Title:

Association of different neural processes during different emotional perceptions of white noise and pure tone auditory stimuli

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Highlights

- We studied effects of white noise and pure tone auditory stimuli on emotions
- White noise and pure tone stimuli induced different valence responses
- Differences in valence responses were related to a subset of process of neuroelectrical responses because EPN, P3, and early-phase LPP were differentially modulated by white noise and pure tone stimuli.
- Different neuroelectrical responses may be elicited by significantly increasing parietal lobe activity, suggesting that this region is involved in generating different valence responses.

Keywords

Sounds of common loudness

Sound frequency characteristics

Event-related potentials

Subjectively experienced valence and arousal responses

Abbreviations

WN; white noise, PT: pure tone, EPN: early posterior negativity, LPP: late posterior positivity, ERP: event-related potentials, LORETA: low resolution brain electromagnetic tomography

Abstract

Sound is a sensory stimulant ubiquitously found throughout our environment. Humans have evolved a system that effectively and automatically converts sound sensory inputs into emotions. Although different emotional responses to sounds with difference in frequency characteristics are empirically recognized, there is a paucity of studies addressing different emotional responses to these sounds conditions, and their neural mechanisms. In this study, we examined effects of pure tone (PT) and white noise (WN) inputs at ordinary loudness levels on emotional responses. We found that WN stimuli produced more aversive responses than PT stimuli. This difference was endorsed by larger late posterior positivity (LPP). In a source localization study, we found increased neural activity in the parietal lobe prior to LPP. These findings show that WN stimuli produce aversive perceptions compared with PT stimuli, at typical loudness levels. In addition, different emotional responses were processed in a similar manner as visual stimulations, as reflected by increased LPP activation. Various emotional effects of WN and PT stimuli, at ordinary loudness levels, could expand our understanding of adverse effects of noise as well as favorable effects associated with music.

1. Introduction

Human life is surrounded by various kinds of sounds, from appetitive sounds like birds chirping to aversive sounds like a dog's growl. Human auditory systems can unconsciously and automatically convert these sounds to emotional responses, depending on sound characteristics.

Studies have shown that emotional responses to sound occur almost instantly, at speeds where only electroencephalography-based technologies are suitable [11]. For example, stimulation-linked neural activities can occur as fast as 200 ms after stimulation presentation, and these changes are recorded as an event-related potential (ERP). In addition, ERPs that follow rapidly changing electro-neural events are also linked to emotions; ERPs occurring 300 ms after stimulus presentation also correlate with valence responses.

Loudness is often linked to aversive emotions, and sounds with extraordinary loudness (up to 100 dB) are used for evoking aversive emotions [2, 15]. However, loud sounds such as these elicit responses mediated by vestibular processes that directly link to the autonomic nervous system [27], in addition to cochlear functions that link to higher auditory cognitive processes.

In daily life, one is unlikely to routinely encounter 100 dB sounds; sounds at approximately 50 dB are most commonly heard, and most human conversations and mechanical noise occur at moderate loudness levels [3]. Even at moderate loudness levels, sound can induce different emotional responses. At typical loudness levels, vestibular processes do not play a major role, and emotional experiences coupled with these sounds cannot explain the range of observed emotional responses [5, 26]. Thus, acoustic characteristics alone could play a role in this process. Indeed, pioneering work by Halpern reported the contribution of sound frequency spectral on perceived discomfort [10]. However, there is a paucity of studies addressing the neural response underling sound frequency dependent emotional responses.

Naturally occurring sounds comprise several resonant frequencies that follow a power law relationship [12, 25]. These naturally occurring sounds can be affectively coupled with emotional (including violent) events, even if the sound itself does not convey emotion. This coupling effect occurs during emotional responses to certain sounds. To avoid this affective coupling, PTs are often used [14, 23]. WN is another example of an unnatural sound where similar sound intensities are delivered across a wide frequency range [25]. Because artificial sounds cannot naturally occur, they are less likely to relate to natural life events.

However, little is known about how the human brain codes different frequency properties or if sounds at ordinary loudness levels can induce emotionally distinct responses.

In this study, we examined differences in neural activity relative to sound frequency type, and the relation of this activity to subjective feelings at ordinary loudness. To address these problems, we used PT and WN as sound sources and observed neural activity by combining ERPs with low resolution brain electromagnetic tomography (LORETA).

2. Material and Methods

2.1. Subjects

Subjects were recruited by advertisements, and seventeen healthy adult volunteers (10 men, age mean +/- standard error: 21.6+/-0.50 years) participated in this study. Subjects were given gift card equivalent to ¥2500 for their participation. Subjects had no psychiatric disorders, hearing problems, or smoking history. No subjects used medication or took caffeine on the day of the study. All subjects were right-handed as confirmed by the Edinburgh handedness inventory. All subjects were informed about the purpose and design of the study and provided written informed consent prior to completing any study-related procedures. This study was approved by the ethical committee at Shiga University of Medical Science, Japan.

2.2 Experimental design and settings

The affective stimulus was a 500-ms burst of 50 dB[A] WN with instantaneous (10 ms) rise/fall times. WN includes all frequency bands within the audible range. As a control, we used 1000-Hz PT stimuli because sounds with 1000 Hz peaks are observed most often [12] and 1000 Hz peaks are less affected by age-related losses in hearing sensitivity [6]. We presented stimulations in a passive task context where subjects were instructed to simply view the fixation point that was presented.

Auditory stimulations were provided through headphones (AKG closed-back headphones, K404). The stimulus sound was programmed to randomly produce each frequency 75 times, with randomized stimulus intervals (2000 ± 200 ms) using E-Prime v 2.0 software (Psychology Software Tools, 2013).

During the experiment, subjects remained seated on a chair that was placed 70 cm in front of a cathode ray tube (CRT) display in a sealed room. The illumination in the room was maintained at 80 lux. Subjects were directed to look at a white cross fixation point that appeared against the black CRT background. The first 5 min were designated as the silent condition in which no sound was administered. After this, the stimulus sound was administered for approximately 5 min.

We scored subjective emotional responses using the Self-Assessment Manikin (SAM), which is a two-dimensional subjective scoring system used for assessing affective stimuli using the International Affective Picture System [1]. This is a nine-point rating scale consisting of two sets of figures for measuring valence responses (1 = unpleasant; 9 = pleasant) and arousal responses (1 = arousing; 9 = calming). Study participants scored SAM scores for both WN and PT stimuli, immediately after each experiment.

2.3. Electroencephalography data acquisition

Electroencephalography (EEG) signals were recorded using NetStation software (Electrical Geodesics Inc., Eugene OR, USA), and 64-channel recordings were made through the HCGSN v.1.0. gel cap. Data were sampled at 500 Hz and referenced to Cz. Electrode impedances were kept at <60 kΩ throughout the experiments, according to methods described elsewhere [13]. Subjects were asked to remain awake, and we confirmed vigilance by online observation of the EEG signal.

2.4. ERP data processing

EEG data were processed using EEGLAB (version 13.4.4b) [7], an open source toolbox that runs on MATLAB (The Mathworks, Inc. version 2015a). EEG data were re-referenced to the average of the left and right mastoids. First, data were bandpass filtered offline by 0.1–50 Hz, and gross artifacts were visually rejected following independent component analysis, excluded components produced by eye movements, and EMG. All data were re-referenced to the average of both mastoids. We epoched all data segments from 500 ms prior to and 1500 ms post stimulations, and baseline corrections were done by subtracting the average 100–0 ms prior to stimulation. The number of epochs used for individual ERP calculation in PT condition ranged from 38 to 73 epochs (average: 5.76 epochs), and 37 to 71 epochs or 53.94 epochs (average: 53.94 epochs) in WN condition. To compare component amplitudes, we compared averages of Pz, P3, and P4 electrode potentials between WN and PT conditions to capture potential fluctuations that is maximal at centro-parietal sites [28]. To investigate the regions involved in these differential processes, we used time-series LORETA analysis for every 2 ms, to estimate the current source density distribution for each ERP component [17].

Statistical analyses

Data are shown as mean: M and standard error of mean: SE, unless otherwise stated. Student’s t tests were used for between-group comparisons, and we calculated Cohen's *d* estimate effect size [4]. Statistical analyses were performed using IBM SPSS Statistics for Macintosh, Version 22.0 (IBM Corp. Armonk, NY). The effect size was estimated using

Cohen's *d*, following definition and criteria described elsewhere [4]. LORETA images were statistically compared between sound conditions by using voxel-by-voxel t-test, which were corrected by the calculation of exact randomization probabilities (5000 randomizations). The threshold for *p* value to determine statistical significance was set at $p < 0.05$.

2.5. Correlational analysis

We examined correlations between subjective feelings and ERPs. To assess the role of time-specific components, we subdivided ERPs into five components: N1P2, early posterior negativities (EPN); P3; early LPP (eLPP); and late LPP (lLPP) which span 150–200, 200–300, 300–450, 450–650, and 650–900 ms post stimulations. These divisions are described elsewhere [21]. In addition, we defined ERP 900–1100 ms after stimulations as POST. The intra-individual differences in ERP amplitudes between PT and WN were compared against intra-individual self-reported differences in emotional ratings as previously reported [9].

3. Results

3.1. Subjective emotional ratings of WN and PT

First, we examined emotional responses evoked by WN and PT. Both sound stimuli evoked comparable arousal responses [WN: M = 4.00, SE = 1.58; PT: M = 4.71, SE 1.26, $t(16) = 1.73$, $p = 0.104$, paired Student's t-test, two-tailed, Cohen's $d = 0.25$]. However, subjects perceived significantly aversive responses, with moderate effect sizes for WN [WN: M = 2.76, SE = 1.15; PT: M = 3.94, SE = 1.30, $t(16) = 4.09$, $p = 0.001$, paired Student's t-test, two-tailed, Cohen's $d = 0.48$]. These data showed that WN evoked more negative valence responses than PT, without differing effects on arousal.

3.2. Neurophysiological response to sound stimulations.

Next, we examined neuroelectrical responses with the two types of sound stimulations. This analysis showed that both sound stimuli produced changes in scalp-recorded electrical potentials, having posterior negative peaks at approximately 200 ms corresponding to EPN. EPNs were followed by central positivity approximately 300 ms after stimulation (Figure 1a). Furthermore, we found continuous LPP that lasted until 1000 ms after stimulation during WN conditions. The fluctuation patterns were also confirmed at other electrode sites (Supplementary Figure 1).

Comparison of component amplitudes showed a significant main effect of ERP components [F (4,128) = 45.1, $p < 0.0001$] and sound stimulation conditions [F (1,32) = 13.45, $p = 0.0009$] as well as a significant interaction between ERP components and stimulation conditions [F (4,128) = 4.919, $p = 0.0010$] (Figure 1b). Because significant interactions were found, we conducted a simple main effects analysis by comparing differences in condition-dependent amplitudes within each component. We found significantly positive amplitudes in EPN, P3, eLPP, and lLPP components in WN conditions than PT conditions (Table 1).

3.3. Association between subjective feelings and neurophysiological responses

Because subjective emotional responses and ERPs differed between the two sound conditions, we examined if intra-individual differences of emotional responses and ERP amplitudes were correlated with each other. To this end, we conducted a correlation analysis of amplitude differences in ERP and differences in subjective emotional ratings induced by PT and WN. We found no correlation between arousal ratings and ERP changes (Table 2). However, amplitude differences in EPN and eLPP were significantly correlated with differences in valence responses, and similar tendencies were found for P3 (Table 2). These results showed that valence responses were specifically correlated with early-stage neuroelectrical responses.

3.4. Source localization

The time series analysis by LORETA found significantly larger electrical activities during the WN condition, starting from 294 ms to 328 ms, that corresponds to the EPN/P3 transitions. In this time range, significantly increased electrical activity was found in the parietal lobe, with its peak in the left inferior parietal lobule (left parietal lobe, Brodmann 40, Figure 2). However, no significant difference were observed when we compared electrical activities on

ERP component basis (Supplementary figure 2).

4. Discussion

In this study, we tested the neural substrates underlying sound perception of WN and PT auditory stimuli.

It was of note that even at the common loudness levels, WN evoked more aversive feelings than PT. Although it remains to be determined if PT is comparable with neutral stimulations, we noted that WN induced more aversive responses than PT.

To the best of our knowledge, this is the first report indicating WN functions as an aversive stimulus, even without extreme loudness. This finding provided further support to previous observations that short bursts of WN (but not PT) are commonly used as aversive stimuli. In contrast to our findings, continuous WN is often reported as having favorable effects, such as facilitating sleep [24]. This difference may be explained by opposite salience effects elicited by continuous WN versus short bursts of WN. Continuous WN may mask salient stimulations, whereas short bursts of WN enhance salience.

The sound stimulations were followed by neuro-electrical responses that closely follow ERPs evoked by other modalities, such as P3 and LPP [11, 28]. Although we found significantly positive amplitudes in EPN, P3, eLPP, and lLPP components in WN condition, no significant changes due to sound conditions were observed for N1P2 and POST (Table 1). This result was similar to results of previous studies using visual stimulation [8]. These data further confirmed that ERP components were modulated by sound characteristics in a way similar to visual stimulations, such that aversively rated WN was associated with more pronounced LPP. Because compared with neutral stimulation, pronounced LPP relates to both aversive and appetitive stimulation [28], increased LPP indicates that WN functioned as a valence-inducing stimulus.

Our examination on source localization have found increased electrical activity in the parietal lobe during WN presentation, starting during EPN and lasting until the first half of P3. The increased local activity in WN at this time window is thought to be important as such significant difference were not observed in other time windows or ERP components. Although P3 as a whole did not show amplitude differences between the two conditions, different electrical activity, location specific to parietal lobe and time specific to a part of P3 time window, may have led to profound positivity of LPP.

The differing emotional effects of PT and WN are linked to differing patterns of neural activity that are quantitatively correlated to valence responses, but not arousal. The correlation was exclusively found in EPN and P3 time windows.

It is particularly interesting that increased electric activity was found in the left parietal lobe. Studies have indicated that this region, especially left inferior parietal cortex (IPC), plays a role in binding of cross-modal stimulations (e.g. audio–visual) [16], as represented by bouba-kiki effect which maps vocal speech sounds into visual shapes [19]. In addition, this region was also shown to play a pivotal role in relating visual inputs to emotions [20]. In contrast to integrative role of left IPC, right IPC is involved in processing spatial localization of auditory stimuli. Based on these studies, it was suggested that auditory stimuli may be converted into emotional processes in the left parietal lobe during the time period corresponding to P3, which may lead to later processes, reflected as LPP. In addition, in terms of auditory perception, this region is implicated as the neural basis of the Bouba-Kiki effect, which maps vocal speech sounds into visual shapes [18]. Auditory stimuli may be converted into emotional processes in the parietal lobe during the time period corresponding to P3, which may lead to later processes, reflected as LPP.

While visual presentations of emotional stimuli have been related to increased negativity of EPN [22], PT elicited more negative EPN than WN. Previous studies have shown that EPNs are related to perceptual encoding, whereas LPPs relate to stimulus representations in working memory [22]. This finding suggests that PT requires neural processes similar to stimulation attracting attentions, although WN later involves working memory processes relating to aversive responses.

Current study has several limitations. Firstly, because we used a pair of sound stimulations, it is not appropriate to generalize current finding as universal response to aversive sound stimulation. To better understand sound characteristics dependent responses, more study with combinations of sound characteristics should be conducted. Also, because the current study has been done with young subjects, current findings could be affected by age specific responses. Further study should be conducted to show general emotional and neural response to sound stimulations at commonplace loudness.

5. Conclusions

We found that different emotions were induced by sounds with differential frequency characteristics at moderate sound levels. This emotional perception was based on late neural electrical responses similar to loud aversive sounds as well as aversive pictorial stimulations. However, opposite early neural responses were found as EPNs were more negative possibly because PTs attract more attention.

These results showed that neural responses found in studies using loud sounds cannot be generalized, and future studies should use moderate sound levels for clarifying the effects induced by noise and music at normal sound levels.

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Figure 1 Topographic representations and traces of ERPs evoked by PT and WN.

Panel A: Scalp distribution of potentials in each ERP component is topographically represented. Note that the positive potentials are evident in the posterior region during eLPP and lLPP under WN conditions. Panel B: ERPs evoked by WN (blue line) and PT (green line) are presented. Shaded colors represent mean ± standard error.

Figure 2 Source localization of differences in ERP

Differences in neuroelectrical activity induced by WN and PT are presented. Voxels with significantly increased neuroelectrical activity during WN conditions are shown in yellow to red gradations. Color bars shows the locations of extreme *t*-value that corresponds to locations of significant difference (P<0.05, corrected for multiple comparison).

Table 1 Amplitude differences in ERP components

Mean amplitude and mean ± standard error of each ERP component is shown. Significant amplitude differences are observed in EPN, P3, eLPP, lLPP, although these differences are not present in POST.

Table 2 Correlation between emotional differences and neuroelectrical responses

Spearman's correlation analyses between amplitude difference and differences in emotional ratings between WN and PT are shown. Significant correlations are found in EPN and early LPP.

[1] M.M. Bradley, P.J. Lang, Measuring emotion: the Self-Assessment Manikin and the Semantic Differential, J Behav Ther Exp Psychiatry 25 (1994) 49-59.

[2] L.E. Campbell, M. Hughes, T.W. Budd, G. Cooper, W.R. Fulham, F. Karayanidis, M.C. Hanlon, W. Stojanov, P. Johnston, V. Case, U. Schall, Primary and secondary neural networks of auditory prepulse inhibition: a functional magnetic resonance imaging study of sensorimotor gating of the human acoustic startle response, Eur J Neurosci 26 (2007) 2327-2333.

[3] R. Chepesiuk, Decibel hell: the effects of living in a noisy world, Environ Health Perspect 113 (2005) A34-41.

[4] J. Cohen, Statistical power analysis for the behavioral sciences, Academic Press, New York, 1977, xv, 474 p. pp.

[5] T.J. Cox, Scraping sounds and disgusting noises, Applied Acoustics 69 (2008) 1195-1204.

[6] K.J. Cruickshanks, T.L. Wiley, T.S. Tweed, B.E. Klein, R. Klein, J.A. Mares-Perlman, D.M. Nondahl, Prevalence of hearing loss in older adults in Beaver Dam, Wisconsin. The Epidemiology of Hearing Loss Study, Am J Epidemiol 148 (1998) 879-886.

[7] A. Delorme, S. Makeig, EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis, J Neurosci Methods 134 (2004) 9-21.

[8] D. Foti, G. Hajcak, J. Dien, Differentiating neural responses to emotional pictures: evidence from temporal-spatial PCA, Psychophysiology 46 (2009) 521-530.

[9] G. Hajcak, S. Nieuwenhuis, Reappraisal modulates the electrocortical response to unpleasant pictures, Cogn Affect Behav Neurosci 6 (2006) 291-297.

[10] D.L. Halpern, R. Blake, J. Hillenbrand, Psychoacoustics of a chilling sound, Percept Psychophys 39 (1986) 77-80.

[11] F. Jaspers-Fayer, M. Ertl, G. Leicht, A. Leupelt, C. Mulert, Single-trial EEG-fMRI coupling of the emotional auditory early posterior negativity, Neuroimage 62 (2012) 1807-1814.

[12] K.H. Kim, D.X. Ho, R.J. Brown, J.M. Oh, C.G. Park, I.C. Ryu, Some insights into the relationship between urban air pollution and noise levels, Sci Total Environ 424 (2012) 271-279.

[13] J.J. LaRocque, J.A. Lewis-Peacock, A.T. Drysdale, K. Oberauer, B.R. Postle, Decoding attended information in short-term memory: an EEG study, J Cogn Neurosci 25 (2013) 127-142.

[14] F. Maclennan-Smith, W. Swanepoel de, J.W. Hall, 3rd, Validity of diagnostic pure-tone audiometry without a sound-treated environment in older adults, Int J Audiol 52 (2013) 66-73.

[15] J.S. Morris, C. Buchel, R.J. Dolan, Parallel neural responses in amygdala subregions and sensory cortex during implicit fear conditioning, Neuroimage 13 (2001) 1044-1052.

[16] J. Neufeld, C. Sinke, W. Dillo, H.M. Emrich, G.R. Szycik, D. Dima, S. Bleich, M. Zedler, The neural correlates of coloured music: a functional MRI investigation of auditory-visual synaesthesia, Neuropsychologia 50 (2012) 85-89.

[17] R.D. Pascual-Marqui, C.M. Michel, D. Lehmann, Low resolution electromagnetic tomography: a new method for localizing electrical activity in the brain, Int J Psychophysiol 18 (1994) 49-65.

[18] V.S. Ramachandran, E.M. Hubbard, Psychophysical investigations into the neural basis of synaesthesia, Proc Biol Sci 268 (2001) 979-983.

[19] V.S. Ramachandran, E.M. Hubbard, Synaesthesia--a window into perception, thought and language, Journal of Consciousness Studies 8 (2001) 3-34.

[20] P. Sarkheil, R. Goebel, F. Schneider, K. Mathiak, Emotion unfolded by motion: a role for parietal lobe in decoding dynamic facial expressions, Soc Cogn Affect Neurosci 8 (2013) 950-957.

[21] S. Schindler, M. Wegrzyn, I. Steppacher, J. Kissler, Perceived communicative context and emotional content amplify visual word processing in the fusiform gyrus, J Neurosci 35 (2015) 6010-6019.

[22] H.T. Schupp, T. Flaisch, J. Stockburger, M. Junghofer, Emotion and attention: event-related brain potential studies, Prog Brain Res 156 (2006) 31-51.

[23] J.S. Snyder, O.L. Carter, S.K. Lee, E.E. Hannon, C. Alain, Effects of context on auditory stream segregation, J Exp Psychol Hum Percept Perform 34 (2008) 1007-1016.

[24] M.L. Stanchina, M. Abu-Hijleh, B.K. Chaudhry, C.C. Carlisle, R.P. Millman, The influence of white noise on sleep in subjects exposed to ICU noise, Sleep Med 6 (2005) 423-428.

[25] F.E. Theunissen, J.E. Elie, Neural processing of natural sounds, Nat Rev Neurosci 15 (2014) 355-366.

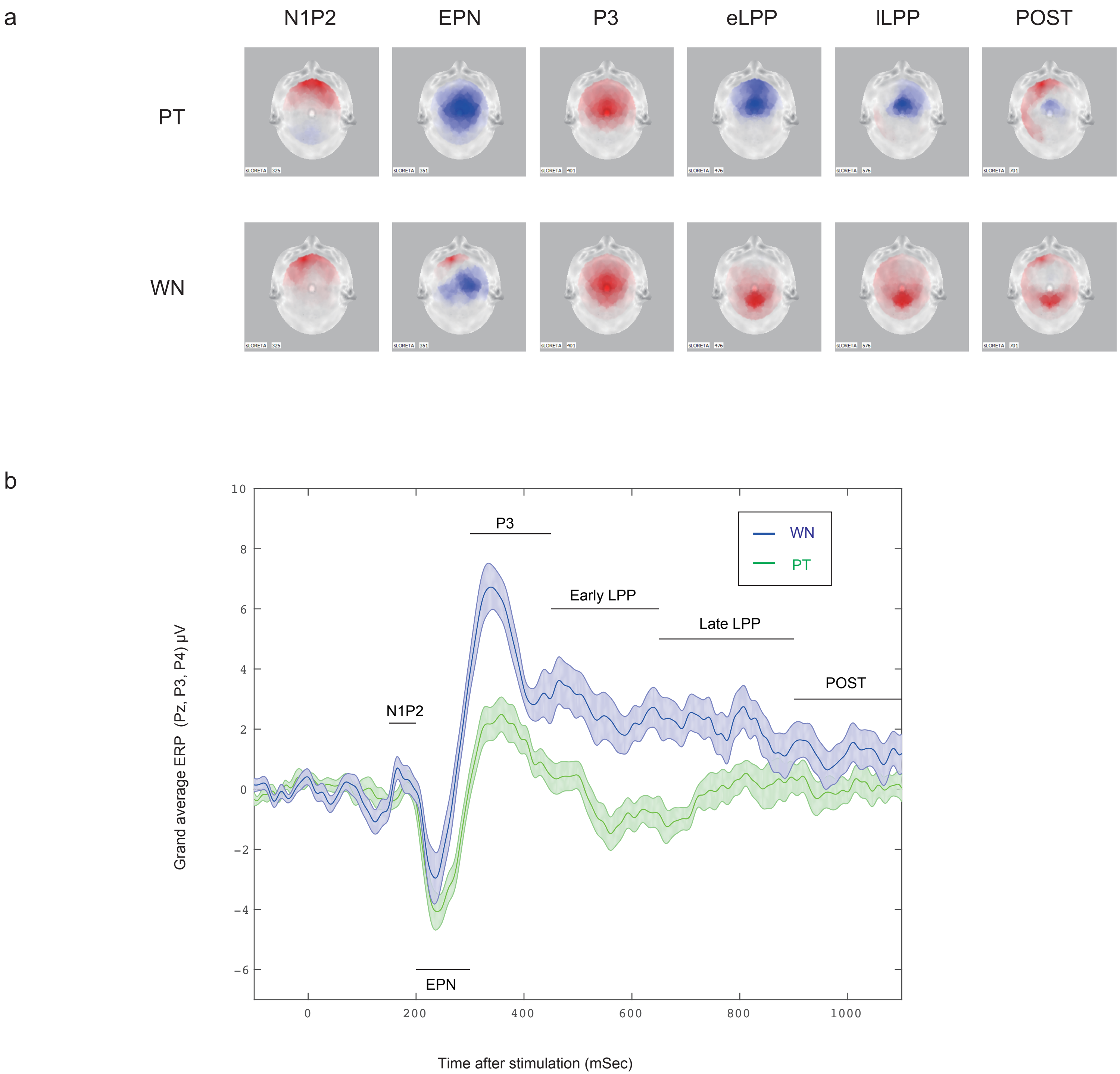
[26] C. Thornton, R.M. Sharpe, Evoked responses in anaesthesia, Br J Anaesth 81 (1998) 771-781.

[27] N.P. Todd, F.W. Cody, Vestibular responses to loud dance music: a physiological basis of

the "rock and roll threshold"?, J Acoust Soc Am 107 (2000) 496-500.
[28] A. Weinberg, G. Hajcak, Beyond good and evil: the time-course of neural activity elicited by specific picture content, Emotion 10 (2010) 767-782.

	N1P2	EPN	P3	eLPP	lLPP	POST
PT	-0.3±1.38	-2.7±2.12	1.41±1.97	-0.69±2.08	-0.33±1.96	-0.13±1.78
WN	-0.01±1.5	-0.8±2.47	4.41±2.15	2.34±2.56	1.76±2.48	0.92±2.42
	$P>0.05$	$P<0.05$	$P<0.01$	$P<0.01$	$P<0.05$	$P>0.05$

		Spearman's ρ	95% Confidence Intervals	P
Valence	N1P2	-0.43	(-0.76 to 0.08)	0.09
	EPN	-0.60	(-0.84 to -0.15)	0.01
	P3	-0.44	(-0.76 to 0.07)	0.08
	eLPP	-0.56	(-0.82 to -0.09)	0.02
	lLPP	-0.35	(-0.72 to 0.18)	0.17
Arousal	N1P2	0.30	(-0.23 to 0.69)	0.25
	EPN	0.15	(-0.37 to 0.6)	0.55
	P3	-0.04	(-0.52 to 0.46)	0.83
	eLPP	0.15	(-0.37 to 0.6)	0.56
	lLPP	-0.04	(-0.52 to 0.46)	0.82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Grand average ERP (Pz, P3, P4) μV
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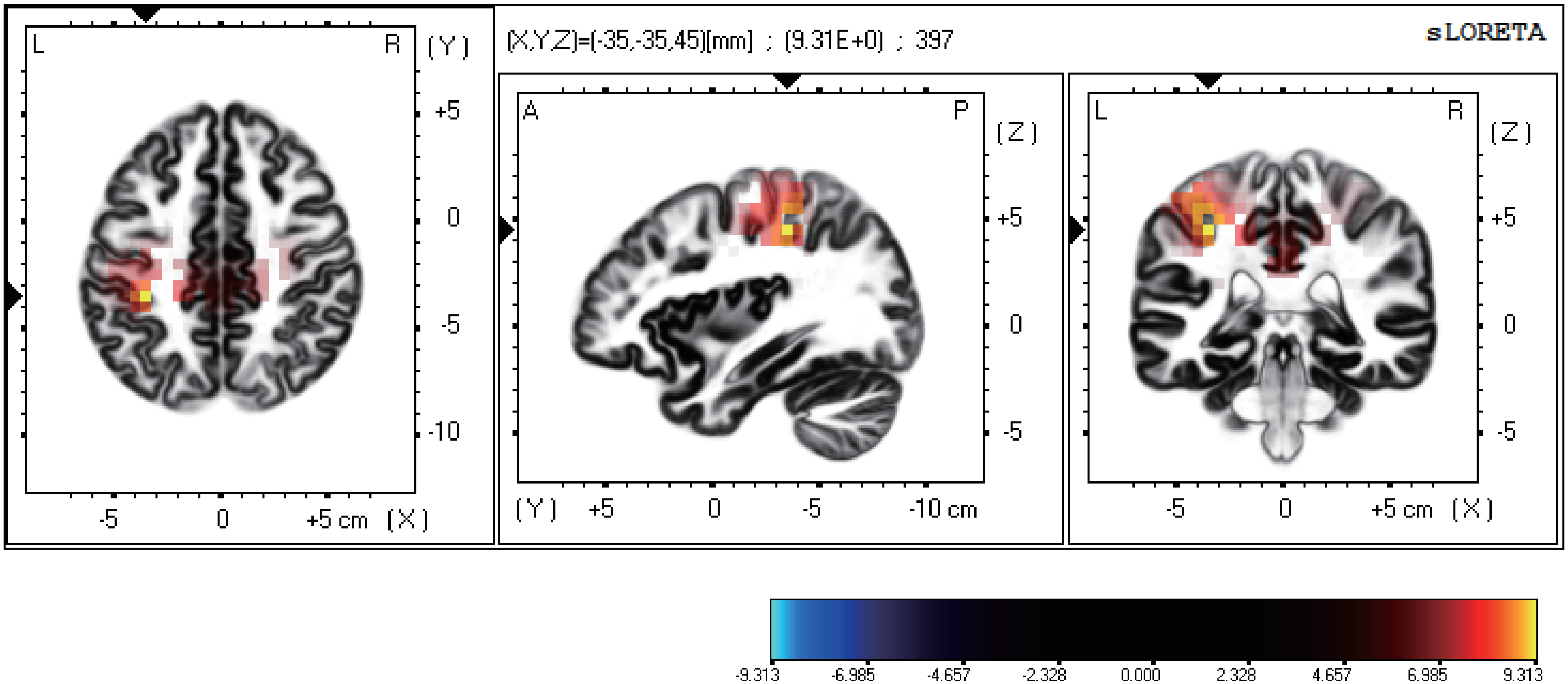

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