beats occurring on subdivisions or integer ratios of this interval-length (e.g. the one-fourth and three-fourth positions in the test bar). In line, besides high ratings in response to probe beats occurring at the one-third position following the triple meter rhythms, increased ratings were also observed in response to probe beats presented at the two-thirds position, and to some extent to probe beats on the one-sixth, three-sixth and five-sixths positions. This result can best be described by our H_1 hypotheses; the temporal pattern is processed in accordance with a higher order, or hierarchical notion of musical meter.

4.2. P3 data

Though the behavioural data in this experiment fitted the a priori constructed hypotheses well, AEP data were less conclusive. Although a priori we expected to measure a classical P300 we observed the emergence of both a P3a and P3b component, as confirmed by both their scalp distributions and ANOVA results in our data. That is, the P3a, or novelty P3, exhibits an anterior/frontal scalp distribution and precedes the P3b with a maximum amplitude over the central/parietal areas (Comerchero and Polich, 1999).

Overall, in our experiment P3a amplitudes increased and P3a latencies decreased when the inter-stimulus interval between the presented probe beat and the preceding beat increased. In addition, P3b amplitudes decreased at Pz with an increase in the inter-stimulus interval between the presented probe beat and the preceding beat.

The main reason to include a silent measure was to avoid confounding effects of fast habituation over contexts. Though this phenomenon has been extensively described to occur when two events are presented with a short ISI, i.e. with maximal effects observed with ISI of 500 ms (Jongsma et al., 2000, 1998; Besson and Fäita, 1995; Jacobsen et al., 2003) it has also been found that these effects are more pronounced when three or more events are presented (Jongsma et al., 1998; Cardenas et al., 1997).

In the current study, both P3a and P3b show substantial effects of ISI. Though we still suffer from the confounding effects of fast habituation within each context (increasing ISIs

from probe 1 to 7), we have excluded this effect when we compare ERPs of each individual probe beat over context; i.e. for each probe beat, the trials have been exactly the same for the last three events, lasting for more than a second, whether evoked within the duple- or triple-meter context.

However, in the current experiment, participants had to be able to keep an internal representation of the presented meter. One could imagine that such a task is much easier for rhythmically trained participants than for musically untrained participants. Therefore, our results might predominantly reflect this ability, and only partly reflect an increment of hierarchical levels to process temporal patterns with rhythmical training. Therefore, repeating the experiment without the silent measure might lead to more straightforward behavioural results. Unfortunately, AEPs elicited in such a paradigm would be difficult to interpret.

4.3. *Musically untrained participants*

With regard to the musically untrained participants P3a was affected both by electrode site, context and probe tone position. That is, P3a was maximal over Cz, appeared to be overall higher within the duple meter context and increased with probe beat position.

The main context effect seems odd. Generally, higher P3 amplitudes are observed with better performance. Apparently, judging probe beats within the duple meter context was easier than judging them within the triple meter context for this group. Within this triple meter context, more events were presented and the overall tempo was increased. Thus, more information had to be processed and stored. It remains to be investigated why only musically untrained participants showed this general effect. In addition, this effect could be predominantly ascribed to a specific context effect on the probe beat presented at the 1/3 position; visual inspection of Fig. 6a shows a marked increase of P3a amplitude in response to probe beats presented at the 1/3 position within the duple meter context. A post-hoc *t*-test illustrates that this effect is significant at Fz and Cz ($P < 0.05$). This finding seems to support at least partly our H_0 hypotheses.

Within the P3a domain (200–400 ms) fairly low CCs were observed within the group of musically untrained participants. Though we did not observe the predicted higher CCs for both probe beat at the 1/2 bar position in the duple-meter context with the probe beat at the 1/3 bar in the triple meter context, these findings resembled the values as predicted by the H_0 hypothesis.

4.4. *Rhythmically trained participants*

Besides a main effect of electrode site (P3a was maximal at Cz), a three-way interaction effect between electrode site, context and probe beat was observed. When analysing electrode sites separately, context \times probe beat interaction effects were observed at Cz and Pz. A P3a amplitude effect of context was observed on the probe beat presented at the half bar position at Cz and at the 1/6 and 1/3 position at Pz. P3a amplitude was low when the predicted expectancy was high and vice versa. Though the statistical effects seem minor, the overall pattern emerging from the two middle panels of graph 7b seems to support our H_1 hypotheses. In addition, calculated CCs within the P3a domain of rhythmically trained participants approach estimated CCs as predicted by the H_1 hypotheses.

4.5. Musical expectancies and P3

Within the field of EP research, one of the most established ideas about temporal information processing comes from research extracting the so-called mismatch negativity, or MMN (Takegata et al., 2001; Jaramillo et al., 2000; Takegata and Morotomi, 1999; Alain et al., 1999a,b). MMN is, like the EP P3 component, typically elicited by infrequently occurring, deviant, stimuli. It has been found that infrequent changes in temporal parameters of stimuli can also elicit an MMN (Takegata et al., 2001; Alain et al., 1994; Nordby et al., 1994). However, both MMN and P3 research concerned with temporal information processing so far focused on determining whether or not stimuli deviated from a regular pattern. These approaches thus lead to a sequential approach of temporal information processing, not taking into account the possibility that a listener constructs a mental representation of meter that influences the perception of incoming events. Previous experiments using EPs to study music processing have shown that unexpected, or “wrong” notes at the end of a melody elicit a late positive component (500–600 ms) (Besson and Fäita, 1995) comparable to a P3b. Therefore, this component has been proposed to be a good electrophysiological marker of musical expectancy. However, in this study we found that rhythmical violation predominantly affected the P3a component whereas no significant effects on the P3b component were observed.

Conventionally, a P3a is elicited by unattended, or attended yet ignored, salient stimuli (Escera et al., 1998). Therefore, this component is thought to be related to the capture of attention by salient events and of great interest to an investigation of automatic versus controlled processes. In this study, a P3a emerged in reaction to probe beat stimuli that had to be both attended and responded to. This is in line with Trainor et al. (2002) who also observed a P3a to attended stimuli that were targets in a melodic, musical task. They found that the detection of harmonic violations were associated with a frontally orientated P3a (300–350 ms) that preceded a parietally orientated P3b (350–450 ms). Another study concerned with musical expectancies (Regnault et al., 2001) varied the harmonic function of a target chord. They also reported a large P3a, maximal over Cz, appearing around 200–300 ms. Again, this P3a was increased when expectancy was violated and smaller when harmonic expectancy was confirmed. This main effect of context was not observed for a LPC (i.e. a late positive component, maximal over Pz) or P3b. No main effects of musical training were found. Since the P3a has been proposed to reflect the orienting of attention (Escera et al., 1998) it seems that musical stimuli, both in their melodic and rhythmic aspects, engage the attention system.

The results of all of the above mentioned studies are interesting for several reasons. First, it shows that musical (both rhythmic and harmonic) context modulates expectancies as can be measured predominantly by a P3a component. Second, it demonstrates that a cognitive effect of musical context occurs at a fairly early latency (ca. 250 ms). This context effect has even been reported to precede a sensory effect of consonance affecting a P3b (Regnault et al., 2001). They argued that though the completion of sensory effects might be relatively slow, an earlier effect of musical expectations can build up over the presentation of the entire trial and has therefore anticipatory properties.

The next step will be to localize the brain structures involved in processing musical rhythms. Already Tillmann et al. (2003) found that the inferior frontal regions are sensitive

to harmonic expectancy violation. Comparable activation networks have also been reported for target detection (normally eliciting a P3b) and novelty processing (known to elicit a P3a). They proposed a role of the inferior frontal regions for the integration of information over time. Depending on a presented context, expectations for future events arise. The comparison of incoming versus expected events allows the detection of deviant, incoherent events. In particular, the P3a appears to be sensitive to violation of musical expectancies with respect to both rhythm and harmony and therefore provides a useful tool to study music perception.

4.6. Rhythmic training

Though no main group effects were observed with respect to our P3a and P3b data, interaction effects revealed stronger effects of context within the group of rhythmically trained participants than in our group of musically untrained participants. In addition, we observed clear group effects with respect to our behavioural data and CCs of the P3a domain such that data of musically untrained participants could be explained fairly well by the H_0 hypotheses and rhythmically trained participants could be explained reasonably well by the H_1 hypotheses. Others have also reported different findings between musically trained and untrained participants. Recently, [Russeler et al. \(2001\)](#) found a more pronounced attention effect for musicians in a pitch detection task compared to untrained subjects that indicates changes in neural organisation as a consequence of long-term training. In line, [Pantev et al. \(2001\)](#) reported an increase in neuronal representation specific for the processing of piano tones in musicians. [Koelsch et al. \(2002\)](#) found a MMN in slightly impure chords presented among perfect major chords in professional violinist but not in nonmusicians. In line, [Schulze \(1989\)](#) suggests that categorical perception is a function of learning: if sufficient training is provided, perceivers may learn to identify and discriminate between rhythmic categories which without training might have been part of a single, more undifferentiated category. More specifically, [Drake et al. \(2000\)](#) reported that musical training enhances the ability to extract a hierarchical structure from rhythmical sequences. We also found differences between musicians and nonmusicians such that with an increase in musical experience, there seems to be an increase in hierarchical levels in which rhythmical sequences can be perceived.

However, there was a significant age difference between our two groups. Age differences on the AEP P3 have been reported such that P3 amplitudes decrease ([Takakura et al., 2003](#); [Fjell and Walhovd, 2003](#)) and latencies increase ([Fjell and Walhovd, 2003](#)) due to a general increase in hearing thresholds. In this study, we did observe a main group effect on P3a latency, such that rhythmically trained participants had in general longer latencies, which may have resulted from the age difference between our two groups. Thus, the age-effect in this study may have contaminated the effects of rhythmical training. Interestingly, [Regnault et al. \(2001\)](#) used groups with a similar age-difference (musicians mean age 32; nonmusicians mean age 24) but did not observe clear group differences. Also, a general effect of probe beat position appeared in our results and may have masked context- and group effects. Still, by introducing a silent measure between the first two context measures and the test bar, for each probe beat, the last three stimuli of each trial for both condition were exactly the same. It is therefore unlikely that observed differences between two conditions

on a single probe beat can be ascribed to recovery phenomena. Using this silent measure however may have resulted in less clear results. In addition, since the number of dependent variables was large in this study, analyses lost power. We thus recommend for future experiments to use fewer probe tones preceded by a greater array of preceding rhythms inducing different meters.

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