Predictive processing of pitch trends in newborn infants

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Abstract

The notion of predictive sound processing suggests that the auditory system prepares for upcoming sounds once it has detected regular features within a sequence. Here we investigated whether predictive processes are operating at birth in the human auditory system. Event-related potentials (ERP) were recorded from healthy newborns to occasional ascending pitch steps occurring in the 2nd or the 5th position within trains of tones with otherwise monotonously descending pitch. If the trains were processed in a predictive manner only deviant pitch steps occurring in the later train position would elicit the discriminative mismatch response (MMR). Deviants delivered in the 5th but not in the 2nd position of the tone trains elicited a significant MMR response. These results suggest that newborns represent pitch trends within sound sequences and they process them in a predictive manner.

Keywords:
MMN, newborn infants, ERP, MMR, predictive processing, pitch, abstract rules

Highlights (3-5 max 85 char/point)

Newborn infants process sounds in a predictive manner.

Newborn infants detect violations of pitch trends.

Newborn infants show adult-like capabilities in processing non-repetitive sound patterns.

Abbreviations (1st page footnote)

ANOVA	Analysis of variance
EEG	Electroencephalogram
ERP	Event-related potential
ISI	Inter-stimulus interval
MMN	Mismatch negativity
MMR	Mismatch response

1. Introduction

Whereas the role of attention in perception has been acknowledged since the early days of psychology (e.g., James, 1890), the notion that perception may also be of essentially predictive nature has been only relatively recently considered in a systematic manner (e.g., Gregory, 1980). Some modern theories of perception specify Helmholtz' (1860/1962) theoretical framework of utilizing learned information for disambiguating the sensory input in terms of generative models providing predictions about distal objects and their behavior (e.g., Ahissar and Hochstein, 2004; Creutzig et al., 2009; Friston and Kiebel, 2009; Schütz-Bosbach and Prinz, 2007; Winkler et al., 2009). Proponents of the predictive view of perception point out that it can be used to unify theories of perception and action (Friston, 2010; Hohwy, 2007; Hommel et al., 2001; Tishby and Polani, 2011) as well as to guide computational modelling of perceptual decisions (e.g., Hohwy et al., 2008; Mill et al., 2013) and brain responses elicited by unexpected stimuli (e.g., Garrido et al., 2009; Wacongne et al., 2011). Since predictive processing theories follow the empiricist tradition, one may ask whether the predictive principle itself is learned or it is an innate capability of the human brain.

Applying predictive processing principles to auditory perception is especially attractive, because sounds are ephemeral and the patterns formed by them, which are regarded by some as the processing units or perceptual objects in the auditory modality (Kubovy and Van Walkenburg, 2001; Griffith and Warren, 2004; Winkler, 2010), unfold in time. Predictive processing allows for faster assessment of sensory information (e.g., Bar, 2007; Bendixen et al., 2009), which is essential for the real-time decoding of complex auditory scenes (Bregman, 1990). There is still scarce direct evidence for predictive processing in the auditory system (for a review, see Bendixen et al., 2012). However, the properties of brain responses elicited by deviant auditory events (the mismatch negativity [MMN] event-related potential [ERP]) are generally compatible with the notion that predictions for upcoming sounds are checked against the actual sound input and deviations are processed as prediction errors (Winkler, 2007; Winkler and Czigler, 2012). Auditory deviance-related brain responses (termed the mismatch response [MMR] as they are not full equivalents of the adult MMN, see, e.g., Kushnerenko et al., 2007) have been recorded from newborn infants (Alho et al., 1990; for a review, see Kushnerenko et al., 2013). This allows one to assess whether the neonatal auditory system can detect violations of predictive acoustic regularities.

In adults, two sets of deviance-detection paradigms provide the most compelling evidence for the notion that predictive processes underlie deviance detection: Violations of simple contingent inter-tone relations, such as "if the current sound is long, then the next will be high; if the current sound is short, then the next will be low" (Bendixen et al., 2008; Paavilainen et al., 2007) and those of sensory trends, such as monotonously falling of pitch (Tervaniemi et al., 1994), elicit MMN. Because the responses elicited by violations of inter-tone contingencies have been found to be of rather low amplitude in adults and the signal-to-noise ratio of ERP measurement in neonates is substantially lower than that in adults, we chose to measure in neonates the response to sensory trend violations. Although it is difficult to establish a direct analogy between the adult MMN and the infant MMR (see Trainor, 2012), deviations from both simple and complex pitch regularities have been shown to elicit MMR in newborn infants: e.g., MMR has been elicited by deviations from a repeating pitch (Novitski et al., 2007) irrespective of timbre variance (Háden et al., 2009), by violations of the constancy of the direction (Carral et al., 2005) and size (Stefanics et al., 2009) of pitch change within tone pairs varying in absolute pitch, as well as by rare chords categorically differing from the majority of chords (Virtala et al., 2013).

These previous studies established that neonates encode the direction and size of pitch steps. Thus, it is possible that a series of tones with descending pitch will evoke prediction for the continuation of this trend in newborn infants. If this was the case, violating the pitch trend should elicit an error signal, such as the MMR. To test this possibility, we presented newborn infants with trains consisting of 6 tones descending in pitch in uniform 3-semitone steps ("standard"). Trains started with a pitch randomly taken from the 622-1480 Hz pitch range (Figure 1). Half of the trains contained a tone that was 3 semitones higher in pitch than the previous one ("deviant"). Ascending pitch steps occurred with equal probability either in the 2nd or the 5th position. Because the brain must first extract the descending-pitch regularity before forming a prediction for the continuation of the trend, we expected that MMR to the violation of the pitch trend could be elicited by the late but not by the early ascending-pitch tones. MMR elicitation by deviants at the early position would suggest that the newborn brain was sensitive to the overall probability of ascending vs. descending pitch steps in the stimulus block. No MMR found in either position would suggest that the newborn brain does not detect pitch trends.

[Insert Figure 1. at about here]

2. Results

At Position 2, standard and deviant tones elicited ERP waveforms with their differences peaking at ca. 185 ms and 460 ms from stimulus onset at Cz (Figure 2). Both differences appeared to be more pronounced over posterior right electrodes. However, no significant main effect or interaction including Stimulus-type was obtained in the Stimulus-type (Deviant vs. Standard tone) × Frontality (Frontal vs. Central vs. Parietal electrodes) × Laterality (Left vs. Midline vs. Right electrodes) ANOVAs separately conducted on the amplitudes averaged from either the 146-226 ms or the 420-500 ms interval.

[Insert Figure 2. at about here]

At Position 5, standard tones elicited a response with an early and late negative peak (note that the second peak followed the onset of the next tone in the sequence), whereas deviant tones elicited a slower positive response with a peak between 200 and 300 ms (Figure 3). The ANOVA (see structure above) for the early window (93-173 ms) showed a significant main effect of Stimulus-type ($F(1, 32)=7.55$, $p=0.009$, $\eta_p^2=0.19$) as well as a significant interaction between

Stimulus-type, Frontality, and Laterality (F(4, 128)=2.58, p=0.050, $\eta_p^2=0.07$, $\varepsilon=0.85$). The interaction was due to more positive ERP responses elicited by the deviant tones over frontal and central midline locations compared to standard tones as shown by a post-hoc Tukey HSD test (df=128, $p<0.05$) . The ANOVA (see structure above) for the late window (242-322 ms) yielded only a significant main effect of Stimulus-type (F(1, 32)=6.83, p=0.014, $\eta_p^2=0.16$).

[Insert Figure 3. at about here]

Deviant minus standard difference waveforms for the two positions were compared by Position [2nd vs. 5th] × Frontality [Frontal vs. Central vs. Parietal] × Laterality [Left vs. Midline vs. Right]) ANOVAs for the two windows, where Position 5 deviant and standard responses significantly differed from each other (as the Position 2 deviant and standard responses did not significantly differ from each other).A significant main effect of Position(F(1, 32)=4.14, p=0.050, $\eta_p^2=0.11$) was found in the early (93-173 ms) but not in the late (242-322 ms) .

[Insert Figure 4. at about here]

3. Discussion

Significant discriminative ERP responses were elicited by ascending-pitch deviant tones embedded in descending-pitch tone trains in the 5th but not in the 2nd position of the trains. The deviant minus standard difference waveforms also differed between the two positions. These results support the hypothesis that the regularity of the descending pitch pattern was extracted by the newborn brain and a prediction for the continuation descending pitch has been formed. The discriminative MMR response then represents the mismatch between the prediction and the actual input.

The lack of a significant discriminative response for 2nd position deviants rules out the alternative interpretation that the low probability of the deviant ascending pitch steps would be the cause of the MMR response, because then2nd position deviants should have elicited a similar response as the 5th position deviants. Another possible alternative interpretation suggests that the infant brain represented the whole train as a single unit. However, the deviant trains were not too rare (25% of all trains, each separately) and this interpretation again cannot explain why MMRs were found in the 5th but not for the 2nd position deviants.

Carral et al. (2005) showed MMRs to occasional pitch direction changes in sound pairs. Therefore, the absence of MMR response for the 2nd–position deviants needs further explanation. In Carral et al.’s (2005) experiment the inter-stimulus interval (ISI) was 50 ms within and 410 ms between sound pairs, promoting the tone sequences to be processed in terms of pairs. In contrast, in the current experiment, a uniform 200 ms ISI was set within the trains, which were separated by 600 ms of silence, thus promoting the tone sequences to be processed in terms of trains. In adults, temporal organization of sounds has been shown to act as a strong grouping factor that governs what regularities each sound is related to. For example, Sussman and Gumenyuk (2005) found that the AAAAB cyclical pattern was detected within an isochronous sequence and the “B” tones did not elicit MMN when the onset-to-onset interval was 200 ms. With slower presentation rates, the sequence was represented in terms of discrete tones and the “B” tones elicited the MMN response. Further, when tones have been grouped into short patterns, tones belonging to one group were not checked against the regularity of another group (Winkler et al., 2001). On this principle, the deviants occurring at the 2nd position should not elicit an MMR because they are not compared to the previous “pairs” as “pairs” are not represented as units of the tone sequences. In support of this assumption, temporal grouping has been shown to occur in newborn infants. Using the paradigm of Sussman and Gumenyuk (2005), Stefanics and colleagues (2007) found no MMR to the “B” tones when the AAAAB pattern was cyclically repeated, but MMR was elicited by the B tones when the order of the tones was randomized.

The current results are compatible with the notion of predictive processing occurring in the neonatal auditory system. If the newborn auditory system detected the regularity of descending pitches in the short sequences before the 5th position (i.e., extracting the regularity from 3 successive descending pitch steps), then it could form a prediction for the pitch of the next tone, which would be violated by the ascending pitch steps. This interpretation is compatible with the predictive interpretation of MMN (Bendixen et al., 2012; Winkler, 2007 and 2010). There are also some alternative explanations to be considered. Firstly, infants could have detected that most pitch steps were descending and thus found ascending ones being deviant. However, in this case, an MMR should have been elicited also at the 2nd position. Secondly, infants could have detected that the majority of the trains had descending steps at each position (i.e., treating descending-only trains as the prototype). However, again, this explanation leads to expecting MMR elicitation also at the 2nd position. Finally, it is possible that infants formed a pitch-step standard separately for each train (from the first three pitch step of each train) and compared that with the pitch steps occurring later in the train. Predictions from this explanation are inseparable from those of the predictive explanation. Therefore, the current results do not conclusively prove that the neonatal brain works in a predictive manner. If the MMR is a precursor of the adult MMN for which some results suggest predictive sound processing (e.g., Bendixen et al., 2008, 2015; Paavilainen et al., 2007), then it is likely that the current results reflect predictive processing. For a definitive answer to this question, studies using one of these stimulus paradigms or that of Bendixen et al. (2009) should be conducted with newborns.

In conclusion, newborn infants extract pitch trends from sound sequences and their responses to deviations from such pitch trends is compatible with the notion that they process sounds in a predictive manner. Predictive processing has been suggested as a basic principle of perception (e.g., Gregory, 1980). The current results suggest that this principle may already characterize human perception at birth.

4. Experimental procedures

4.1 Participants

ERPs were recorded from 33 (18 male) healthy, full-term newborn infants during day 1-3 postpartum in a dedicated experimental room at the maternity ward of the Military Hospital in Budapest. The mean gestational age of the infants was 39.18 weeks (SD=0.76), mean birth weight 3531 g (SD=313.44), and all infants had an Apgar score of 9/10 (1 minute/5 minute). An additional seven infant's (3 male) data was recorded, but discarded due to excessive electrical artifacts. The study was conducted in full accordance with the Helsinki Declaration and it was approved by the central medical research ethics committee of Hungary (ETT-TUKEB). Informed consent was obtained from the mother or both parents. The mother was given the possibility to be present at the recording and she could terminate the measurement at any point.

4.2 Stimuli and procedure

The experimental design was a modified version of Tervaniemi et al. (1994). Sinusoidal tones of ~75 dB SPL and 50 ms duration including 5-5 ms rise and fall times (raised cosine ramp) were presented to newborn infants. Tones with a pitch between 220 Hz and 1480 Hz in twelve 3 semitone steps (220, 262, 311, 370, 440, 523, 622, 740, 880, 1047, 1245, and 1480 Hz; numbered from 1 to 12) were presented binaurally by E-Prime software (Psychology Software Tools, Inc., Pittsburgh, PA) through ER-1 headphones (Etymotic Research Inc., Elk Grove Village, IL, USA) connected via sound tubes to self-adhesive ear-couplers (Natus Medical Inc., San Carlos, CA, USA) placed over the infants' ears. During the auditory stimulation the infant was lying on her back in an infant cot with a shaped pillow holding her head in position to avoid the infant inadvertently removing some electrodes. The experiment was terminated if the infant became fussy or cried for several minutes. A single stimulus block consisting of 3600 sounds was presented. The stimulus block contained 600 trains of 6 tones descending in pitch in 3-semitone steps. The ISI was 200 ms within and 600 ms between trains. The pitch of the first tone of the train was randomly selected (with equal probability) from the upper half of the 12 values. Half of the trains included a deviant ascending step at Position 2 or 5 (150 trains, each). Descending only, Position-2 deviant and Position-5 deviant trains were delivered in a random order. The overall deviant (ascending step) probability was thus p=0.083. The total duration of the stimulus presentation was ca. 22 minutes.

4.3 EEG recording

The electroencephalogram (EEG) was recorded with Ag/AgCl electrodes attached to the scalp at the F3, Fz, F4, C3, Cz, C4, P3, Pz and P4 locations according to the International 10-20 System. The common reference electrode was placed on the tip of the nose and the ground electrode on the forehead. . Eye movements were monitored by measuring the voltage between an electrode placed lateral to the outer canthus of the left eye and an electrode placed at the 10-20 location termed Fp1. EEG was digitized with 24 bit resolution at a sampling rate of 1000 Hz by a direct-coupled amplifier (V-Amp, Brain Products GmbH, Munich, Germany). The signals were on-line low-pass filtered at 110 Hz.

4.4 Data Analysis

EEG was filtered off-line between 1 and 30 Hz. For each stimulus, an epoch of 600 ms duration including a 100 ms pre-stimulus interval was extracted from the continuous EEG record. Epochs with a voltage change exceeding 100 µV on any EEG or EOG channel were rejected from further analysis. The remaining epochs were baseline-corrected by the average voltage in the 100 ms pre-stimulus period (separately for each tone in the train) and averaged separately for standards and deviants at Positions 2 and 5 within the train. All artifact-free epochs were averaged together. Although some studies suggested morphological ERP differences as a function of the infant's sleep state (e.g. Friderici et al., 2002; Friedrich et al., 2004; Suppiej et al., 2010), the specific differences were not reliably replicated (possibly because the assessment of sleep states was done by somewhat different procedures) and other studies found less clear differences (Cheour et al., 2002) or did not find significant morphological differences at all (Martynova et al, 2003). In the current study, infants were awake in only 6% of the recording time (62% in quiet, 32% in active sleep). Therefore, in accordance with the comparable studies (Carral et al., 2005; Stefanics et al., 2007), responses were not sorted according to sleep states for the current analysis. Further, although some studies separated infants showing positive and negative deviance-related responses into different groups (He et al., 2009; Partanen et al., 2013), in a developmentally homogeneous group, such as the current one (healthy infants born to term), there is no reason to do so. We treated all infants' data as exemplifying the same ERP response.

Due to the makeup of the stimulus paradigm, the distribution of pitches differed between the standard and deviant tones at both train positions. Therefore, only epochs elicited by tones 6-10 were analyzed for Position 2 and tones 4-8 for Position 5. By restricting the analyses to these specific pitches, the distribution of the pitches in the compared responses (i.e., standard and deviant at the same position of the train) became approximately equal. Only infants with more than 60% artefact free trials for all 4 stimulus types/position were included in the analyses. The mean number of artifact-free trials per infant was 175 (137-204, SD=18.35) for standards and 89 (64-104, SD=10.58) for deviants at position 2 and 177 (133-204, SD=19.37) for standards and 88 (70-104, SD=10.01) for deviants at position 5.

Response amplitudes were averaged from 80 ms wide time windows centered on the peaks of group-average deviant minus standard waveforms at the Cz electrode, which typically shows the most reliable MMR response (cf. Figure 4). Measurement windows were separately established for Position 2 (yielding windows 146-226 ms and 420-500 ms) and 5 (yielding windows 93-173 ms and 242-322 ms). The effects of the stimulus type were analyzed with three-way repeated-measures analysis of variance (ANOVA; Stimulus-type [Deviant vs. Standard] ×

Frontality [Frontal vs. Central vs. Parietal] × Laterality [Left vs. Midline vs. Right]), separately for Positions 2 and 5. The difference waveforms obtained at Positions 2 and 5 a series of Position [2^{nd} vs. 5^{th}] × Frontality [Frontal vs. Central vs. Parietal] × Laterality [Left vs. Midline vs. Right]) ANOVAs were carried out on the Deviant minus Standard difference waves for the two positions. Measurement windows that produced significant Stimulus-type effects in the previous ANOVAs were used. Greenhouse-Geisser correction of the degrees of freedom was applied where appropriate and the ε correction factor is shown together with the η_p^2 effect size value.

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Figure captions

Figure1.:
Overview of the experimental paradigm with the three types of trains (Descending-only train, 2nd position deviant, 5th position deviant). Frequency levels are shown on the y-axis, timing on the x-axis.

Figure 2.:
Group-average (N=33) ERP responses to standard (dashed lines) and deviant (solid lines) tones in Position 2. The crossing of the axes is at the onset of the tone in Position 2 and the onset of the next one is indicated by an arrow. The measurement windows are indicated by grey-shaded rectangles.

Figure 3.:
Group-average (N=33) ERP responses to standard (dashed lines) and deviant (solid lines) tones in Position 5. The crossing of the axes is at the onset of the tone in Position 5and the onset of the next one is indicated by an arrow. The measurement windows are indicated by grey-shaded rectangles.

Figure 4.:
Group-average (N=33) deviant minus standard difference waves for responses elicited in Position 2 (dashed lines) and Position 5 (solid lines). The crossing of the axes is at the onset of the tone in the position of interest. A black arrow indicates the onset of the next tone. The measurement windows are indicated by grey-shaded rectangles.

Figure

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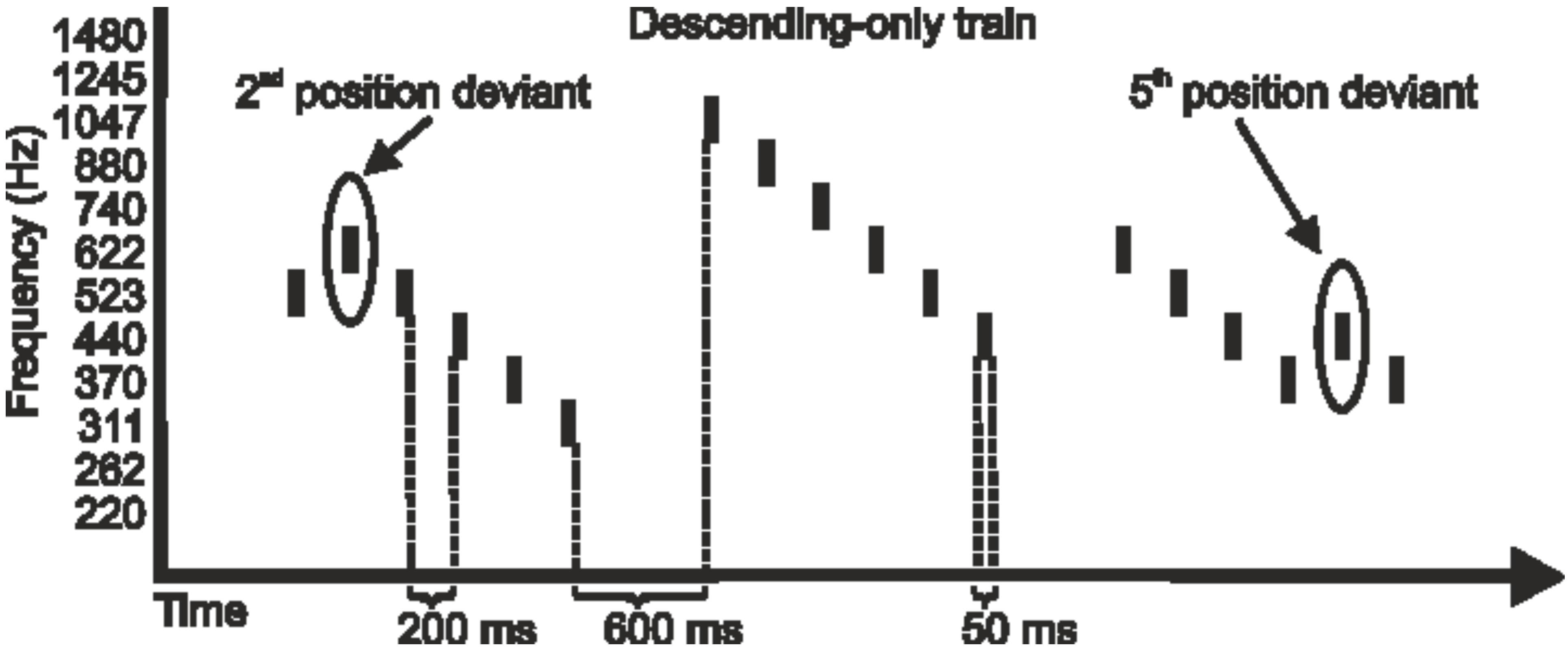

Figure

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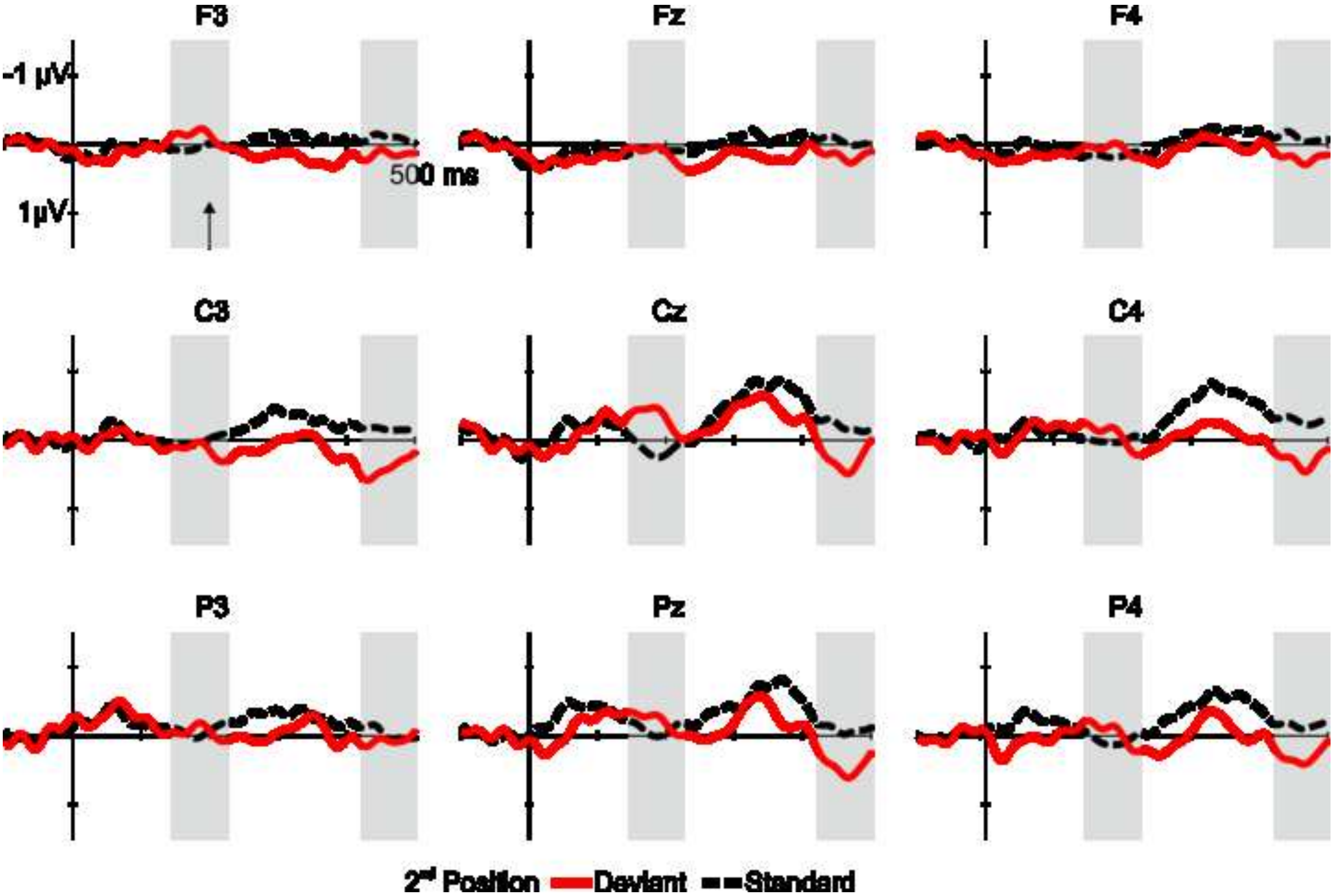

Figure

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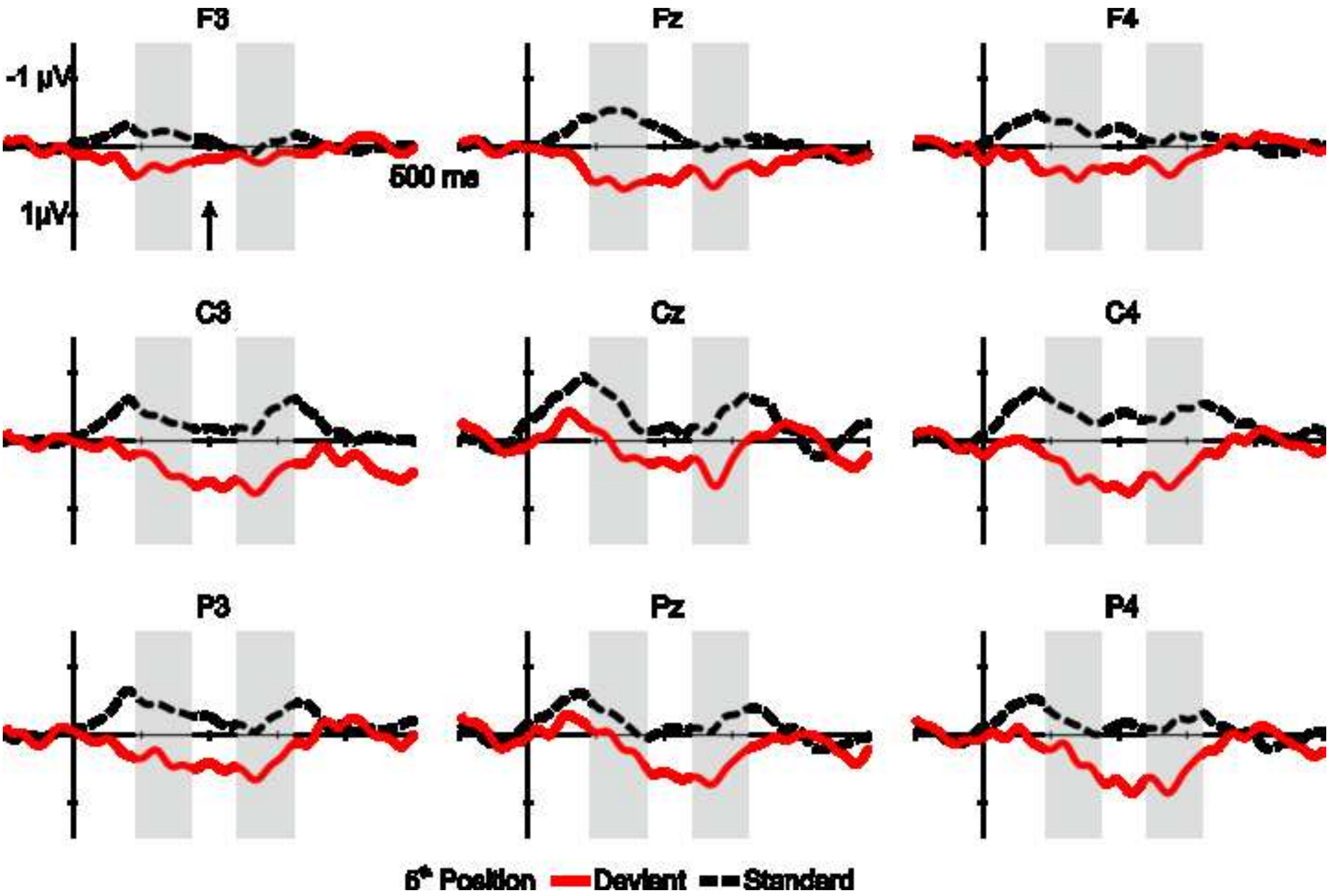
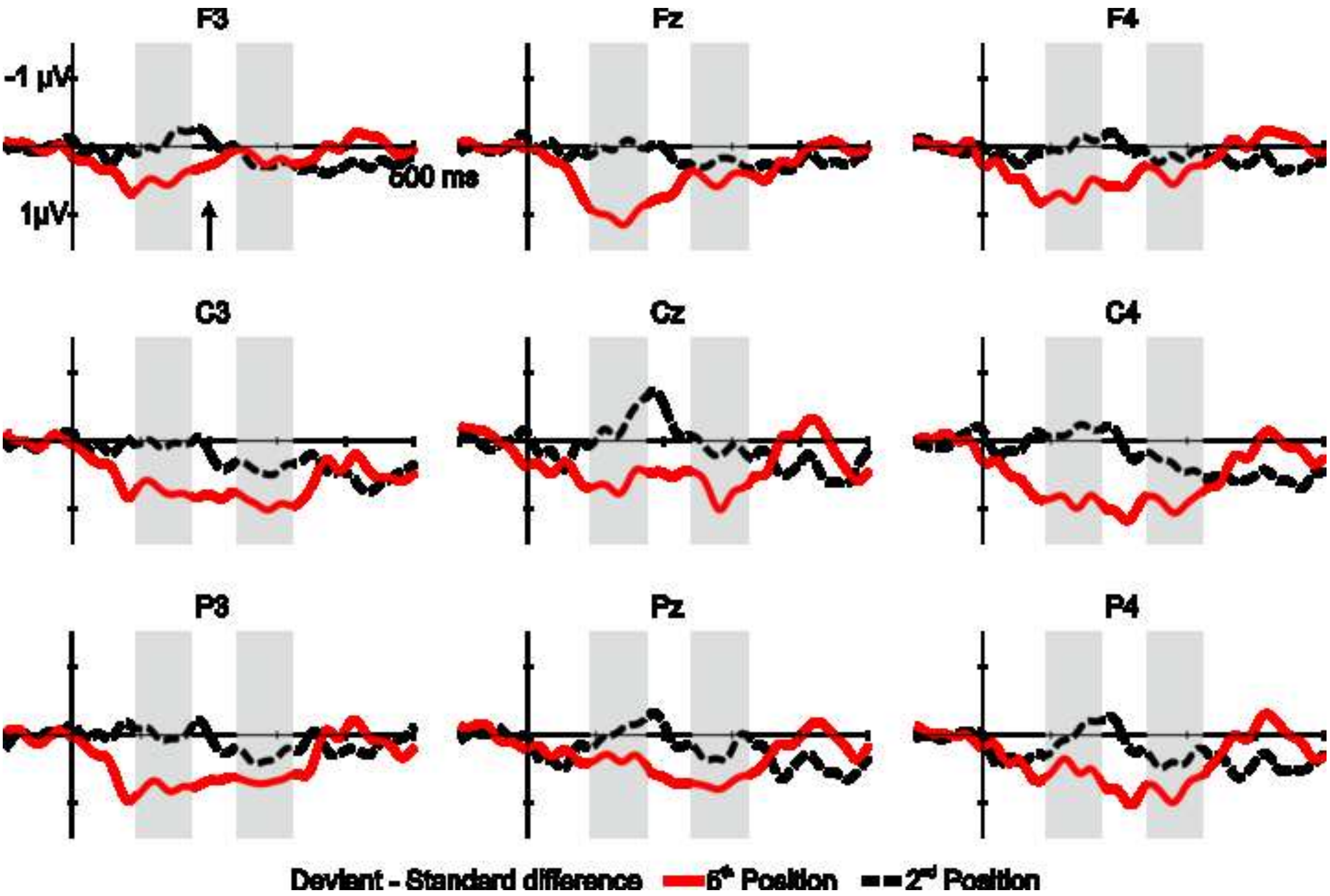


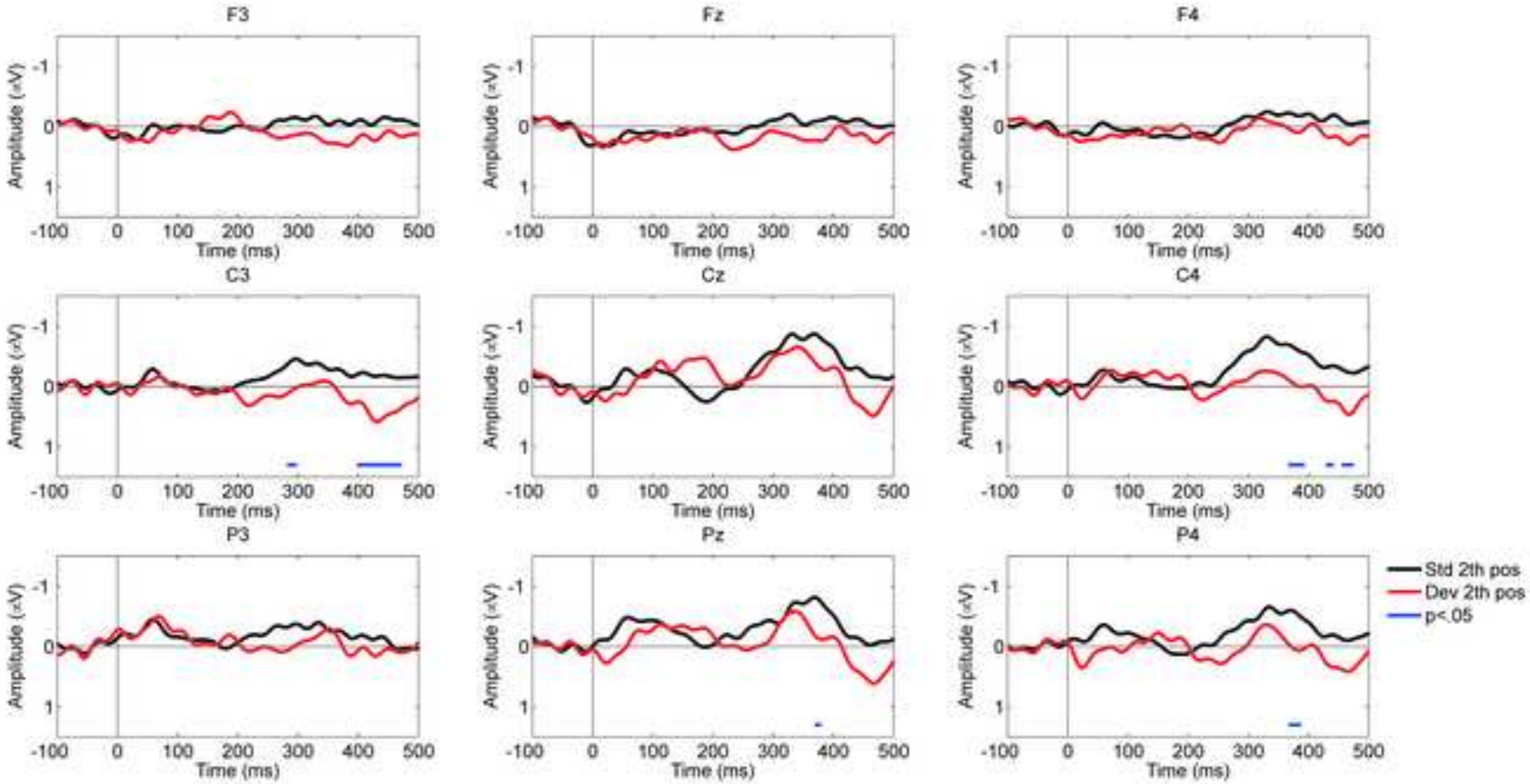

F3
Fz
F4
-1 µV
1µV
500 ms
C3
Cz
C4
P3
Pz
P4
Deviant - Standard difference
6th Position
2nd Position

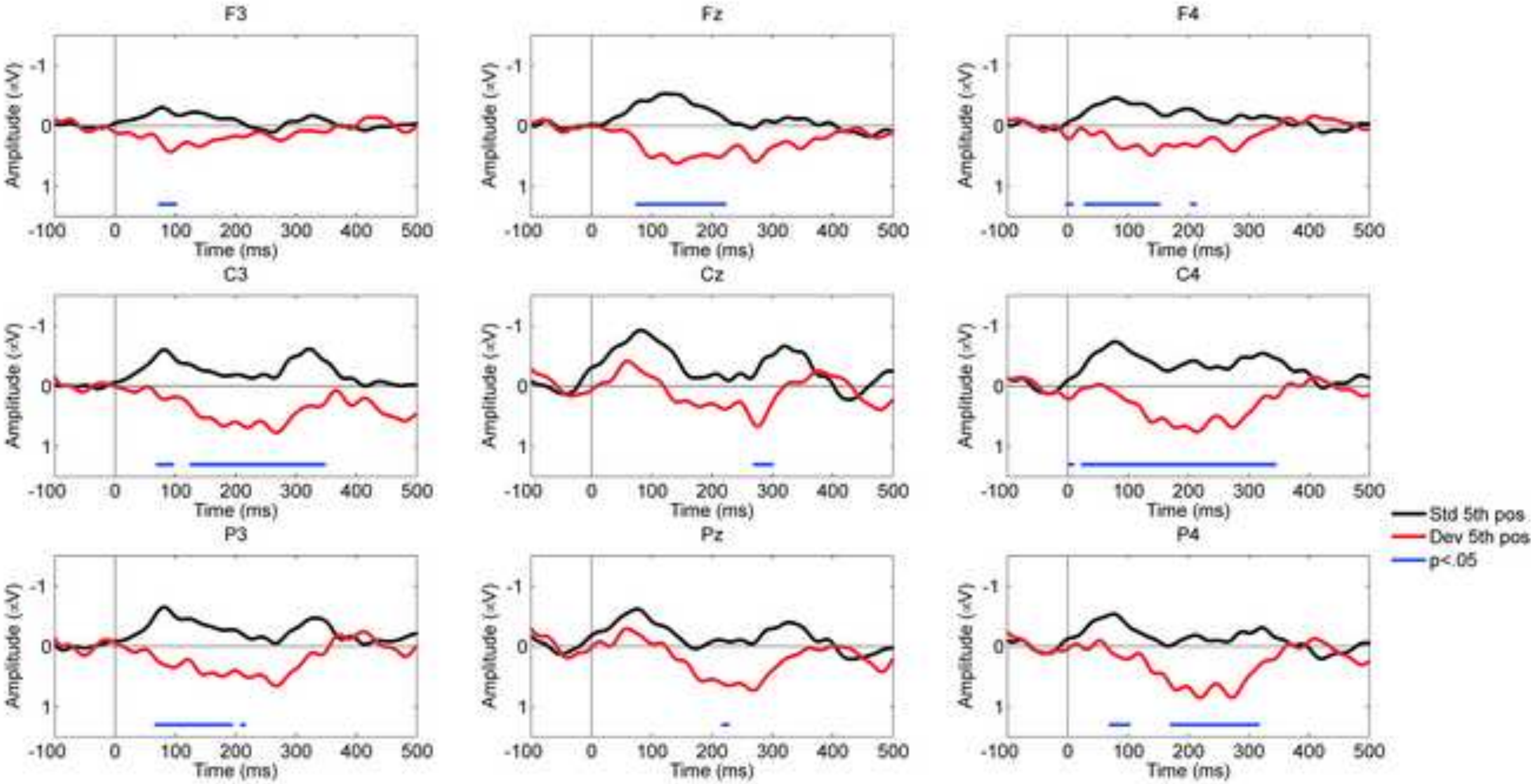
Tukey HSD test results (p-value) for the Stimulus-type (Standard vs. Deviant tone; S, D respectively) × Frontality (Frontal vs. Central vs. Parietal electrodes; F, C, P respectively) × Laterality (Left vs. Midline vs. Right electrodes, 3, Z, 4 respectively)

Cell No.	Tukey HSD test; variable DV_1 (stddev5_93_173) Approximate Probabilities for Post Hoc Tests Error: Within MSE = ,42170, df = 128,00								
	SD	FCP	3Z4	1 -,1842	2 -,4699	3 -,2907	4 -,3157	5 -,5066	6 -,4191
1	1	1	1		0,947800	1,000000	0,999997	0,861635	0,992668
2	1	1	2	0,947800		0,999738	0,999967	1,000000	1,000000
3	1	1	3	1,000000	0,999738		1,000000	0,997223	0,999998
4	1	2	1	0,999997	0,999967	1,000000		0,999398	1,000000
5	1	2	2	0,861635	1,000000	0,997223	0,999398		1,000000
6	1	2	3	0,992668	1,000000	0,999998	1,000000	1,000000	
7	1	3	1	0,996902	1,000000	1,000000	1,000000	1,000000	1,000000
8	1	3	2	1,000000	0,982529	1,000000	1,000000	0,937755	0,998606
9	1	3	3	1,000000	0,907729	0,999998	0,999974	0,791546	0,982465
10	2	1	1	0,166368	0,000195	0,021193	0,011884	0,000083	0,000792
11	2	1	2	0,000783	0,000036	0,000060	0,000046	0,000036	0,000036
12	2	1	3	0,049548	0,000053	0,004202	0,002169	0,000040	0,000131
13	2	2	1	0,032735	0,000044	0,002485	0,001258	0,000038	0,000085
14	2	2	2	0,928885	0,030238	0,515672	0,397921	0,013187	0,083941
15	2	2	3	0,008402	0,000037	0,000484	0,000243	0,000036	0,000042
16	2	3	1	0,056280	0,000057	0,004966	0,002574	0,000041	0,000152
17	2	3	2	0,873902	0,018450	0,410427	0,303572	0,007712	0,054710
18	2	3	3	0,107121	0,000103	0,011563	0,006275	0,000055	0,000381

Cell No.	Tukey HSD test; variable DV_1 (stddev5_93_173) Approximate Probabilities for Post Hoc Tests Error: Within MSE = ,42170, df = 128,00							
	7 -,4021	8 -,2151	9 -,1642	10 ,30721	11 ,54252	12 ,37400	13 ,39394	14 ,11194
1	0,996902	1,000000	1,000000	0,166368	0,000783	0,049548	0,032735	0,928885
2	1,000000	0,982529	0,907729	0,000195	0,000036	0,000053	0,000044	0,030238
3	1,000000	1,000000	0,999998	0,021193	0,000060	0,004202	0,002485	0,515672
4	1,000000	1,000000	0,999974	0,011884	0,000046	0,002169	0,001258	0,397921
5	1,000000	0,937755	0,791546	0,000083	0,000036	0,000040	0,000038	0,013187
6	1,000000	0,998606	0,982465	0,000792	0,000036	0,000131	0,000085	0,083941
7		0,999540	0,991566	0,001272	0,000036	0,000200	0,000122	0,114010
8	0,999540		1,000000	0,098401	0,000330	0,025812	0,016463	0,846895
9	0,991566	1,000000		0,225759	0,001365	0,073344	0,049608	0,961688
10	0,001272	0,098401	0,225759		0,992520	1,000000	1,000000	0,999194
11	0,000036	0,000330	0,001365	0,992520		0,999886	0,999981	0,384899
12	0,000200	0,025812	0,073344	1,000000	0,999886		1,000000	0,976804
13	0,000122	0,016463	0,049608	1,000000	0,999981	1,000000		0,953538
14	0,114010	0,846895	0,961688	0,999194	0,384899	0,976804	0,953538	
15	0,000047	0,003838	0,013578	0,999985	1,000000	1,000000	1,000000	0,796344
16	0,000237	0,029650	0,082675	1,000000	0,999811	1,000000	1,000000	0,981882
17	0,076088	0,764147	0,924265	0,999836	0,488298	0,990784	0,978756	1,000000
18	0,000613	0,060142	0,150619	1,000000	0,998103	1,000000	1,000000	0,996255

Cell No.	Tukey HSD test; variable DV_1 (stddev5_93_173) Approximate Probabilities for Post Hoc Tests Error: Within MSE = ,42170, df = 128,00			
	15 ,45312	16 ,36764	17 ,13418	18 ,33336
1	0,008402	0,056280	0,873902	0,107121
2	0,000037	0,000057	0,018450	0,000103
3	0,000484	0,004966	0,410427	0,011563
4	0,000243	0,002574	0,303572	0,006275
5	0,000036	0,000041	0,007712	0,000055
6	0,000042	0,000152	0,054710	0,000381
7	0,000047	0,000237	0,076088	0,000613
8	0,003838	0,029650	0,764147	0,060142
9	0,013578	0,082675	0,924265	0,150619
10	0,999985	1,000000	0,999836	1,000000
11	1,000000	0,999811	0,488298	0,998103
12	1,000000	1,000000	0,990784	1,000000
13	1,000000	1,000000	0,978756	1,000000
14	0,796344	0,981882	1,000000	0,996255
15		1,000000	0,872205	0,999999
16	1,000000		0,993148	1,000000
17	0,872205	0,993148		0,998964
18	0,999999	1,000000	0,998964	


F3
Fz
F4
C3
Cz
C4
P3
Pz
P4
Amplitude (µV)
-1
0
1
-100
0
100
200
300
400
500
Time (ms)
Std 2th pos
Dev 2th pos
p<.05


F3
Fz
F4
C3
Cz
C4
P3
Pz
P4
Amplitude (μV)
-1
0
1
-100
0
100
200
300
400
500
Time (ms)
Std 5th pos
Dev 5th pos
p<.05