AFTERMATH OF 3/11:
A PILOT STUDY ON THE RELATIONSHIP BETWEEN INDIRECT EXPOSURE TO EARTHQUAKES AND AUDITORY ATTENTION

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The present study investigated the relationship between mental stress by indirect exposure to earthquakes and the auditory attention. In a previous study, we recorded event-related brain potentials during an auditory oddball paradigm from young adults who live in the areas affected by the Great East Japan Earthquake and a following long-term earthquake swarm. The results showed that earthquake-induced mental stress is positively related to the deviant P3a, indicating a relationship between mental stress and a heightened involuntary attention. In contrast, the present study showed that, for young adults (n = 13) who live outside the earthquake-affected areas and have been indirectly exposed to earthquakes (e.g., through the media), earthquake-induced mental stress is not related to the deviant P3a. Although the present data are preliminary given the small sample size, the clear contrast supports the view that the heightened involuntary attention would be specific to people who have directly experienced earthquakes.

Key words: earthquake, indirect exposure, mental stress, involuntary attention, voluntary attention, auditory ERP

INTRODUCTION

On 11 March 2011, the Great East Japan Earthquake (=magnitude 9.0) struck vast areas on the Pacific side of northeastern Japan. It was followed by a long-term earthquake swarm, in which about 600 earthquakes (>magnitude 5.0) repeatedly struck these areas over the next year (Japan Meteorological Agency, 2012a, 2012b). People living in the earthquake-affected areas were continuously exposed to alarming events and many of them are considered to have developed mental stress, even though they do not always manifest clinically-diagnosable symptoms such as posttraumatic stress disorder (PTSD; Kotozaki & Kawashima, 2012; Sekiguchi et al., 2013).

Concurrent with the prolonged earthquake swarm, reports detailing intriguing subjective experiences appeared in social media. These reports indicated that many people living in the affected areas feel that, since the 3/11 earthquake, they are becoming
abnormally sensitive to sudden background noises that they often hear in their everyday lives (e.g., the sound of construction work and the sound of the washing machine on spin cycle). The people who live in the affected areas (including the authors and their neighbors) have actually experienced such abnormal sound sensitivity, but few of them have complained of obvious clinically-diagnosable symptoms. Therefore, this abnormal sensitivity seemed likely to reflect a phenomenon that emerged in a large majority of clinically-normal people living in the affected areas.

This phenomenon motivated us to investigate the relationship between earthquake-induced mental stress and the auditory attention, namely the involuntary orienting of attention to sudden, task-irrelevant sounds (Kimura, Ueda, Takeda, Sugimoto, & Katayama, 2013). From 20 October to 2 December 2011, we recorded event-related brain potentials (ERPs) during an auditory oddball paradigm from clinically-normal young adults living in the affected areas (i.e., 29 graduate and undergraduate university students living in Tsukuba city or the surrounding area, which is located about 300 km from the epicenter of the Great East Japan Earthquake). The oddball paradigm consisted of a standard stimulus (1800 Hz tone), a target stimulus (2000 Hz tone), and deviant stimuli (a variety of sudden, task-irrelevant sounds). We examined the relationship between attention-related ERPs and earthquake-induced mental stress as indexed by the Japanese version of the Impact of Event Scale-Revised (IES-R; a self-report questionnaire designed to measure current subjective distress in response to a specific traumatic event, Asukai et al., 2002; for the original version, Weiss & Marmar, 1997). The results showed that (1) the magnitude of P3a (Courchesne, Hillyard, & Galambos, 1975; Squires, Squires, & Hillyard, 1975) elicited by deviant stimuli was positively related to the degree of mental stress as indexed by the hyperarousal subscale score of the IES-R, while (2) the magnitude of P3b (Sutton, Braren, Zubin, & John, 1965) elicited by target stimuli was not significantly related to the degree of mental stress. The P3a is an electrophysiological reflection of the involuntary orienting of attention to task-irrelevant information, while the P3b is an electrophysiological reflection of the voluntary allocation of attention to task-relevant information (Näätänen, 1990; Soltani & Knight, 2000). Thus, these results suggest that (1) mental stress is closely related to a heightened involuntary orienting of attention to sudden, task-irrelevant sounds, while (2) the voluntary allocation of attention to task-relevant sounds has remained rather intact regardless of the degree of mental stress.

While our previous study shed light on the relationship between mental stress and auditory attention, it is totally unclear whether this relationship is specific to people who live in the earthquake-affected areas or it can be generalized to people who live outside the earthquake-affected areas and have indirectly experienced earthquakes (e.g., through the media). This question is not trivial, since several studies have suggested that even indirect exposure to traumatic events can act as a low-impact trauma and result in mental health problems (Neria & Sullivan, 2011; Schlenger et al., 2002; Silver, Holman, McIntosh, Poulin, & Gil-Rivas, 2002; Zimering, Gulliver, Knight, Munroe, & Keane, 2006). For example, indirect exposure to the September 11 attacks via television was associated with an increased risk of PTSD symptoms (Schlenger et al., 2002). In the present study, we conducted a pilot test to examine the relationship between mental stress and auditory
attention in young adults who live outside the earthquake-affected areas and have been indirectly exposed to earthquakes, by using the same experimental protocol as in our previous study (Kimura et al., 2013).

METHODS

This study was conducted from 19 January to 27 February 2012, which was approved by the Kwansei Gakuin University (KGU) Research Ethics Review Board under the KGU Regulations for Research with Human Participants.

Participants
Fourteen undergraduate and graduate students of Kwansei Gakuin University who live outside the earthquake-affected areas (i.e., Hyogo and the surrounding prefectures) participated in this study. The data from one participant were excluded from the analysis because of excessively high scores in the IES-R (total score: 81 points), which left 13 participants (5 women, 8 men; age range = 19–23 years, mean = 21.0 years). Ten participants were right-handed and three were left-handed. All participants reported normal hearing. Written informed consent was obtained from each participant after the nature of this study had been explained and her/his rights as experimental subjects were protected. Hyogo prefecture is located about 750 km from the epicenter of the Great East Japan Earthquake. Therefore, the physical shockwave of the Great East Japan Earthquake was fairly weak and the subsequent long-term earthquake swarm had little to no effects at this distance (Japan Meteorological Agency, 2012b). As is well known, on 17 January 1995, Hyogo and the surrounding prefectures were severely affected by the Great Hanshin Earthquake. However, this disaster is considered to have very little or no effects on the present participants, because out of the present 13 participants, 7 had not been born yet, 2 had been born but lived in different areas, and 4 had been born and lived in Hyogo or the surrounding prefectures but had no explicit memory about the disaster due to their ages (1–2 years). Based on the program listing in Hyogo prefecture, television programs associated with the earthquake disaster were still fairly frequent during the experimental period (on average, about seven programs per day, for two months from January to February 2012).

Prior to the auditory oddball experiment, the participants completed the Japanese version of the IES-R; the IES-R was explicitly anchored to the earthquake. The IES-R consists of 22 items measured on a five-point Likert scale (from 0 to 4 points) that are categorized into three subscales representative of the major symptom clusters of PTSD: intrusion (8 items), avoidance (8 items), and hyperarousal (6 items). Thus, the IES-R provides a total score (possible range: 0–88 points) and three subscale scores for intrusion (0–32 points), avoidance (0–32 points), and hyperarousal symptoms (0–24 points). In the present study, total IES-R scores of the 13 participants ranged from 0 to 35 points, and thus the present sample was assumed to reflect a range from healthy individuals to those at mild risk for the development of PTSD (Asukai et al., 2002). Note that the total IES-R scores were roughly comparable to those of the participants in Kimura et al. (2013; i.e., from 0 to 40 points).

Stimuli and Procedure
The auditory oddball experiment consisted of six blocks, each consisting of 100 trials, in which four types of stimuli (standard, target, lower-frequency deviant, and higher-frequency deviant stimuli) were presented binaurally on stereo headphones (SENNHEISER, HD265). The standard stimulus was an 1800 Hz pure tone (number of trials per block = 70 times; A-weighted sound level ($L_{Aeq}$) for 10 s = 65 dB). The target stimulus was a 2000 Hz pure tone (10 times; 65 dB). The lower-frequency deviant stimulus category consisted of five types of sounds with fundamental frequencies between 100 and 300 Hz (subway, airplane, truck, washing machine, and compressor; 2 times each; 80 dB). The higher-frequency deviant stimulus category consisted of five types of sounds with fundamental frequencies between 700 and 1000 Hz (vacuum cleaner, rain, cicada, printer, and tapping machine; 2 times each; 61 dB). Note that we used these two categories of deviant stimuli based on a consideration of the degree of similarity to an “earthquake sound” (Michael, 2011). This sound is an underground rumbling in a low-frequency range that is usually heard immediately before the arrival of an actual physical shockwave of a quake; the frequencies of lower-frequency deviant stimuli were
close to audible frequencies of an earthquake sound, whereas the frequencies of higher-frequency deviant stimuli differed significantly from the frequencies of an earthquake sound. The different sound levels for the two categories of deviant stimuli were adopted to keep the sensation level of each stimulus approximately the same. The duration of each stimulus was 1000 ms (including rise and fall times of 5 ms each) and the stimulus onset asynchrony was 2000 ms. The order of trials was randomized, with two limitations: (1) at least five standard stimuli were presented at the beginning of each block and (2) at least one standard stimulus was presented between the target, lower-frequency deviant, and higher-frequency deviant stimuli. The participant was seated in a reclining chair in a sound-attenuated and electrically-shielded room and asked to press a mouse button with the right index finger as quickly and accurately as possible when the target stimulus was presented. They were also asked to try to keep their eyes open and minimize any eye movement and blinking during each block.

**Recordings**

The electroencephalogram (EEG) was recorded with a digital amplifier (NeuroScan, NuAmps amplifier) and silver-silver chloride electrodes placed at 21 scalp sites (Fp1, Fp2, F7, F3, Fz, F4, F8, FCz, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, Oz, and O2 according to the extended International 10–20 System). All electrodes were referenced to the nose tip. To monitor blinks and eye movements, the vertical and horizontal electrooculograms (EOGs) were also recorded with two electrodes above and below the right eye and two electrodes at the right and left outer canthi of the eyes, respectively. The impedance of all electrodes was kept below 10 kΩ. The EEG and EOG signals were digitized at a sampling rate of 1000 Hz and bandpass-filtered at 0.1–30 Hz (second-order Butterworth filter). Averaging epochs were 1100 ms featuring a 100-ms pre-stimulus baseline. In the averaging procedure, the first three epochs in each block, epochs with a response error, and epochs in which the signal changes exceeded ±100 μV on any of the electrodes were omitted. As a result, the averaging numbers for the standard, target, lower-frequency deviant, and higher-frequency deviant stimuli were, on average, 322, 50, 51, and 51 times, respectively.

**Data Analysis**

Behavioral performance was quantified in terms of reaction time (ms), hit rate (%), and false alarm rate (%). Responses were scored as a hit if the button was pressed within 200–2000 ms after the onset of a target stimulus, whereas responses were scored as a false alarm if the button was pressed within 200–2000 ms after the onset of standard, lower-frequency deviant, or higher-frequency deviant stimuli.

The amplitudes of P3a elicited by the lower- and higher-frequency deviant stimuli were quantified as the largest positive-going peak at the Cz electrode that occurred within the time window between 200 and 450 ms after stimulus onset, while the amplitudes of P3b elicited by the target stimulus were quantified as the largest positive-going peak at the Pz electrode that occurred within the time window between 250 and 600 ms after stimulus onset. The relationship between each ERP component and each IES-R score was assessed by a two-tailed Spearman’s rank correlation analysis. Because the relationship between the ERP amplitudes and the IES-R scores was assumed to be not necessarily linear, we chose Spearman’s rank correlation analysis. Because of the exploratory nature of the present study, no correction for multiple correlations was applied.

**RESULTS**

No participant exhibited obvious difficulty in performing the auditory oddball task. The mean reaction time was 506 ms ($SD = 88$), the hit rate was 96.5% (4.9), and the false alarm rate was 0.21% (0.15).

Fig. 1 shows the grand-average ERPs elicited by the standard, target, lower-frequency deviant, and higher-frequency deviant stimuli at four midline electrodes (Fz, Cz, Pz, and Oz). The lower- and higher-frequency deviant stimuli elicited P3a with a peak at 313 and 319 ms, respectively. The target stimulus elicited P3b with a peak at 397 ms. Fig. 1 also shows topographical maps taken at the peak latency of P3a for the lower- and higher-
frequency deviant stimuli and P3b for the target stimulus. The P3a elicited by both lower- and higher-frequency deviant stimuli had a central (Cz) maximum scalp distribution. The P3b elicited by the target stimulus had a parietal (Pz) maximum scalp distribution.

Fig. 2A shows scatter plots for the relationships between the peak amplitude of P3a elicited by the lower-frequency deviant stimuli (electrode: Cz) and the IES-R scores. The two-tailed Spearman’s rank correlation analysis revealed no significant relationship between P3a and the total IES-R (Spearman’s \( \rho = -.07, p = .81 \); left panel), the intrusion subscale (\( \rho = -.16, p = .60 \); central left panel), the avoidance subscale (\( \rho = .09, p = .76 \); central right panel), or the hyperarousal subscale scores (\( \rho = -.31, p = .30 \); right panel).

Fig. 2B shows scatter plots for the relationships between the peak amplitude of P3a elicited by the higher-frequency deviant stimuli (electrode: Cz) and the IES-R scores. The correlation analysis revealed no significant relationship between P3a and the total IES-R (\( \rho = -.01, p = .99 \); left panel), the intrusion subscale (\( \rho = -.11, p = .72 \); central left panel),
the avoidance subscale ($\rho = .12, p = .69$; central right panel), or the hyperarousal subscale scores ($\rho = -.26, p = .40$; right panel).

Fig. 2C shows scatter plots for the relationships between the peak amplitude of P3b
elicited by the target stimuli (electrode: Pz) and the IES-R scores. The correlation analysis revealed no significant relationship between P3b and the total IES-R score ($\rho = -0.44, p = .13$; left panel). For the subscale scores, P3b was significantly related to the intrusion subscale score ($\rho = -0.56, p < .05$; central left panel), but not to the avoidance subscale score ($\rho = -0.28, p = .35$; central right panel) or the hyperarousal subscale score ($\rho = -0.52, p = .07$; right panel).

**DISCUSSION**

The present study did not find any significant relationship between earthquake-induced mental stress and the magnitude of P3a in response to either lower- or higher-deviant stimuli. These results imply that, for young adults who live outside the earthquake-affected areas, the involuntary orienting of attention to sudden, task-irrelevant sounds is not strongly associated with the degree of mental stress. This is in clear contrast to our previous finding with young adults living in the earthquake-affected areas that mental stress, as indexed by the hyperarousal subscale score of the IES-R, was positively related to the magnitude of P3a in response to both lower- and higher-deviant stimuli (Kimura et al., 2013). Given the relatively small sample size in the present study, the lack of significant effects should be interpreted cautiously. However, as can be seen in Figs. 2A and 2B, there was not even a slight sign of such a positive relationship between the magnitude of P3a and the hyperarousal subscale score of the IES-R (please compare to Figs. 2A and 2B in Kimura et al., 2013). Taken together, the present P3a result leads to the notion that the relationship between mental stress and a heightened involuntary orienting of attention to sudden, task-irrelevant sounds would be specific to people who have directly experienced a number of earthquakes. This notion is consistent with the idea that the stress-related enhancement of involuntary attentional orienting may be a type of adaptive biological reaction that facilitates rapid detection of potential dangers (Attias, Bleich, Furman, & Zinger, 1996; Kimble, Kaloupek, Kaufman, & Deldin, 2000).

Unexpectedly, the present study also showed that mental stress, as indexed by the intrusion subscale score of the IES-R, was negatively related to the magnitude of P3b in response to target stimuli. This result may imply that, for young adults who live outside the earthquake-affected areas, the degree of mental stress is related to a reduced voluntary allocation of attention to task-relevant sounds. It has been reported that PTSD is sometimes accompanied by a reduced voluntary allocation of attention (Charles et al., 1995; McFarlane, Weber, & Clark, 1993; Metzger, Orr, Lasko, & Pitman, 1997). However, the present P3b result is clearly in contrast to our previous finding with young adults living in the earthquake-affected areas that there was no sign of a significant relationship between mental stress and the magnitude of P3b (Kimura et al., 2013). One may argue that this relationship is very unlikely, since the relationship was not observed even for young adults in the earthquake-affected areas. We consider two possible explanations. First, this relationship may be simply a Type I error; the statistical analysis without corrections for multiple correlation did not allow us to rule out this possibility. Second, this relationship might truly represent
a phenomenon that can emerge more obviously in people who live outside the earthquake-affected areas. For example, while the main cause of mental stress in people who live in the earthquake-affected areas is supposed to be their own life-threatening experiences, the main cause of mental stress in people who live outside the earthquake-affected areas is supposed to be the thought of others’ life-threatening experiences. Such a qualitative difference in the main cause may explain the emergence of the relationship only in people who live outside the earthquake-affected areas. That is, intrusion symptoms attributable to the thoughts of others’ life-threatening experiences may specifically relate to the functioning of the voluntary allocation of auditory attention (for suggestive findings, see Caska & Renshaw, 2013; Gurrera, O’Donnell, Nestor, Gainski, & McCarley, 2001; Gurrera, Salisbury, O’Donnell, Nestor, & McCarley, 2005; Jakšić, Brajković, Ivezic, Topić, & Jakovljević, 2012; Reynaud, Khoury-Malhame, Rossier, Blin, & Khalifa, 2012). However, any conclusions require more reliable examination with a larger sample size.

CONCLUSIONS

For people who live outside the earthquake-affected areas and have been indirectly exposed to earthquakes through the media, earthquake-induced mental stress was not significantly related to a heightened involuntary orienting of attention to sudden, task-irrelevant sounds. This is in clear contrast to our previous finding with people who live in the earthquake-affected areas and have been directly exposed to a number of earthquakes. Although the present data are very preliminary, given the small sample size, the clear contrast supports the view that the heightened involuntary attention would be specific to people who have directly experienced earthquakes.

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