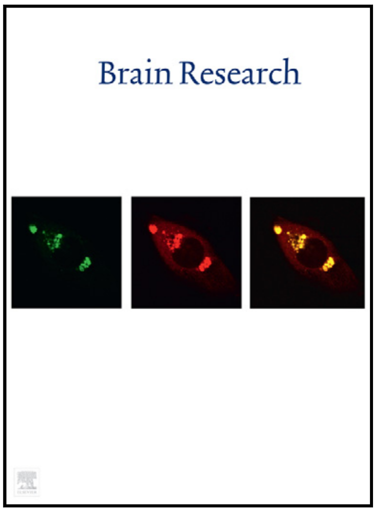

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Asymmetric effect of automatic deviant detection: the effect of familiarity in visual mismatch negativity

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Key words: visual change-detection, visual mismatch negativity, visual search, search asymmetry, familiarity

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Abstract

The visual mismatch negativity (vMMN) component is regarded as a prediction error signal elicited by events violating the sequential regularities of environmental stimulation. The aim of the study was to investigate the effect of familiarity on the vMMN. Stimuli were patterns comprised of familiar (N) or unfamiliar (И) letters. In a passive oddball paradigm, letters (N and И) were presented as either standard or deviant in separate conditions. VMMNs emerged in both conditions; peak latency of vMMN was shorter to the И deviant compared to the vMMN elicited by the N deviant. To test the orientation-specific effect of the oblique lines on the vMMN, we introduced a control experiment. In the control experiment, the patterns were constructed solely from oblique lines, identical to the oblique lines of the N and И stimuli. Contrary to the first experiment, there was no significant difference between the vMNNs elicited by the two orientations. Therefore, the differences in vMMNs to И and N deviants are not attributable to the physical difference between the И and N stimuli. Consequently, the vMMN is sensitive to the familiarity of the stimuli.

1. Introduction

Since the beginning of cognitive psychology it is a well demonstrated fact that conscious recognition of environmental changes are restricted by a limited capacity mechanism, and this mechanism is closely connected to the construct called attention (e.g. Neisser, 1967; but for a qualification of this view see Lamme, 2003). As a demonstration of the limited capacity in vision, large environmental changes remain unnoticed if these events are outside the focus of attention (for a review see e.g. Simons, 2000). However, as research on event-related potentials (ERPs) shows, non-attended stimuli violating regularities, either in the auditory or the visual modality, elicit characteristic components, (auditory) mismatch negativity (MMN), and visual mismatch negativity (vMMN). (For reviews on MMN see e.g. Näätänen et al., 2007; for vMMN see Czigler, 2007; Kimura, 2012). Emergence of the mismatch components is an indirect evidence of the registration of regularities, otherwise deviation cannot be identified.

A recent study reported that an attribute of the automatic processes underlying vMMN is similar to search asymmetry, a well-documented finding of research on visual attention (Czigler et al., 2014). In many visual search tasks it is faster to find certain target stimuli among certain distractors than *vice versa* (for a review see Wolfe, 2001). Similarly, in the above mentioned vMMN study (Czigler et al., 2014), a particular deviant stimulus within the sequence of particular standard stimuli elicited vMMN with shorter latency than sequences with the reversed role of stimuli. The stimuli in this study were Q and O characters, i.e., a type of stimuli frequently used in studies of search asymmetry (e.g. Carrasco et al., 1998; Rosenholtz, 2001; Saiki, 2008; Spratling, 2012; Treisman and Souther, 1985). There is no generally accepted explanation of search asymmetry, and even in case of Q and O stimuli there are different explanations. According to the most frequent consideration, this kind of asymmetry is due to the low-level perceptual differences caused by the presence (or absence) of an additional feature (in this case, an additional vertical line on one of the circles; Treisman and Souther, 1985).

In other cases it is difficult to attribute the asymmetry to simple perceptual factors. Search asymmetry in some studies was connected to the familiarity vs. novelty of the target and distractor stimuli. Search for an unfamiliar target among familiar distractors is more efficient than search for a familiar target among unfamiliar distractors. A typical example of the familiarity-related search asymmetry is that it is faster to find mirror-imaged letters (e.g. И) among normal letters (N) than *vice versa* (e.g. Frith, 1974; Flowers and Lohr, 1985; Wang et al., 1994; Malinowsky and Hübner, 2001; see Wolfe, 2001 for other examples of the familiarity effect). It should be noted that various cases of search asymmetry cannot be explained by a unitary theory. While the asymmetry of the Q vs. O search is explained by the asymmetry of feature appearance vs. disappearance (Treisman and Souther, 1985), explanation of the familiarity-based asymmetry is less obvious. As Wang et al. (1994) demonstrated, in a visual search task, faster identification of the И target (among N distractors) was due to the faster processing of N distractors, and the slower detection of N target (among И distractors) was due to the slower processing of И distractors. That is, the more efficient processing was attributed to the familiarity of the distractor.

In this study, our aim was to investigate whether the stimulus-familiarity has an effect on vMMN as well, as was reported in visual search studies. To this end normal and reverse letters, more precisely, N and reversed N (И) were used. Interestingly, the expected *direction* of asymmetry of vMMN is disputable. On the one hand, at a superficial level one may expect that the direction of asymmetry would be identical in visual search and vMMN paradigms (i.e., faster search for N target, and smaller vMMN latency to the И deviant). Indeed , in the previous study with Q and O stimuli we obtained results showing shorter vMMN latency to the Q deviant (Czigler et al., 2014). On the other hand, considering the theoretical interpretations of the search asymmetry (faster processing of a familiar stimulus), the expectation would be just the opposite. Following this reasoning, in the vMMN paradigm shorter vMMN latency is expected to the N deviants, because processing of the familiar letter is faster. However, one could also expect shorter vMMN latency for the И deviant. This is because a familiar stimulus acquired a more efficient memory representation, and the contrast between the deviant stimuli and the representation of the standard is more salient than the contrast in the opposite case. In spite of the apparently *ad hoc* flavor of this alternative, it is near the explanation of familiarity related search asymmetry. This is because in both cases the effects are due to the 'less important' (distractor and standard) stimuli. In the present study we tested the above mentioned alternatives.

In Experiment 1 we compare the effects of N and И deviants. However, dissimilarity can be due to the different orientation of the oblique line *per se*, therefore in Experiment 2 we investigate deviant effects without the vertical lines.

2. Results

2.1. Experiment 1

2.1.1. Behavioral results

According to the two-way ANOVA, participants' performance differed in the two tasks [$F(1,13)=27.451$, $p<0.01$, $\eta^2=0.679$]. Performance in the red-task (88.6 %; S.E.M = 1.6 %) was higher than performance in the green-task (81.6 %; S.E.M = 2.3 %). Condition main effect as well as task*condition interaction was not significant.

2.1.2. Event-related potential results

Figure 1 shows the ERPs, the deviant *minus* standard difference potentials for the N and И deviant conditions and the scalp distributions of the differences in a 20 ms range around the average latency values of largest negativity, (measured at PO3, POz, PO4, O1, Oz and O2). The average peak latencies and mean amplitudes are listed in Table 1. We obtained neither latency nor amplitude difference on P1 to the standard N and И stimuli. However, standard И stimuli elicited larger N1 amplitude than the N stimuli over the right side, as reflected by the significant stimulus x laterality interaction [$F(2,26)=3.887$, $p<0.05$, $\varepsilon=0.952$, $\eta^2=0.230$, and the significant results ($p<0.001$) of the Tukey HSD tests]. Furthermore, N1 latency was longer at the occipital locations as the anteriority main effect points out [$F(1,13)=8.150$, $p<0.05$, $\eta^2=0.385$]. No significant stimulus related effect appeared on the P2 amplitude. However, we found significant stimulus main effect on the latency values of P2 components [$F(1,13)=6.500$, $p<0.05$, $\eta^2=0.333$].

As Figure 1 shows, in the difference potentials both the deviant N and the deviant И stimuli elicited a posterior negativity. Furthermore, as Figures 1 and 2 show, the latency of the negativity was longer for the N deviant (128 vs. 140 ms). This latency difference is reflected in the significant stimulus main effect [$F(1,13)=7.805$, $p<0.05$, $\eta^2=0.375$]. Contrary to the apparent difference, we obtained no significant amplitude effect on the range of the negative difference potential.

Comparing N1 latency and the latency of the difference potentials, in addition to the significant stimulus (N, И) main effect [$F(1,13)=8.792$, $p<0.05$, $\eta^2=0.403$], component x stimulus interaction was also significant [$F(1,13)=6.250$, $p<0.05$, $\eta^2=0.325$]. According to the Tukey HSD tests, the interaction (and main effect) was due to the shorter latency of the И-related negative difference ($p<0.05$ in all comparisons).That is, the latency of the difference potentials in the И-deviant condition was shorter than both N1s' latencies and N-deviant related negativity.

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2.1.3. Interpretation of the results

As the main result of this experiment, both the N and И stimuli elicited a deviant-related posterior negativity in the 100-180 ms latency range, but the peak latency of this negativity was shorter for the И deviant. One may say that the negativity can be attributed to the different stimulus-specific refractoriness of the deviant and standard stimuli (c.f. May and Tiitinen, 2010; Kimura et al. 2009, 2010; Kimura and Takeda 2013). However, the significant component*stimulus interaction contradicts this possibility. In case of refractoriness of a unitary N1 component, the latency of the exogenous activity and the latency of the deviant-related negativity should be similar in both conditions. In fact the latency of the difference potential in the И condition was shorter than the latency of the other difference potential as well as both N1s' latencies. That is, the latencies of the deviant-related and exogenous activities were not similar in either of the conditions. Additionally, unlike the N1 component, the latency of the vMMN was similar at the PO and O locations. It should be noted that the interpretation of the latency difference as an argument against refractoriness is not without problem. Latency difference may arise as condition or stimulus dependent changes of latent components (Luck, 2005). As for the present study, emergence of the vMMN may influence the latency of the negativity. This case corresponds to our interpretation. However, one may say that N1 consists of various subcomponents with different refractoriness characteristic. In fact, some studies reported various posterior visual subcomponents in the N1 range (Di Russo et al., 2001; Hopf et al., 2002; Vogel and Luck, 2000). These subcomponents emerged as effects of attention, and their characteristics are unknown in a passive paradigm. Furthermore, no study reported different refractoriness effects on the subcomponents. Consequently, the obtained latency difference does not exclude with full confidence the possibility of stimulus-specific refractoriness. A stronger control of refractoriness is the equal probability procedure (comparison of the ERPs of the oddball deviant with ERPs elicited by identical stimuli from a sequence of a large variety of stimuli, with the same probability as the oddball deviant; Kimura et al., 2009, 2010). Unfortunately in case of binary stimuli like the N and И this procedure cannot be used. The ERP difference between the N and И deviants as a refractoriness effect of an N1 subcomponent is a possibility of familiarity-related N1 effect elicited by non-attended stimuli. So far there are no data showing such effects, but it is a testable possibility. In sum, the negativity is attributed the emergence of vMMN, and we consider that the deviant И elicited this component earlier than the deviant N.

To interpret the vMMN-asymmetry in this study, it is necessary to clarify a more simple possibility, the perceptual anisotropy (the perception of the lines are directionally dependent) of the system underlying the vMMN (c.f. Takács et al., 2013), i.e., the possibility that the sensitivity to oblique lines in forward and backward directions (/ and \) is different. This possibility has some support from the larger N1 to the N stimuli over the right posterior locations. To investigate the possibility of vMMN difference for the two deviant-standard relations, in Experiment 2, we presented oblique lines without the vertical lines of the N and И stimuli. Accordingly, in this experiment there was no familiarity difference between the two stimuli. Nevertheless, the physical differences between the standards and the deviants, i.e. the orientations of the oblique lines, were identical in Experiment 1 and Experiment 2.

2.2. Experiment 2

2.2.1. Behavioral results

According to the two-way ANOVA, participants' performance differed in the two tasks [$F(1,13)=41.321$, $p<0.01$, $\eta^2=0.761$]. Performance in the red-task (78.8 %; S.E.M = 1.9 %) was higher than performance in the green-task (66.3 %; S.E.M = 1.9 %). Condition main effect as well as task*condition interaction was not significant.

2.2.2. Event-related potential results

As Figure 3 shows, the stimuli elicited the canonical P1, N1 and P2 exogenous components. Table 2 contains the average peak amplitudes and the mean epochs of the components measured at six electrode locations (PO3, POz, PO4, O1, Oz and O2). Comparison of the amplitude of P1 components resulted in significant stimulus x anteriority interaction [$F(1,13)=10.403$, $p<0.01$, $\eta^2=0.445$] showing that the forward leaning lines (/) elicited larger P1 over the PO locations ($p<0,001$ in all Tukey HSD tests). No orientation-related effect appeared in regards to the N1's latency and amplitude, P2 latency was shorter for the backward leaning (\) stimuli [$F(1,13)=6.253$,

$p<0.05$, $\eta^2=0.325$ for the stimulus mean effect]. There was no P2 amplitude difference between the two orientations.

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Deviant-related negativities emerged within the 100-180 ms latency range as shown on Figure 3. The amplitude and latency values of these negativities are listed in Table 2. The latency of the negativities were larger over the PO locations [$F(1,13)=5.081$, $p<0.05$, $\eta^2=0.281$ for the anteriority mean effect] and over the midline [$F(2,26)=6.364$, $p<0.01$, $\varepsilon=0.898$, $\eta^2=0.329$ for the anteriority x laterality interaction]. More importantly, the two difference potentials (to backward and forward lines) were not different in terms of latency and amplitude values (Figure 4).

The latencies of the difference potentials were shorter than the N1 latencies (see Table 2). Accordingly, component main effect was significant [$F(1,13)=22.897$, $p<0.001$, $\eta^2=0.638$]. This main effect was qualified by the significant component x anteriority interaction [$F(1,13)=7.216$, $p<0.05$, $\eta^2=0.357$]. The interaction was due to the longer N1 latency at the PO locations.

2.2.3. Interpretation of the results

We obtained orientation-related differences on the exogenous components, but these differences were unrelated to the N1 component. Furthermore, the difference potentials were similar in the two conditions (i.e. to \ and / deviants). The latencies of the negative difference potentials were considerably shorter than the N1 latencies. We interpret the negative difference potentials as vMMNs, and these components were independent of the orientations of the deviants.

2.3. Comparison of Experiment 1 and 2

2.3.1. Behavioral results

Behavioural results of the two experiments were compared with an omnibus ANOVA. The factors were experiment, task and condition. The analysis revealed significant experiment [$F(1,26)=66.24$, $p<0.01$, $\eta^2=0.718$] and task main effects [$F(1,26)=68.30$, $p<0.01$, $\eta^2=0.724$] and experiment*task interaction [$F(1,26)=5.46$, $p<0.05$, $\eta^2=0.174$]. Performance was lower and performance-difference between the two tasks was higher in Experiment 2.

2.3.2. Event-related potential results

Comparing the two experiments, it is obvious that the deviant-related negativity was larger in Experiment 2 (-0.78 vs. -1.21). This observation is supported by the results of a mixed factor ANOVA (Experiment as between group factor; line orientation, anteriority and laterality as within group factors) on the amplitude of the difference potentials. In this ANOVA we obtained significant main effect of experiment [$F(1,26)=4.718$, $p<0.05$, $\eta^2=0.154$]. Comparison of the latency values of the difference potentials of the two experiments, a similar ANOVA resulted in a significant experiment main effect [$F(1,26)=4.914$, $p<0.05$, , $\eta^2=0.159$], showing the shorter latency in Experiment 2 (134 ms vs. 126 ms). The experiment*stimulus interaction approached the level of significance [$F(1,26)=3.615$, $p=0.068$, , $\eta^2=0.122$], showing a tendency that in contrast to Experiment 1, in Experiment 2 there was no difference between the two orientations.

3. Discussion

A typical result of the familiarity-related search asymmetry is that a mirror-imaged letter among normal letters is found faster than vice versa (e.g. Frith, 1974; Flowers and Lohr, 1985; Wang et al., 1994; Malinowsky and Hübner, 2001). In the present passive oddball study we obtained similar results, vMMN latency to the reversed character was shorter. Accordingly, relationship between search latency and vMMN latency was similar to the results of our previous study using Q and O stimuli (Czigler et al., 2014). In the introduction we raised that one may argue for the reverse results, i.e., shorter vMMN latency for the N deviant. This is because Wang et al. (1994) attributed the familiarity related search asymmetry to the faster processing of familiar stimuli, and in a typical visual search paradigm the number of distractors is larger than the number of targets (in a typical design the latter is only 1). Accordingly, if a familiar stimulus (N) is processed faster, shorter vMMN latency is expected for the N deviant. However, the results of the present study were just the opposite. Therefore, the above reasoning cannot be applied to the vMMN paradigm. Considering the standard stimuli of the vMMN paradigm as an analog of the distractors of the search task, and maintaining the claim that processing of familiar stimuli is more effective, the expected result is shorter vMMN latency in the И deviant condition. However, the question is obvious: in what way are the vMMN standard and the search task distractor similar? At first glance the situations in the two paradigms are different; in the vMMN paradigm there is no need of processing the standard stimuli when the deviant is presented. However, it is important to recall that vMMN emergence is a consequence of a comparison process; representation of regularity is stored in a memory system, and the representation of the incoming event is compared to this representation. This process requires the access of the representation of regularity. We suggest that retrieval of such representation is faster when the regular events are familiar. In other words, vMMN latency difference is due to the more efficient access to the memory representation of familiar events. This way, the identical direction of the visual search and the vMMN results is plausible.

ERP difference between the rare and frequent stimuli, especially in an earlier latency range is frequently attributed to a refractory effect (Kimura et al., 2009, 2010; Kimura and Takeda, 2013). Processing structures with specific sensitivity to a particular stimulus feature respond with diminished intensity to frequent stimulation, whereas rare events stimulate “fresh” networks of neurons. In the present study the latency of deviant *minus* standard difference did not correspond to the latency of the exogenous components. In Experiment 1 N1 latency was similar to both N and И stimuli, whereas the latency of deviant minus standard difference potentials for the two stimuli was different. Therefore, the results of the present study are considered as a memory mismatch effect, instead of the manifestation of stimulus-specific refractoriness.

To control for the possibility of different effects of the two directions of the oblique lines, we conducted Experiment 2. In this control experiment the stimulus patterns consisted only from oblique lines. VMMN in the two experiments had different amplitudes and latencies, in Experiment 2 the latency of the difference potential was shorter and the amplitude was larger. As a *post hoc* explanation, the presence of the vertical lines in Experiment 1 diminished the deviant-standard differences in this experiment for two reasons. First, the vertical lines were identical in the N and И stimuli, therefore the net deviant-standard physical difference in Experiment 1 was smaller; second, presence of the vertical lines might impose a masking effect on the orientation difference. One may argue that task demand may influence vMMN, and the higher task demand of Experiment 2 had a masking effect on the line orientation effects. However, in vMMN studies investigating the effect of task demand no such results were obtained (Heslenfeld, 2003, Pazo-Alvarez et al., 2004), whereas Kimura and Takeda (2013) obtained increased latency (but not amplitude) at higher task demand. In the present study no longer vMMN latency appeared in Experiment 2.

In conclusion, the latency difference between the vMMNs elicited by N and И deviants was caused by the familiarity of the N stimulus. That is, vMMN, a correlate of automatic detection of the violation of sequential regularity is sensitive to the familiarity of stimulation.

4. Methods

4.1. Experiment 1

4.1.1. Participants

Participants were 14 paid students (4 female; mean age=21.9 years; range=19-24 years) from Budapest, Hungary. All had normal or corrected to normal vision. Participants were not familiar with the Cyrillic alphabet. Before the session they gave written informed consent. The study was accepted by the local committee of professional ethics and was carried out in accordance with the Declaration of Helsinki.

4.1.2. Stimuli and procedure

4.1.2.1 Task-irrelevant stimuli

Stimuli were matrices of N or И characters (Figure 5). A matrix consisted of 8 columns and 4 rows (i.e. 32 characters). These stimuli were presented on a 17' LCD monitor (Samsung SyncMaster 740B) with 60 Hz refresh rate. The patterns were presented in the lower part of the display. The size of the whole stimulus pattern was 16.1 x 3.9 degree of visual angle from 120 cm. The luminance of the stimuli and the background were 36.67 cd/m2 and 0.45 cd/m2, respectively. The stimulus presentation time was 300 ms; the average inter-stimulus-interval (ISI) was 517 ms (range: 417-617 ms, even distribution). In the N-deviant condition 59 stimuli were N matrices, and 291 И matrices, in the И deviant condition the numbers were reversed. Within a session there were 2 N deviant and 2 И deviant conditions in random order.

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4.1.2.2 Task-related stimuli and primary task

The only aim of the task, as in the majority of vMMN experiments, was to draw participants' attention away from the task-irrelevant stimulation. The task was a video game presented at the upper half of the screen (task-field, see Figure 5). The video game contains a stationary background and a few moving 'figures'. The background was a canyon embedded into a planet. The 'figures' were dynamically moving spaceships displayed within the area of the canyon (this area termed as game-field; GF). The GF was segmented to 10 vertical and 19 horizontal units which defined the depth and the horizontal coordinates of the canyon. The spaceships moved along the 10*19 grid defined by the coordinates. The movements of the spaceships were either controlled by the participant (player-spaceship; PS; blue color) or an algorithm (task-spaceships; TSs; red or green colors). The task was to move the PS located at the top of the GF (10th vertical coordinate) to the left or to the right with a game pad along the 19 points of the horizontal axis to avoid the red or to catch the green TSs. In each trial, a TS appeared at the end of the GF (1st vertical coordinate) at a random horizontal position (one of the 19 coordinates) with a random color. The probability of the red and green colors were 0.7 and 0.3, respectively. After the appearance, the TS started to move towards the top (10th vertical coordinate) to be caught (green) or to avoided (red) by the PS. The apparently continuous movement of the TSs comprised of little successive shifts. In each shift, the TS moved one coordinate vertically upwards (plus 1 vertical unit per step), and one coordinate horizontally. The horizontal movements (termed as vectors) could be -1 (moving to the left), 1 (moving to the right) or 0 (no horizontal movements). The horizontal coordinate was adjusted according to the vector with a probability of 0.3 or remained the same (p=0.7). The vectors were calculated by an algorithm differently in the case of red and green TSs. In case of red TS, the aim was reduce the (horizontal) distance between the TS and the PS with a probability of 0.4. In case of green TS, the aim was just the opposite, and the probability was 0.3. Furthermore, the vector reversed (folded by -1) if the TS reach the edge of the GF (1st or 19th horizontal coordinate) or at the 4th vertical coordinate. In any other cases, the vector was the same as it was at the previous shift. The impact of the TS and PS (i.e. the performance in one trial) was calculated, when the TS reach the 10th vertical coordinate. The duration of one shift was 116.67 ms, therefore one trial endured for 1166.67 ms (there was no inter-trial interval). In a block, there were 245 trials.

4.1.3. Measuring and analyzing the behavioral data

Participants' performance was expressed as percent values, separate for the two tasks. The number of successful avoids were divided by the total number of red spaceships, which yielded the red-performance. The number of successful collisions were divided by the total number of green spaceships, which yielded the green-performance. Performance was entered into a two way ANOVA with the factors of color (red and green) and stimulus (N and И deviant).

4.1.4. Recording and measuring electric brain activity

Brain electric activity was recorded (DC -100 Hz; sampling rate, 500 Hz; Synamps2 amplifier, NeuroScan recording system) with Ag/AgCl electrodes placed at 61 locations according to the extended 10–20 system by using of an elastic electrode cap (EasyCap). The reference electrode was on the nose tip, and data was offline re-referenced to the average activity. Horizontal EOG was recorded with a bipolar configuration between electrodes positioned lateral to the outer canthi of the eyes. Vertical eye movement was monitored with a bipolar montage between electrodes placed above and below the right eye. The EEG signal was band-pass-filtered offline, with cutoff frequencies of 0.1 and 30 Hz (24-dB slope). Epochs with duration of 600 ms, including a 100 ms pre-stimulus interval, were extracted for each event and averaged separately for the standard and deviant stimuli. The mean voltage during the 100 ms pre-stimulus interval was used as the baseline for amplitude measurements, and epochs with an amplitude change exceeding ±100 µV on any channel were excluded from further analysis. Event-related potentials were averaged separately for the standard and deviant stimuli in the two conditions. Epochs of standards and deviants were entered in the averaging process only if these stimuli were preceded by at least 3 standards. To identify change-related activities, ERPs elicited by standard stimuli were subtracted from ERPs elicited by deviant stimuli in the opposite condition (reverse control, c.f. Kujala et al., 2007), therefore physically identical stimuli were compared in the role of deviant and standard.

Exogenous components (P1, N1 and P2) and difference potentials were measured in a 2 x 3 grid of electrodes over the posterior areas (PO3, POz, PO4, O1, Oz, and O2). Peak latencies were measured with a sliding window algorithm (for detailed description of the algorithm, see Sulykos and Czigler, 2014). Amplitudes were measured by averaging the amplitude values of 20 ms epochs (11 data points) around the respective peak latency. These values were analyzed in three-way analyses of variance (ANOVA) with factors of stimulus (И, N), anteriority (PO, O) and laterality (left, midline, right). To compare the latency values of the exogenous components and the difference potentials, the factor of component was added. When appropriate, the Greenhouse-Geisser correction was used. Effect size is presented as partial eta-squared (η^2). Post hoc comparison was calculated by Tukey HSD tests. Only results related to the purpose of the study are presented.

4.2. Experiment 2

4.2.1. Participants

Participants were 14 paid students (5 female) mean age=22.5 years; range= 19-26 years) from Budapest, Hungary. All had normal or corrected to normal vision. They have participated in event-related potential studies previously. Before the session they gave written informed consent to participate in the study. The study was accepted by the local committee of professional ethics and was carried out in accordance with the Declaration of Helsinki.

4.2.2. Stimuli and procedure

With two exceptions, all aspects of the stimulation (and the procedure) of Experiment 2 were identical to the ones used in Experiment 1. The first exception was the task-irrelevant stimuli applied. In Experiment 2, the patterns were constructed solely from oblique lines, identical to the oblique lines of the N and И stimuli. The second exception concerned the primary task. In Experiment 2, the game field was divided by 11 horizontal units (instead of 19), which resulted in larger horizontal movements of the task-spaceships.

4.2.3. Recording and measuring of behavioral data and brain electric activity

The parameters of the EEG-recording, the preprocessing of the EEG-signal and the statistical analyzes of the behavioral and ERP data were the same as the ones carried out in Experiment 1.

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Figure legends

Figure 1 – Experiment 1. Upper panel: event-related potentials and difference waves in the N and И conditions.

Figure 2 – Experiment 1. Comparison of the deviant-related activities in the N and И conditions. Vertical lines denote the peak latencies of the difference waves in the И condition.

Figure 3 – Experiment 2. Upper panel: event-related potentials and difference waves in the \ and / conditions. Lower panel: difference waves at Oz electrode location and scalp distributions of the deviant-related brain responses.

Figure 4 – Experiment 2. Comparison of the deviant-related activities in the \ and / conditions. Vertical lines denote the peak latencies of the difference waves in both conditions.

Figure 5 – Experiment 1.Experimental stimuli. Upper panel: an example of the stimulus display. Lower panel: the physical characteristics of the task-irrelevant stimuli.

	Stimuli	P1	N1	P2	vMMN
Latency (ms)	N	91.0 (6.3)	140.8 (12.5)	261,1 (12.5)	139.8 (7.1)
	И	90.1 (6.3)	141.3 (13.0)	274.9 (11.0)	127.9 (6.5)
Amplitude (μV)	N	1.98 (1.15)	-1.73 (1.01)	5.17 (1.95)	-1.03 (0.66)
	И	1.79 (1.18)	-2.06 (0.95)	4.85 (1.93)	-0.53 (0.56)

Table 1 – Experiment 1. Grand averages of peak latencies and mean epochs of the exogenous components (P1, N1, P2) and the vMMNs measured at six electrode locations (PO3, POz, PO4, O1, Oz and O2). S.E.M. in parenthesis.

	Stimuli	P1	N1	P2	vMMN
Latency (ms)	\	84.4 (5.5)	148.1 (9.4)	248.9 (12.5)	126.7 (4.3)
	/	87.7 (3.5)	146.4 (10.1)	258.3 (13.6)	127.2 (11.4)
Amplitude (μV)	\	0.89 (0.56)	-2.65 (1.38)	2.97 (1.28)	-1.19 (0.48)
	/	1.09 (0.71)	-2.66 (1.29)	3.10 (1.41)	-1.23 (0.67)

Table 2 – Experiment 2. Grand averages of peak latencies and mean epochs of the exogenous components (P1, N1, P2) and the vMMNs measured at six electrode locations (PO3, POz, PO4, O1, Oz and O2). S.E.M. in parenthesis.

	Stimuli	P1	N1	P2	vMMN
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Figure_1_print_version
Figure 1

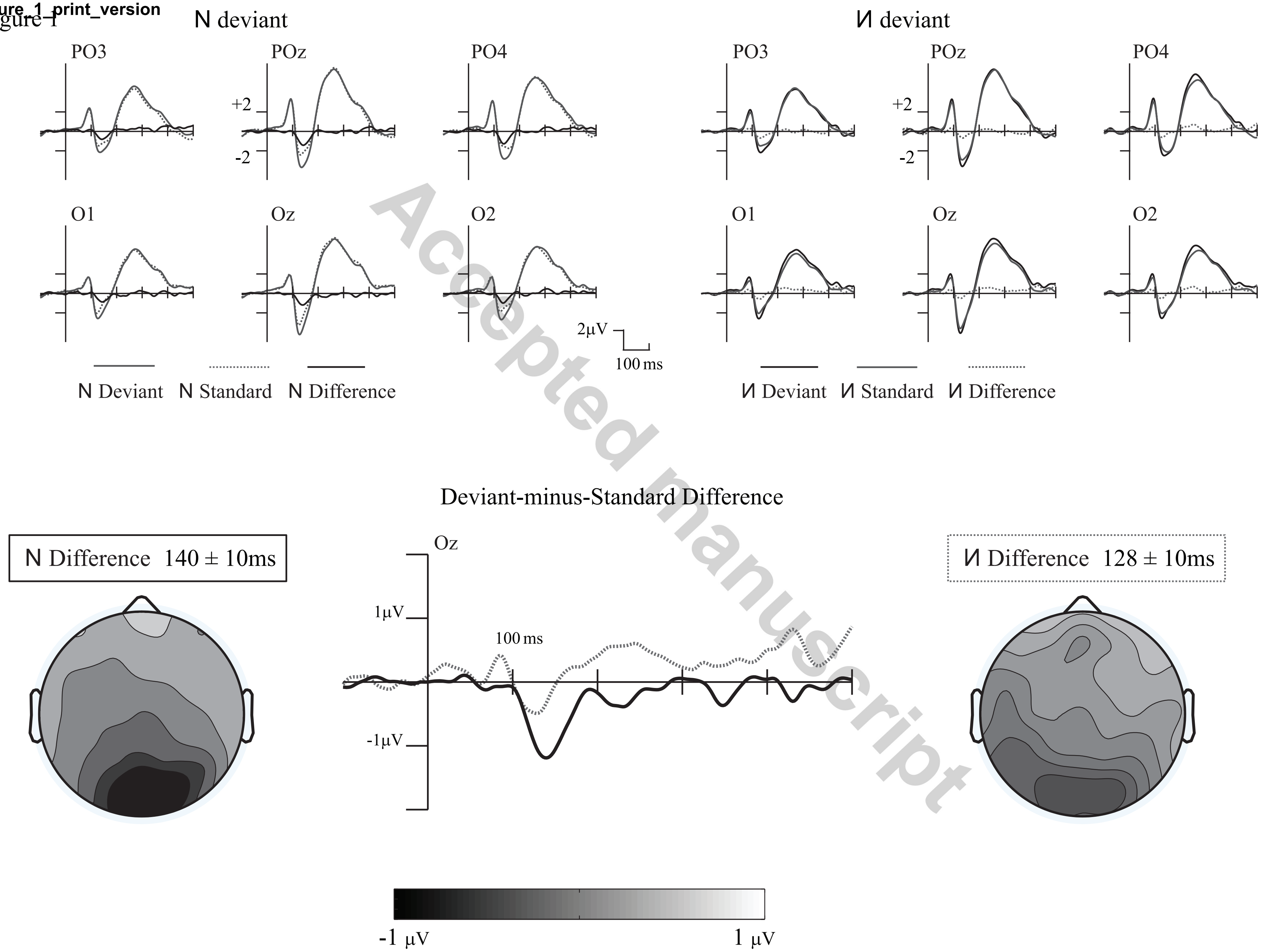

Figure_1_web_version
Figure 1

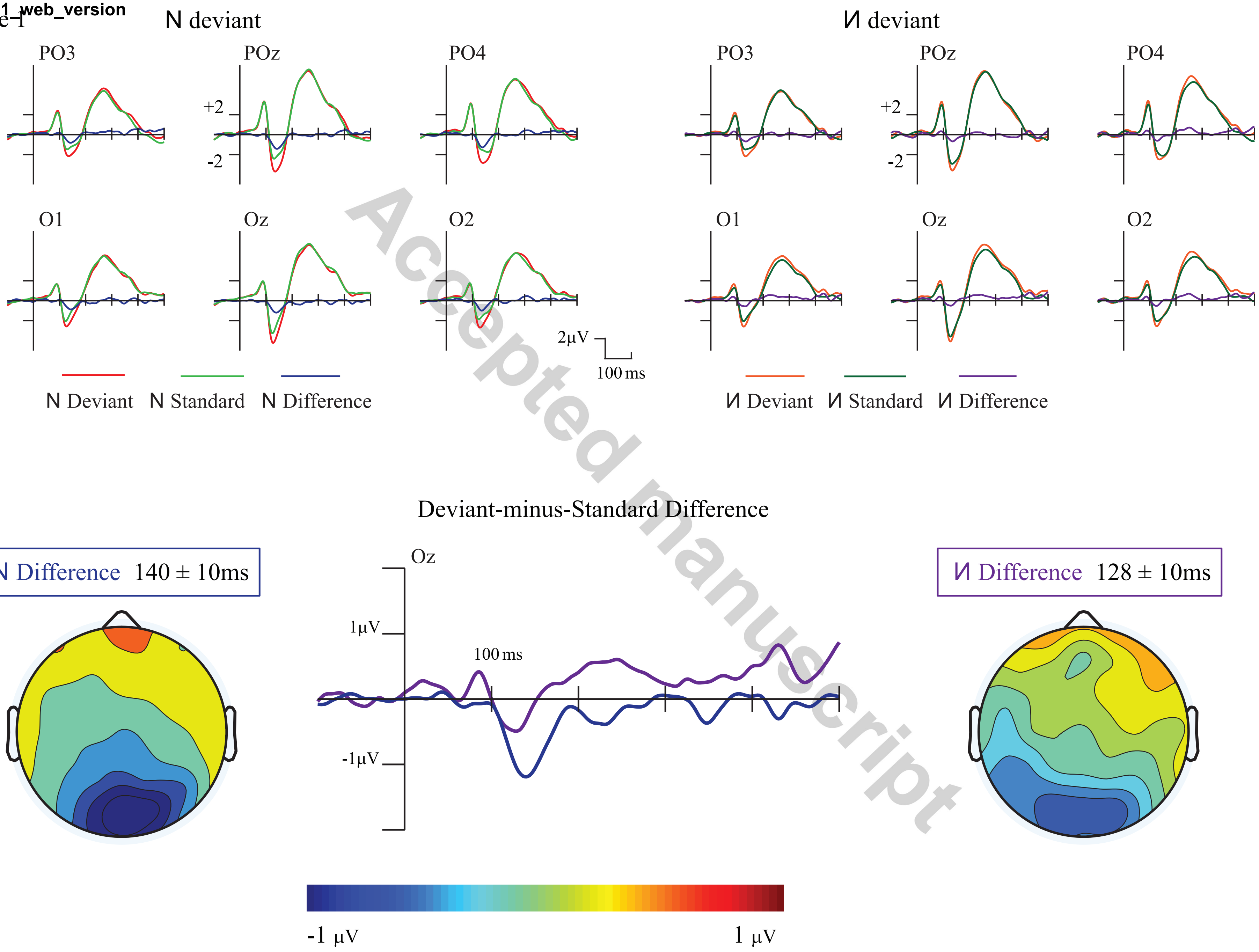

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Figure 2

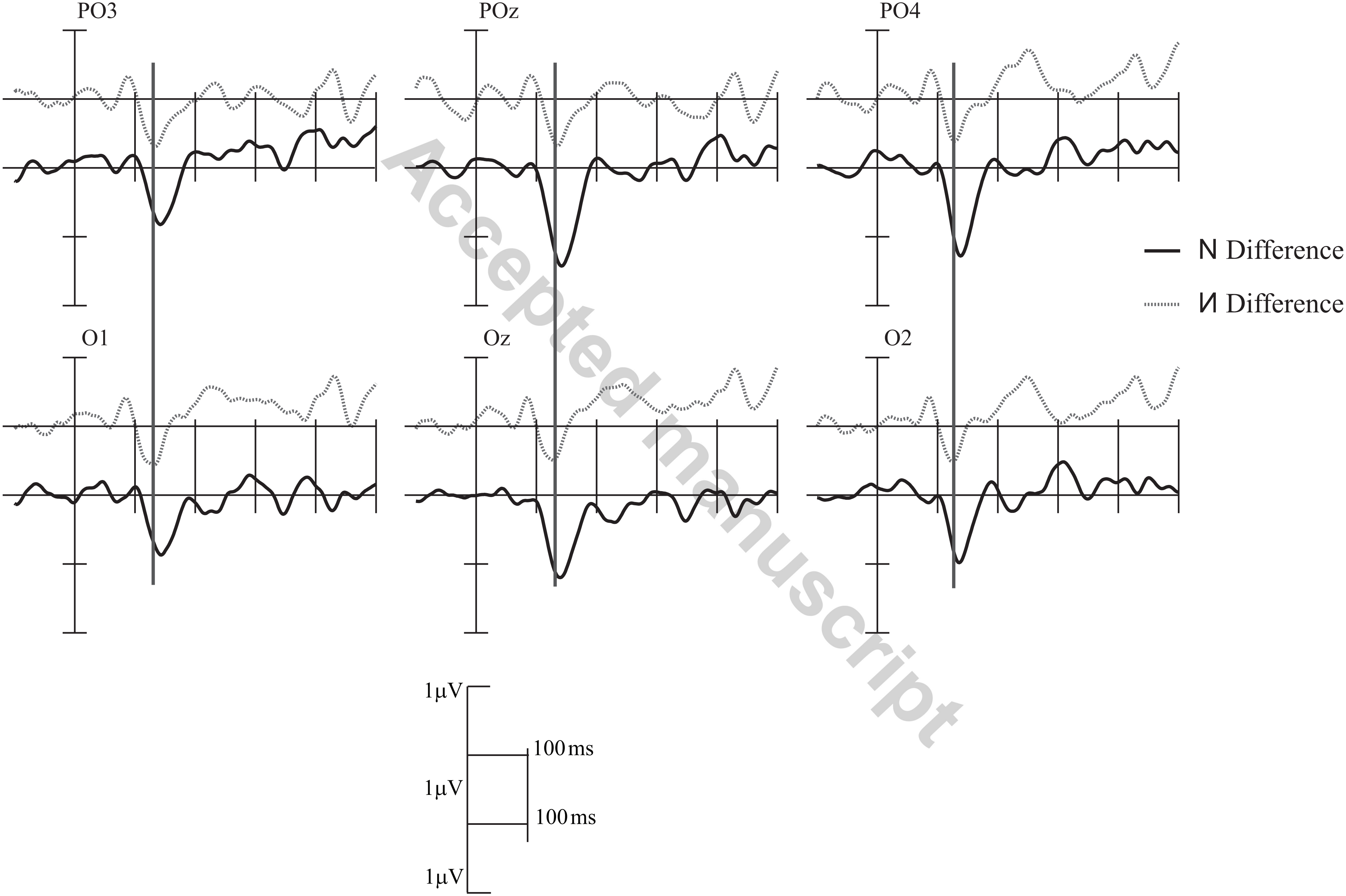

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Figure 2

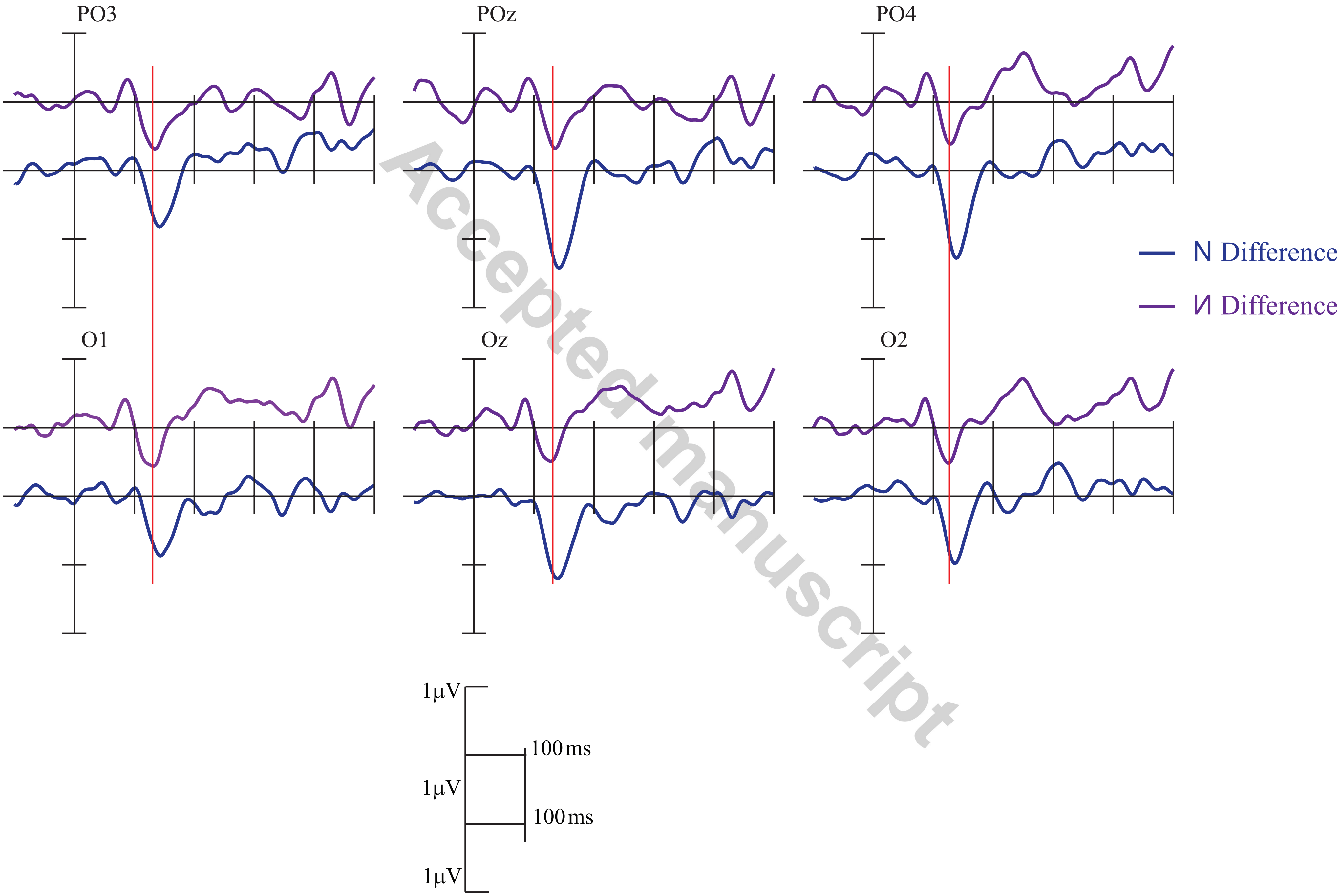

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Figure 3

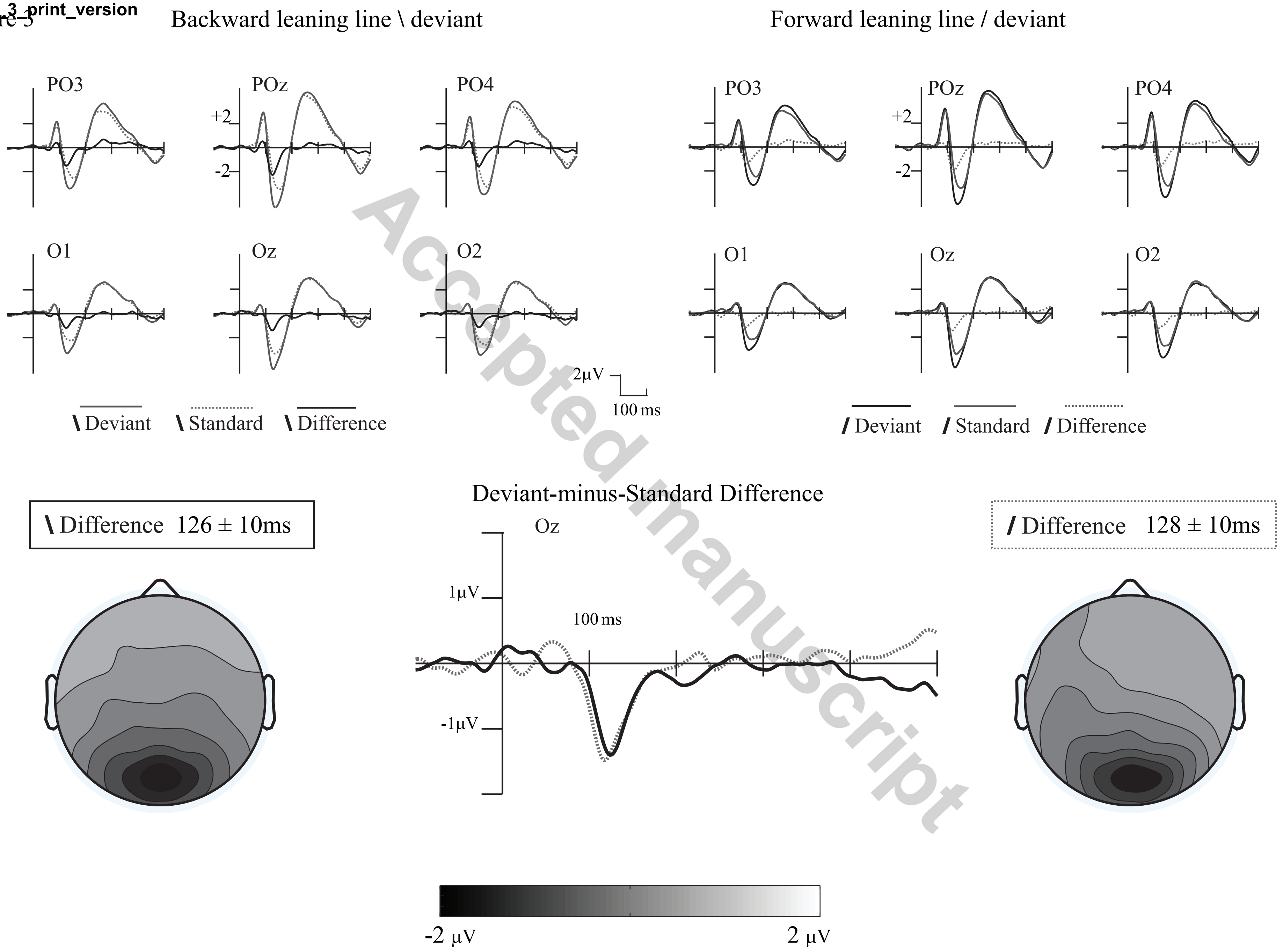

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Figure 3

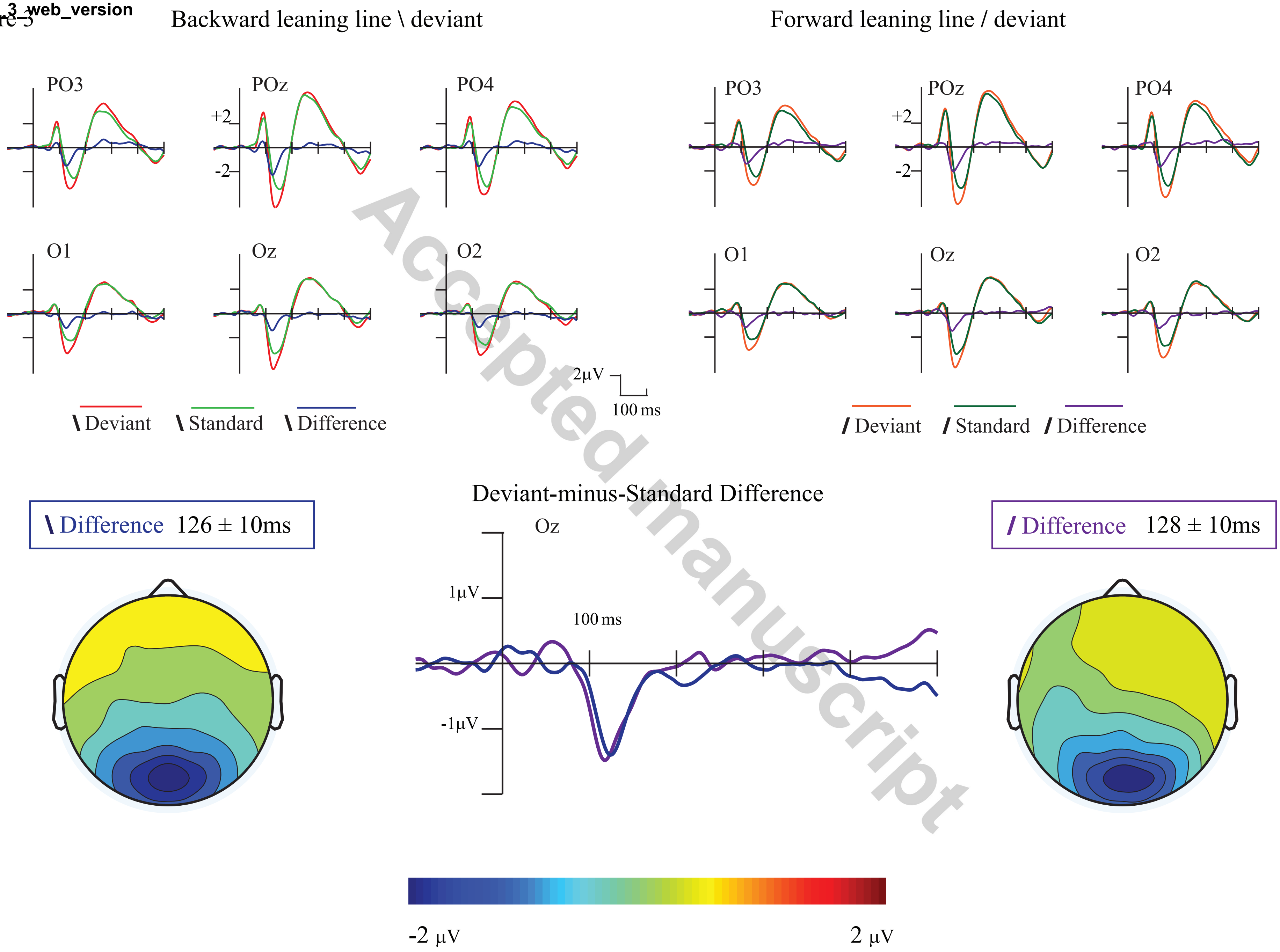


Figure 4

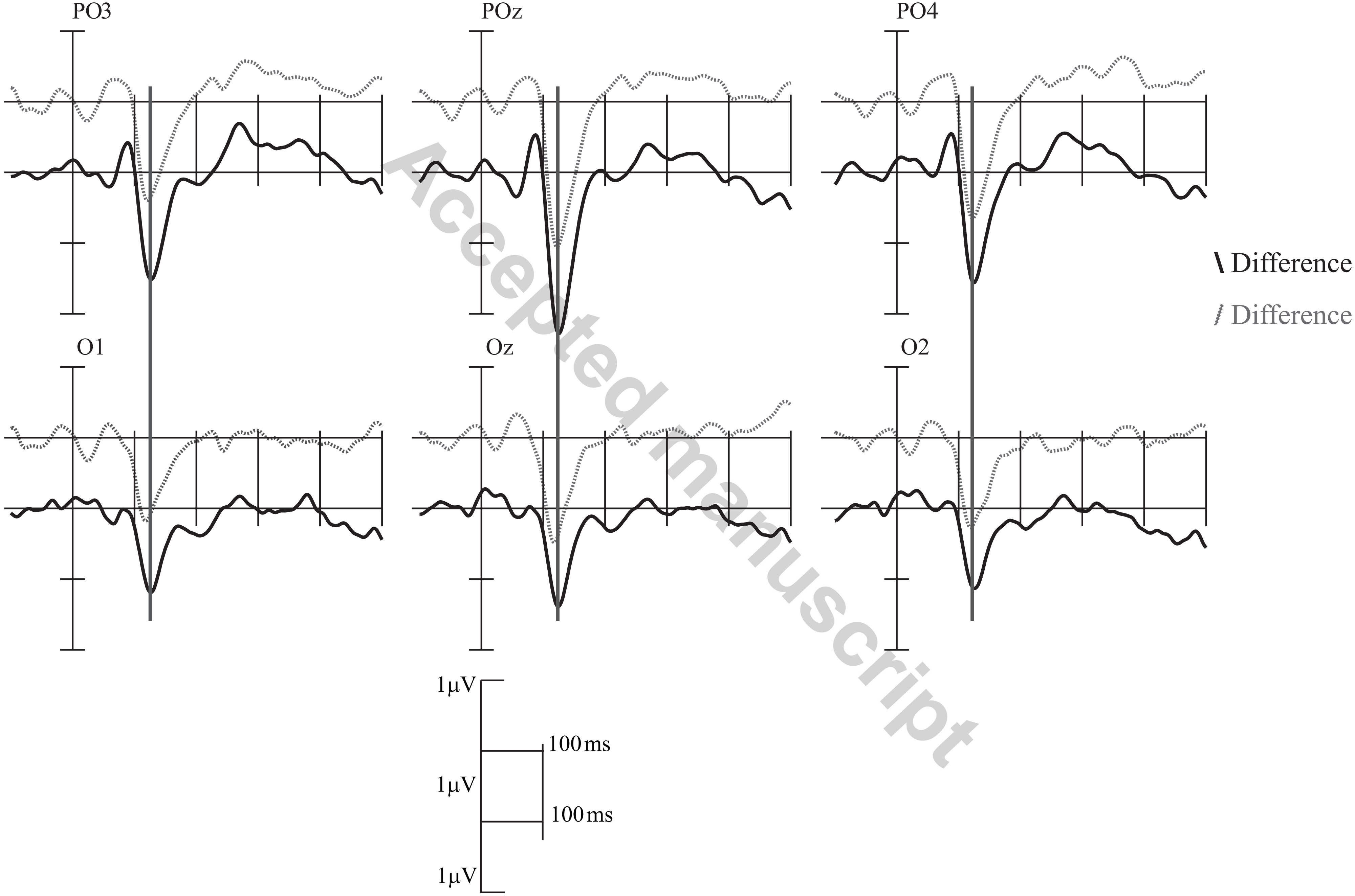

PO3
POz
PO4
O1
Oz
O2
Difference
Difference
1µV
100 ms
1µV
100 ms
1µV

Figure_4_web_version

Figure 4

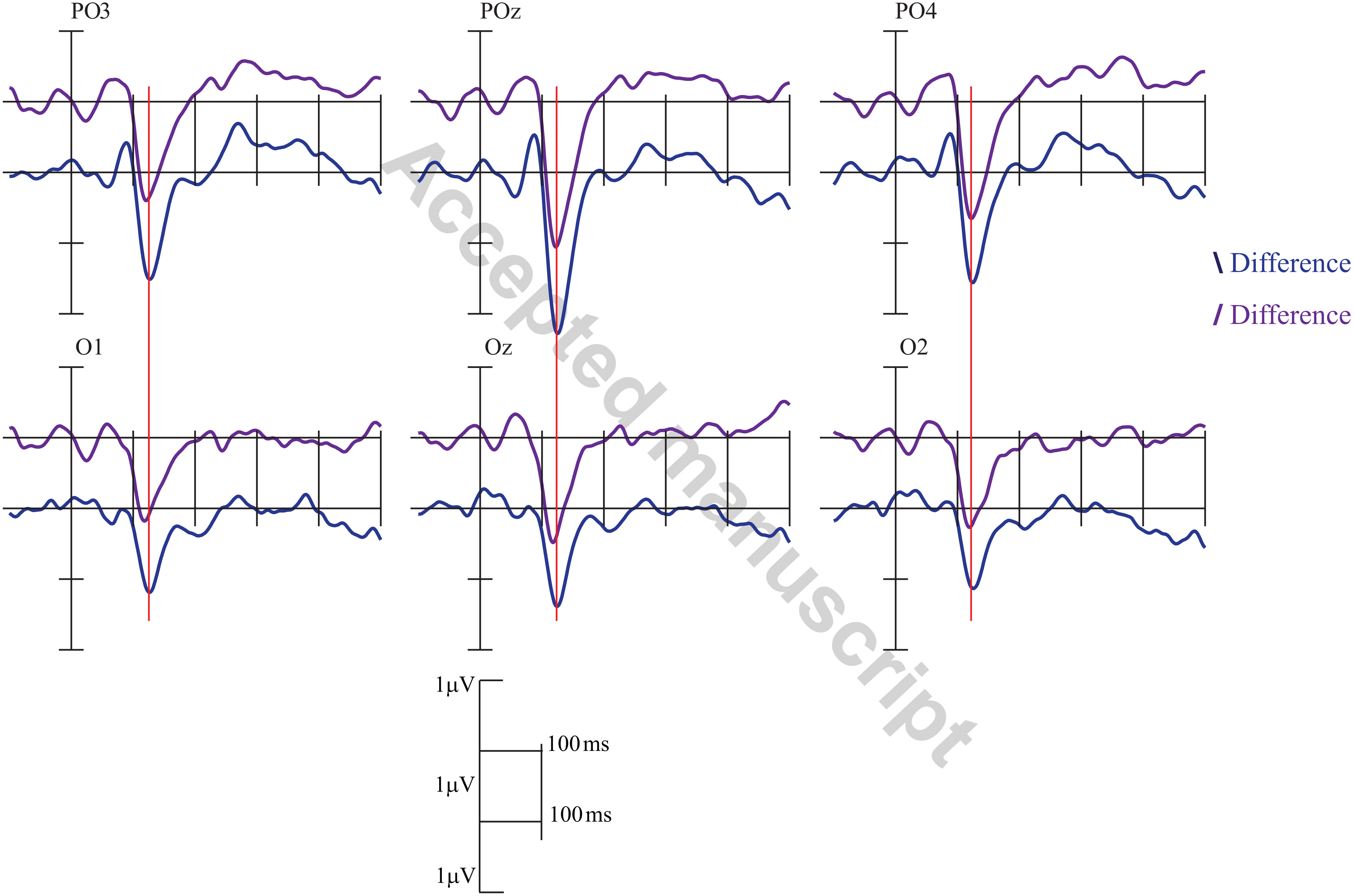
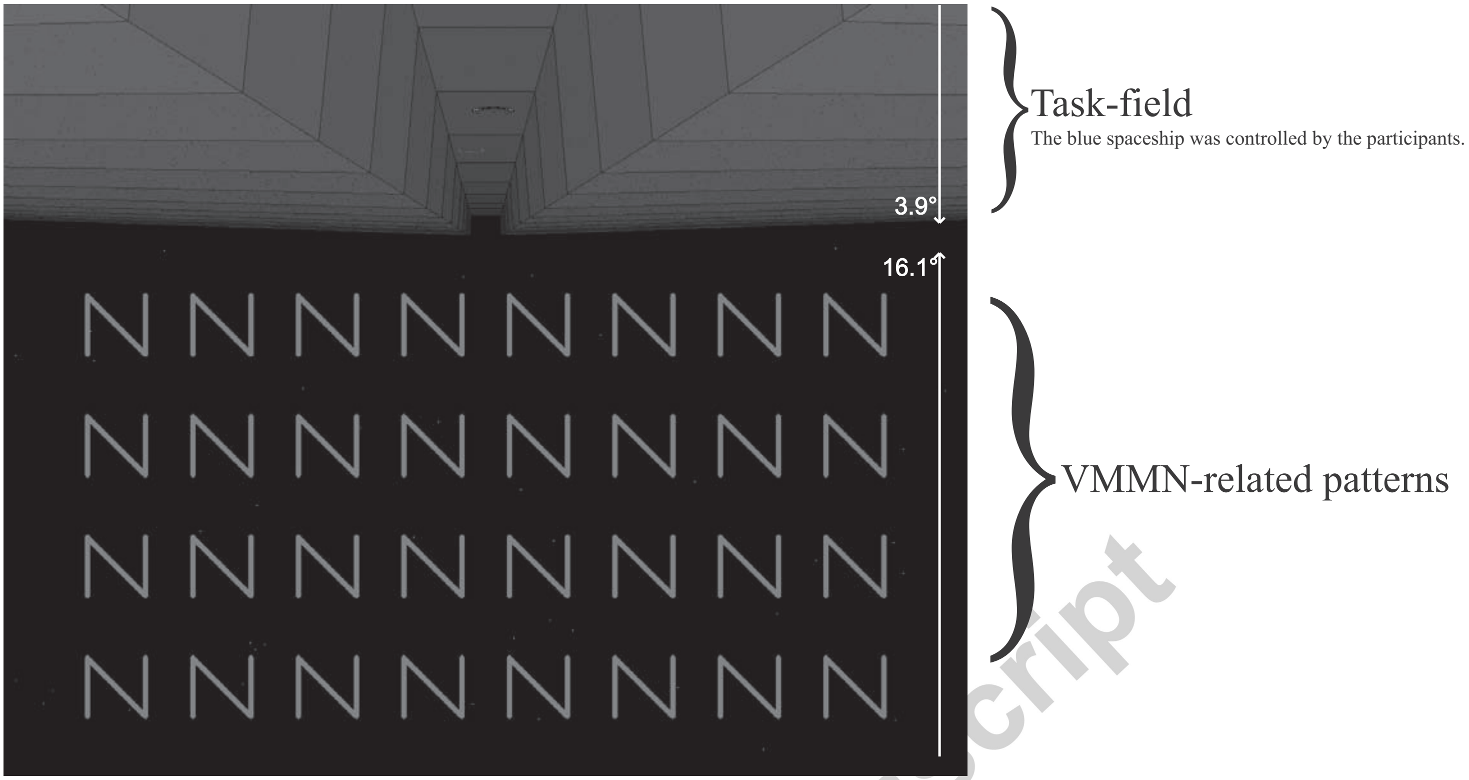


Figure 5_print version

Figure 5



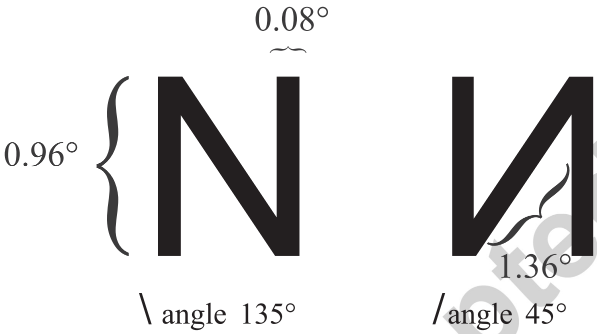
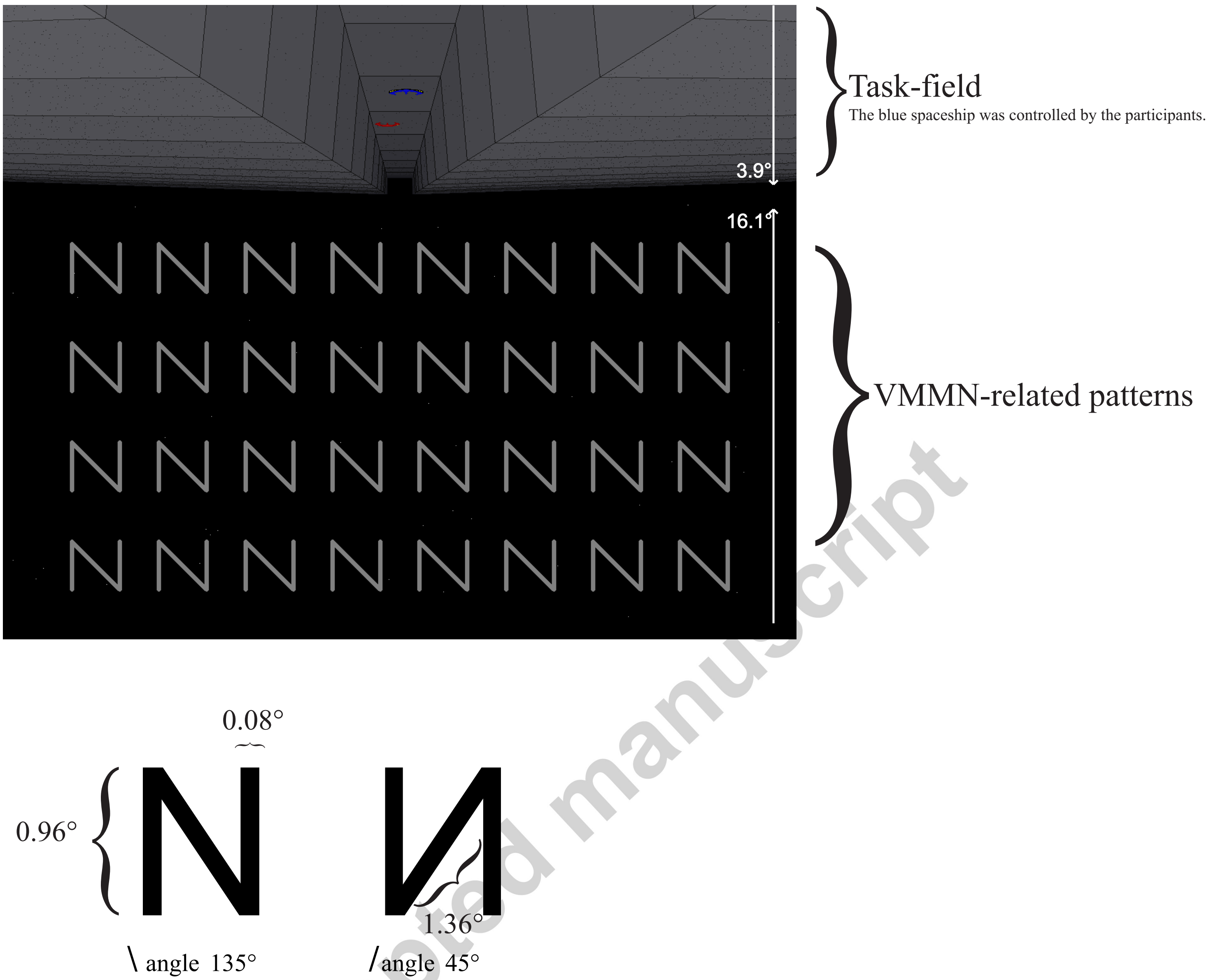


Figure 5


Task-field
The blue spaceship was controlled by the participants.
3.9°
16.1°
VMMN-related patterns
0.08°
0.96°
1.36°
\ angle 135°
/ angle 45°

Highlights

Letters: passive oddball paradigm; N standards and И deviants; reverse control

Oblique lines: passive oddball paradigm; \ standards and / deviants; reverse control

Shorter vMMN latency to unfamiliar (И) than familiar (N) deviants.

No such difference between the vMMNs to \ and / deviants.

Visual mismatch negativity is sensitive to the familiarity of the stimulus.