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Auditory change-related cerebral responses and personality traits

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ABSTRACT

The rapid detection of changes in sensory information is an essential process for survival. Individual humans are thought to have their own intrinsic preattentive responsiveness to sensory changes. Here we sought to determine the relationship between auditory change-related responses and personality traits, using event-related potentials. A change-related response peaking at approximately 120 ms (Change-N1) was elicited by an abrupt decrease in sound pressure (10 dB) from the baseline (60 dB) of a continuous sound. Sixty-three healthy volunteers (14 females and 49 males) were recruited and were assessed by the Temperament and Character Inventory (TCI) for personality traits. We investigated the relationship between Change-N1 values (amplitude and latency) and each TCI dimension. The Change-N1 amplitude was positively correlated with harm avoidance scores and negatively correlated with the self-directedness scores, but not with other TCI dimensions. Since these two TCI dimensions are associated with anxiety disorders and depression, it is possible that the change-related response is affected by personality traits, particularly anxiety- or depression-related traits.

1. Introduction

One of the most important and fundamental brain functions of sensory processing is the rapid detection of changes in the sensory environment. The human change-detection system has been studied by using auditory evoked potentials (AEPs) and auditory evoked fields (AEFs) at high temporal resolution. N1 (magnetic counterpart: N1m) is a well-known AEP/AEF component which peaks at approximately 100 ms after the onset of an auditory stimulus such as a pure tone, click, or human voice. A similar cerebral response peaking at approximately 100–160 ms can be elicited with an abrupt change in a continuous sound's frequency (Inui et al., 2010a; Yamashiro et al., 2011; Weise et al., 2012a,b), intensity (Harris et al., 2007; Dimitrijevic et al., 2009; Inui et al., 2010a; Nishihara et al., 2011; Otsuru et al., 2012; Soeta and Nakagawa, 2012), location (Inui et al., 2010a; Akiyama et al., 2011; Ohoyama et al., 2012), or timbre (Jones et al., 1998). The amplitude of this AEP component varies with the extent of change in the sound (Inui et al., 2010a; Nishihara et al., 2011) and is therefore referred to as the Change-N1 (Inui et al., 2010a).

It was found that the amplitude of Change-N1 is positively correlated with the duration of the standard stimulus prior to the change onset (Yamashiro et al., 2011; Akiyama et al., 2011) and negatively correlated with the probability of the deviant stimulus (Ohoyama et al., 2012). Change-N1 is little affected by the subject's attention (Inui et al., 2010a). Taken together, these findings show that the Change-N1 reflects an auditory preattentive change-detection system and occurs with comparisons between prior and present sensory information using sensory memory. The magnitudes of the Change-N1m show positive correlations between sound-onset and -offset (Yamashiro et al., 2009, 2011), between sound-onset and -frequency change (Yamashiro et al., 2011), between sound-onset and -location change (Akiyama et al., 2011), and between sound increase and decrease (Otsuru et al., 2012). Since these findings suggest that the sensitivity in the change-detection system is intrinsic in individuals, the relationship between the Change-N1 and other intrinsic factors such as personality traits is one of interesting issues to address.

The Temperament and Character Inventory (TCI) is a well-established self-report questionnaire that was proposed as a bio-psychosocial model of personality (Cloninger et al., 1993). TCI-based personality traits have been investigated using biochemical (Minelli et al., 2011; Yasui-Furukori et al., 2013), genetic (Minelli et al., 2011; Hashimoto et al., 2007) and anatomical methods (Pujol

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et al., 2002; Iidaka et al., 2006; Yamasue et al., 2008; Westlye et al., 2011).

It is known that personality traits affect several AEP components such as auditory and visual P300, which reflect attentional cerebral processing (Hansenne, 1999; Kim et al., 2002; Mardaga and Hansenne, 2009). The relationship between personality traits and preattentive cerebral potentials was also examined in an AEP study using mismatch negativity (MMN), in which responses to a deviant angry voice were stronger in individuals with high anxiety tendency (Schirmer and Escoffier, 2010).

We hypothesized that subjects with high anxiety tendency show high sensitivity to simple changes in sound features because Change-N1 is presumably one subtype of defense reactions (Inui et al., 2012). The aim of the present study was to test our hypothesis by evaluating the relationship between Change-N1 with high test–retest reliability (Otsuru et al., 2012; Inui et al., 2012; Kodaira et al., 2013) and personality traits using the TCI.

2. Materials and methods

2.1. Subjects

Sixty-three healthy volunteers (14 females and 49 males, mean age 26.3 years) with normal hearing participated in this study. Most of the subjects were medical school or graduate students. All subjects were free from psychiatric disorders and alcohol/substance abuse. The study was approved in advance by the Ethics Committee of the Mie University Graduate School of Medicine. Written consent was obtained from all subjects.

2.2. Auditory stimulation

Throughout the experiments, each subject was seated in a comfortable chair in a sound-attenuated room, in which he or she watched a silent movie presented on a screen 1.5 m away. Sound stimuli were binaurally presented through headphones. We used a train of 1-ms clicks presented at 100 Hz. The control stimulus was a 500-ms click train with a 60 dB sound pressure level. The sound-decreased stimulus was a 250-ms train at 60 dB, which was immediately followed by a 250-ms train at 50 dB (Fig. 1A). The two stimuli were randomly presented with the same probability and at the intertrial interval of 750 ms.

2.3. Recording change-related N1

Evoked potentials were measured using a signal processor (Neuropack MEB-2306 system, Nihon Kohden, Tokyo, Japan). A recording electrode was placed at Fz referenced to the linked mastoids (Inui et al., 2010a). Electro-oculograms were recorded with a pair of electrodes placed on the supra- and infra-orbits of the right eye. The EEG signals were recorded with a 0.1–100 Hz band pass filter and a sampling rate of 1000 Hz. The electrode impedances were maintained below 5 kΩ. We averaged 120 artifact-free trials of each of two stimulus conditions recorded from each subject. The 100-ms pre-stimulus period was used as the baseline.

A difference waveform was calculated by subtracting the waveform for the control stimulus from that for the sound-decreased stimulus, to avoid the influence of sustained potentials. We measured the amplitude and peak latency of the Change-N1 response in the difference waveform. The amplitude of Change-N1 was determined as the amplitude between the peak of N1 and the following nearest positive peak (P2) to minimize the influence of a baseline shift, as described (Inui et al., 2010a).

For instructive purposes, AEPs with 25 electrodes using a conventional electroencephalograph (EEG-1714, Nihon Kohden, Tokyo, Japan) and AEFs following sound stimuli in a subject are shown in Fig. 1. AEFs were recorded using a whole-head 306-channel magnetoencephalography (MEG) system (Vector-view; ELEKTA Neuromag, Helsinki, Finland). We analyzed MEG signals recorded by 204 planar-type gradiometers. Signals were recorded with a band pass of 1–200 Hz and digitized at 1004 Hz. Trials with noise >2700 fT/cm were excluded from the averaging, and 120 artifact-free trials were recorded for each condition. The MEG data were filtered off-line with a low-pass filter of 35 Hz for subsequent analyses. In the same manner as that used for our AEP study, difference waveforms were calculated. An equivalent current dipole (ECD) for the magnetic components at the peak of Change-N1m was estimated by using the Brain Electric Source Analysis (BESA) software package (NeuroScan, Mclean, VA).

We tested whether our paradigm reflects the auditory change detection system. First, to evaluate the test–retest reliability of the Change-N1 response, the recordings were repeated for 14 subjects on a second day (interval: 72.2 ± 66.9 days). Second, preliminary auditory brain responses (ABRs) were recorded from three subjects. Sound-decrease stimuli with normal and reversed polarity were used. A recording electrode was placed at Cz referenced to the linked mastoids. The ABR signals were recorded with a 10–3000 Hz band pass filter with a sampling rate of 20 kHz. Two or three thousand artifact-free trials were averaged for each subject. Using an off-line filter with a band pass filter from 100 to 1500 Hz, we measured the peak-to-peak amplitude of the V-waves peaking 7–9 ms after each click sound, from the peak to the following largest negativity in each subject. We calculated the mean peak-to-peak amplitudes of four V-waves before and after the change onset across three subjects.

2.4. The TCI questionnaire

Prior to the EEG recording, each subject completed the Japanese 125-item version of the TCI (Kijima et al., 1996). The TCI consists of four temperaments: novelty seeking (NS), harm avoidance (HA), reward dependence (RD) and persistence (P) and three characters: self-directedness (SD), cooperativeness (C), and self-transcendence (ST). The Japanese version of the TCI was confirmed by test–retest reliability (Takeuchi et al., 2011).

2.5. Statistical analysis

Values are expressed as the mean ± standard deviation (SD). Student's *t*-tests were used to examine gender differences in the mean age, Change-N1 values (amplitude and latency), and the scores of the TCI dimensions. Pearson correlation coefficients were used to assess the test–retest reliability of the Change-N1 amplitude. Spearman's partial correlation coefficient controlling for gender was used to assess the relationship between each TCI score and Change-N1 values.

3. Results

Fig. 1 illustrates the scalp topography, neural origin, and time course of Change-N1 (Fig. 1B–D). When it is recorded using MEG, the isocontour map at the Change-N1m peak shows a clear dipolar pattern suggesting an intracellular current directed to the mastoid region. ECDs were estimated to be located in the supratemporal plane of both hemispheres (Fig. 1E). This suggests that a bipolar recording between the frontal and mastoid regions is suitable to detect Change-N1 when it is recorded using EEG. Because of the mediolateral direction of the current, the EEG activity of both hemispheres summates at midline regions. Therefore, the scalp distribution shows the maximal response at Fz (Fig. 1B).

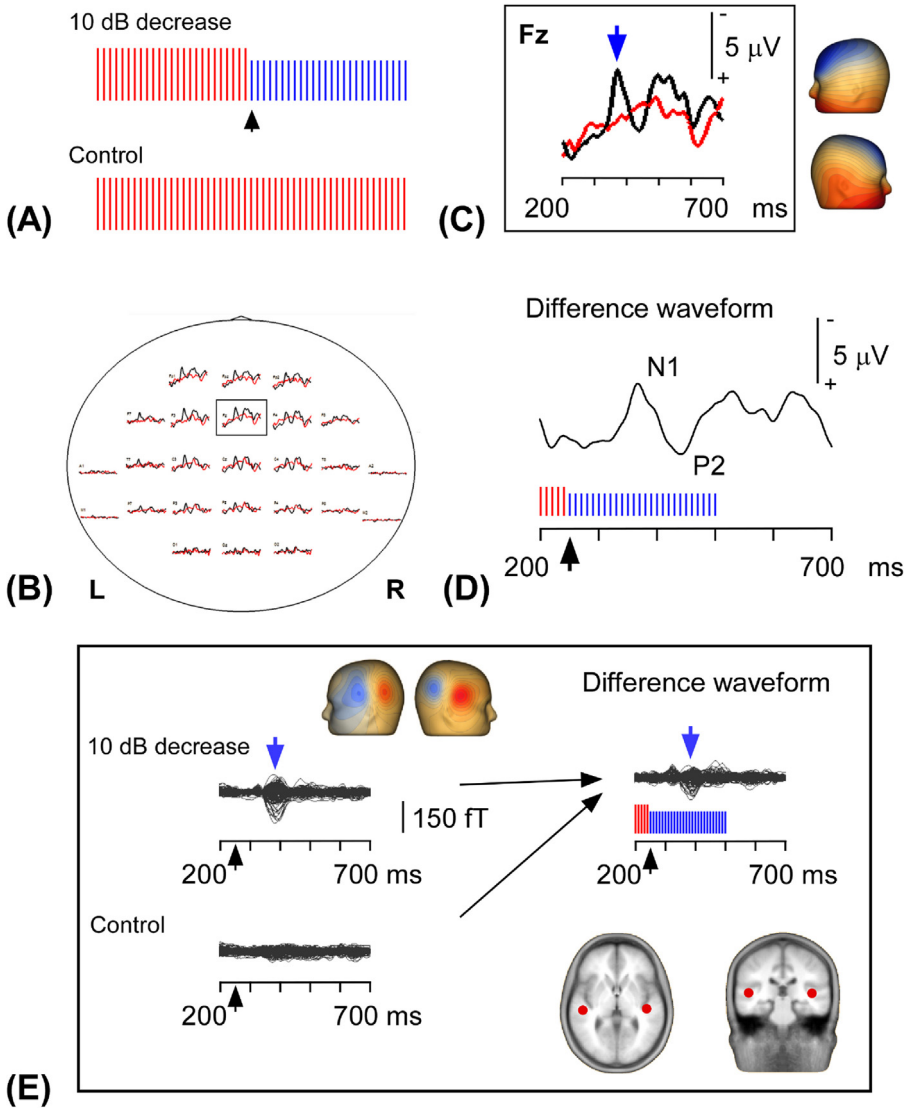

Fig. 1. Change-N1 responses to an abrupt decrease in sound pressure. A. The two sound stimuli (500 ms in duration) used in this study. B. Evoked potentials (referred to the linked mastoids) elicited by the sound-decrease stimulus (black line) and by the control stimulus (red line) recorded from 25 electrodes in a representative subject. C. Enlarged evoked potentials of the Fz electrode indicated by a square and an isocontour map of the peak latency (blue arrowhead). D. Difference waveforms between evoked potentials elicited by an abrupt decrease in sound pressure and those elicited by the control stimulus. E. Magnetic evoked fields in a representative subject. Superimposed waveforms from 204 gradiometers and isocontour maps at the peak of Change-N1m. Equivalent current dipoles of Change-N1m are plotted in the standard brain. In this and the following figures, red and blue bars indicate click sounds at 60 dB and 50 dB, respectively. Black and blue arrowheads indicate the time points of the abrupt decrease in sound pressure and Change-N1m peaks, respectively.

3.1. Test–retest reliability

An abrupt decrease in sound pressure evoked clear Change-N1 peaking at approximately 120 ms in each subject. The mean peak amplitudes of Change-N1 for the first and second sessions were 6.9 ± 2.1 μV and 6.5 ± 2.2 μV, respectively. The mean latencies for the first and second sessions were 122.4 ± 12.6 ms and 120.7 ± 9.7 ms, respectively. Fig. 2A shows grand-averaged waveforms of the two sessions. Fig. 2B shows the scatter plots for the Change-N1 amplitude in the second session (y-axis) against that observed in the first session (x-axis) for all of the subjects. Both the slope of the regression line ($y = 0.88x + 0.4$) and the coefficient ($r^2 = 0.72, p < 0.001$) indicated a good reproducibility for Change-N1.

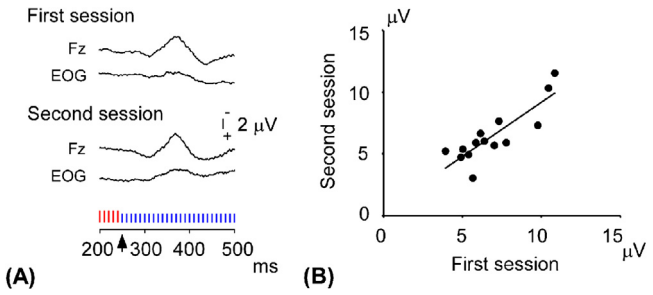

Fig. 2. Test–retest reliability of Change-N1. A. Grand-averaged Change-N1 waveforms in the two sessions. A black arrowhead indicates the onset of the decrease in sound pressure. B. The horizontal and vertical axes indicate the Change-N1 amplitude for the first and second sessions, respectively.

3.2. V-component of the ABR to the sound-decrease stimuli

As shown in Fig. 3, the ABR V-waves to the sound-decrease stimuli were clearly identified in all three subjects tested. In

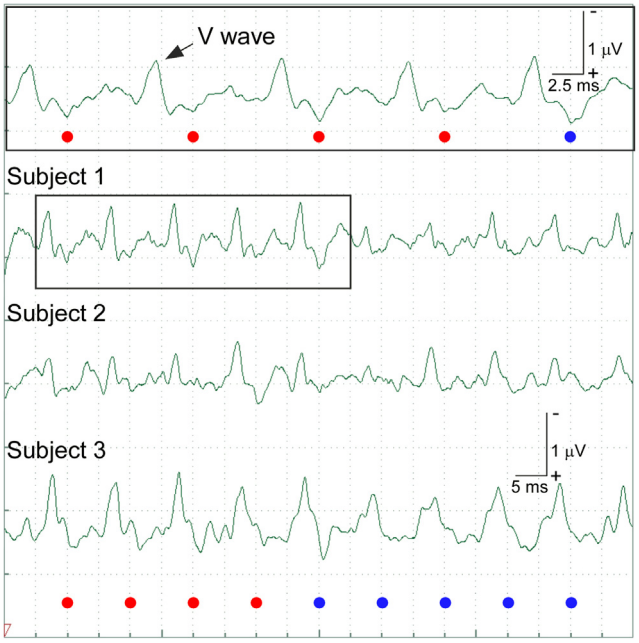

Fig. 3. ABRs ($n = 3$) elicited by the sound-decreased stimulus. ABR waveforms of each of the three subjects and a part of the waveform with a twice-expanded time axis in one subject (rectangle) are shown. The sound stimuli were standard clicks (60 dB, red dots) followed by deviant click sounds (50 dB, blue dots).

the individuals, the peak-to-peak amplitudes of the ABR V-wave elicited by each click sound before an abrupt change in sound pressure were higher than those after an abrupt decrease in sound pressure. The mean data for the peak-to-peak amplitude of the ABR V-wave observed before and after the change onset, averaged across subjects, were 0.73 ± 0.23 and 0.56 ± 0.18 μV, respectively.

3.3. Change-N1 and personality traits

There was no significant gender difference in the mean age (females, 26.9 ± 5.1 years; males, 26.2 ± 5.1 years), Change-N1 amplitude (females, 6.9 ± 2.9 μV; males, 6.0 ± 2.1 μV; $p = 0.14$, $r = 0.17$) or Change-N1 latency (females, 119.8 ± 11.6 ms; males, 125.8 ± 11.4 ms, $p = 0.09$, $r = 0.22$). The scores for the four temperaments and three characters of the TCI for the 63 subjects are indicated in Table 1. There was no significant gender difference in each dimension score.

Fig. 4 shows the scatter plots of the Change-N1 amplitudes against the HA and SD scores. Since a meta-analysis of the gender differences in TCI dimensions showed that females scored higher in HA than males (Miettunen et al., 2007), in our subsequent analysis, we included gender in the partial correlation analysis models (Table 2). We observed a significant correlation between the HA and

Table 1
Scores for TCI dimensions in the 63 subjects.

Variables	Total	Gender differences	
	($n = 63$)	Female ($n = 14$)	Male ($n = 49$)
Novelty seeking (20–80)	50.2 (7.7)	50.1 (7.2)	50.3 (7.9)
Harm avoidance (20–80)	52.7 (8.7)	56.3 (9.7)	51.7 (8.2)
Reward dependence (15–60)	42.3 (5.3)	42.6 (2.8)	42.2 (5.9)
Persistence (5–20)	13.6 (2.4)	13.6 (2.4)	13.7 (2.4)
Self-directedness (25–100)	69.0 (11.2)	67.1 (10.8)	69.6 (11.3)
Cooperativeness (25–100)	76.3 (8.5)	77.5 (4.4)	75.9 (9.4)
Self-transcendence (15–60)	27.1 (7.2)	29.4 (9.8)	26.4 (6.3)

Data are mean ± SD.

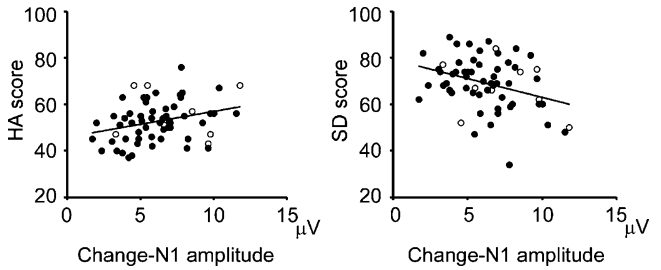

Fig. 4. Relationship between the Change-N1 amplitude and the score of harm avoidance and self-directedness. Plots for males ($n = 49$, closed circles) and females ($n = 14$, open circles).

SD scores ($p < 0.001$; $r = -0.47$). No other correlations among the four temperamental dimensions or the three character dimensions were found. The Change-N1 amplitude was positively correlated with the HA scores ($p < 0.03$; $r = 0.29$) and negatively correlated with the SD scores ($p < 0.05$; $r = -0.27$). No significant correlations were found between the Change-N1 amplitude and the other TCI dimensions. The latency of Change-N1 did not correlate with any of the TCI dimension scores.

4. Discussion

The present results indicate that the Change-N1 amplitude is positively correlated with the HA score and negatively correlated with the SD score, but not correlated with the scores of the other TCI dimensions (NS, RD, P, C and ST). It thus seems possible that specific personality traits might affect the sensitivity in an individual's change-detection system.

We observed high test–retest reliability in the Change-N1 (Fig. 2) in accord with our previous AEF studies (Otsuru et al., 2012; Inui et al., 2012; Kodaira et al., 2013). As shown in a preliminary ABR recording (Fig. 3), the amplitude of the ABR V-wave was attenuated after the abrupt decrease in sound pressure without additional evoked potentials explaining the Change-N1 response at the brainstem level. In general, the V-wave is considered to originate from the lateral lemniscus or the inferior colliculus. This finding was confirmed in an AEF study (Parkkonen et al., 2009). Thus, the lower level of the ascending auditory pathway (from the cochlear nerve up to the brainstem) was not considered to be involved in the activation of the Change-N1 elicited by an abrupt decrease in sound pressure. Based on these findings, we propose that the Change-N1 elicited by an abrupt decrease in sound pressure is a stable index of a higher-order brain function reflecting the brain's ability to respond to sensory events.

In the present study, individuals with a high amplitude of Change-N1 showed a high HA score. Cloninger et al. (1993), in their psychobiological model of temperament and character, suggested that HA is stable throughout life and represents a heritable tendency in an inhibitory response to adverse stimuli. Individuals with high HA scores are characterized as tense, apprehensive, fearful and shyness. Additionally, our subjects with high amplitude Change-N1 values showed low scores for SD (one of the character dimensions), which matures in adulthood. In line with previous studies (Jiang et al., 2003; Jylhä and Isometsä, 2006; Celikel et al., 2009; Yasui-Furukori et al., 2013), we observed a significant correlation between HA and SD scores in the present study. In medical students, high HA scores and low SD scores were linked with a tendency to experience anxiety (Jiang et al., 2003). Since the change-detection system seems to be a defensive mechanism for survival, it was natural that our subjects with high anxiety or a tendency to be depressed had a sensitive change-detection system.

Table 2
Partial correlation coefficients between the subjects' Change-N1 values and their TCI scores, controlling for gender.

	N1 amplitude			N1 latency		
	R	*df*	*p*-Value	*R*	*df*	*p*-Value
Novelty seeking	0.22	60	0.87	0.07	60	0.60
Harm avoidance	0.29	60	<0.03	−0.20	60	0.13
Reward dependence	0.15	60	0.24	0.10	60	0.45
Persistence	0.02	60	0.87	−0.13	60	0.31
Self-directedness	−0.27	60	<0.05	0.13	60	0.32
Cooperativeness	−0.14	60	0.29	0.09	60	0.51
Self-transcendence	0.23	60	0.07	0.10	60	0.43

Similar to the Change-N1, mismatch negativity (MMN) is a well-established tool that reflects preattentive auditory processing (Näätänen et al., 2007). To our knowledge, only two studies reported the relationship between mismatch response and TCI dimension scores. In agreement with the present results, Hansenne et al. (2003) observed a positive correlation between the MMN magnitude and the HA score. An AEF study reported that the P, RD and C dimensions were associated with MMNm values (Matsubayashi et al., 2008). One of the reasons for this discrepancy may be differences in the sound paradigm and the recording method (AEP/AEF).

Our previous AEF studies showed that sudden changes in a continuous sound including the onset and offset of a sound (Yamashiro et al., 2009, 2011), sound feature changes in sound frequency (Yamashiro et al., 2011), sound location (Akiyama et al., 2011) and in sound pressure (Otsuru et al., 2012) all activated a similar region in the superior temporal gyrus (STG). For instructive purposes, an example of the Change-N1m elicited by the same stimulus paradigm used in the present study is depicted in Fig. 1E. We consider that a group of neurons in the STG works as a real-time sensory gate to detect changes in auditory information (Inui et al., 2010b). A recent study using functional magnetic resonance imaging reported that patients with anxiety exhibited increased activity in the STG (Zhao et al., 2014). In a meta-analysis, the STG was confirmed as one of the most frequently identified regions involved in the pathophysiology of depression (Fitzgerald et al., 2008).

In a general population, high HA and low SD scores were associated with a tendency for depression as well as anxiety (Jylhä and Isometsä, 2006). A decrease in the serum BDNF levels, which is associated with anxiety and depression, was positively correlated with HA scores (Minelli et al., 2011; Yasui-Furukori et al., 2013) and negatively correlated with SD scores (Yasui-Furukori et al., 2013) in normal healthy subjects. Wachleski et al. (2008) reported that patients with panic disorder presented higher HA and lower SD scores than normal controls. In a meta-analysis, HA was clearly associated with depression (Kampman and Poutanen, 2011). Celikel et al. (2009) proposed the possibility that the combination of high HA and low SD is specific to depression. The present results show that Change-N1 would be a biomarker of anxiety/depressive states, but further research is needed to clarify the relationship between psychiatric diseases and the change-detection system.

A limitation of this study is the small sample size with the unbalanced gender distribution. As shown in Fig. 3, the Change-N1 amplitude appears to correlate with HA and SD scores in both genders. In light of the gender difference shown in a meta-analysis (Miettunen et al., 2007), we used a partial correlation analysis controlling for gender in the present study.

In conclusion, we first found that the auditory Change-N1 could be used as an index for the change-detection system, which is stable and reflects intrinsic brain function in individuals. We then examined the relationship between Change-N1 values and personality traits assessed by the TCI. The Change-N1 amplitude was positively correlated with HA scores and negatively correlated with SD scores in normal volunteers. Specific personality traits, probably anxiety- and depression-related, might affect the sensitivity of the change-detection system.

Conflict of interest

The authors declare no conflict of interest.

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