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Involuntary attention restoration during exposure to mobile-based 360° virtual nature in healthy adults with different restorative experience: an event-related potential study

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Abstract

Background: Coincident with the global trend of urbanization, a possible association between decreased exposure to nature and increased occurrence of mental disorders has increasingly been reported. Beyond spatial and temporal limitations, new 360° VR technology using one’s own smartphone and portable VR glasses allows modern people to deal with mental fatigue in everyday life.

Objective: Based on Attention Restoration Theory (ART), the current study investigates whether the amplitude of the MMN/P3a complex can act as a potential ERP biomarker of involuntary attention restoration during exposure to 360° virtual nature in healthy young adults with different levels of restorative VR experience.

Methods: A total of 40 healthy adults completed pre-questionnaires on demographics and simulator sickness and post-questionnaires on simulator sickness and perceived restorativeness before and after exposure to virtual nature, respectively. During the VR exposure, their brain activity was measured with EEG (Electroencephalography) by asking participants to conduct a two-tone auditory passive oddball task.

Results: Both amplitude and latency of the MMN/P3a complex between the two between-subject groups were compared. While viewing a nature virtual environment (VE), the high restorative group (N = 19) exhibited significantly reduced P3a amplitudes than the low restorative group (N = 20) did, t (38) = 2.57, P = .02, d = .59. Particularly, a moderate, but significantly negative correlation was found between the self-reported perceived restorative scores and the P3a amplitudes at the fronto-central region (FCz; r = -.38, P = .02). The outcome of 360° virtual nature experience seems to be consistent with that of previous ERP studies on the during-effect of meditation practice. However, the latency of the MMN/P3a complex did not significantly differ between the two restorative groups: (1) aMMN: t (38) = - 1.47, P = .15; (2) P3a: t (38) = - .31, P = .76.

Conclusions: These findings of this study will extend those of previous ART and ERP studies on meditation, restoration, and the management of mental fatigue in the real world into the virtual world via . Considering individuals' restorative experience, the amplitude of the fronto-central MMN/P3a
complex can be potentially employed as a distinct ERP component of interest in involuntary attention restoration during virtual nature experience in healthy young adults.

**Keywords:** 360° VR; virtual nature experience, involuntary attention, attention restoration theory, simulator sickness, perceived restorativeness, during-effect, ERP, MMN/P3a complex amplitude

**Introduction**

From the perspective of ART [1], exposure to “nature” serves as a vital ingredient in healthy human functioning, contributing to replenishing depleted attentional resources. Involuntary attention, later called “Fascination”, is a central component of a restorative experience. While involuntary attention requires no effort and is resistant to fatigue, directed or focused attention requires the capacity to sustain attention that can become depleted by taxing task demands, leading to stress responses or impaired performance [1-3]. Individuals’ depleted attentional resources can be rapidly restored by using involuntary attention and allowing directed attention to be in the resting state [4]. Fascination ranges along a continuum from “soft” to “hard” fascination [1]. Soft-fascinating activities (e.g., walking in a park or seeing a sunset) are moderate, sufficient to effortlessly hold one’s attention for mental reflection and aesthetically pleasant to help offset the pain accompanying reflection on serious matters; hard-fascinating activities (e.g., sports or entertainment) that fill the mind rivet intensely one’s attention in an all-consuming fashion, leaving little or no room for mental reflection [1, 5]. A stream of hard-fascinating environmental events is merely considered as an incoherent collection of impressions, not a restorative experience [1]. That is why such peaceful and moderate nature experience coupled with aesthetic pleasure fosters a fully or more deeply restorative experience than sports/entertainment experience does.

Despite the cognitive benefits of interacting with nature, it becomes difficult for modern people ranging from students to workers to deal with mental fatigue at the right time due to their spatial,
temporal, and social constraints. Prolonged mental effort results in directed attention fatigue [1]. Coincident with the global trend of urbanization, recent studies have consistently reported evidence of a possible link between decreased exposure to nature and increased occurrence of mental disorders [6-8]. Not only does direct contact with nature, such as walking in natural environments [9-11] and bringing plants and flowers into residential and office environments [12], lead to recovery from attentional fatigue and improvement in cognitive performance, but people who suffer from directed attention fatigue can also benefit from indirect contact with nature such as viewing nature through a window [13] or viewing videos or pictures of natural environments [14, 15]. No matter how direct or indirect exposure to nature is, the main point is that modern people need to be provided with more opportunity to access nature and time to reflect on their everyday life in a timely manner. In this context, VR nature exposure therapy can be a promising therapeutic alternative for individuals vulnerable to cognitive overload and at higher risk of mental illness.

Recent ART studies using an ERP method have yet to be conducted to examine the during-effect of contact with real nature and even virtual nature. Compared to self-rating methods, the ERP technique has the advantage of recording objective, electrophysiological signals simultaneously while performing the given tasks. Most ART studies have measured the restorative effect of natural environments on “voluntary” attention with subjective, self-report measures such as the Perceived Restorativeness Scale (PRS) [16] and objective, behavioral responses to cognitive tests, particularly not during but immediately after nature exposure. According to the ERP findings of the during-effects of meditation, the mean auditory MMN (aMMN) amplitude of long-term mediators was larger than that of non-mediators, elucidating that the tendency of more reduced aMMN amplitude resulted from auditory fatigue or cognitive overload [17]. Cahn and Polich [18] revealed that participants, who reported more hours of daily meditation practice, produced the strongest meditation-induced decrease in P3a amplitude. Given that the P3a reflects frontal cortical activity elicited by the engagement of focal attentional system [19], the reduced P3a amplitude may reflect the disengagement of attentional networks to stimulus-driven activation during meditation, thereby meeting the goal of meditation to decrease brain reactivity to attention-demanding stimuli as well as evaluative cognitive processing.
Unlike the P3a, it is less likely to expect a significant decrease in the aMMN amplitude since the aMMN is not affected by what content people see and how immersive visual tasks (from a traditional reading task to a VR task) are [20]. In fact, the modulation of ERP amplitudes during meditative or restorative activities remains still unclear due to the lack of further investigations in applied ERP research settings. Furthermore, either “aMMN” or “P3a” has been separately investigated, and inconsistent experimental protocols were employed in previous ERP studies on meditation.

To our knowledge, the current study will be the first study to demonstrate a potential role of the amplitude of the “MMN/P3a complex” [21-23] reflecting involuntary attention restoration during exposure to restorative nature VEs in healthy young adults with different levels of restorative experience. Considering the previous outcomes of ERP amplitude changes during meditative activities [17, 18], it can be postulated that ERP amplitudes during exposure to 360° virtual nature will exhibit a similar pattern. However, we hypothesize that compared to people with a low level of restorative experience, those with a high level of restorative experience will show a significant reduction in P3a amplitude, not in aMMN amplitude due to its pre-attentive nature both in the real world [24] and the virtual world [20]. We further hypothesize that there will be a negative correlation between self-reported PRS scores and P3a amplitudes.

**Methods**

**Participants**

Forty healthy volunteers (22 males and 18 females), aged 19 to 36 years ($M = 23.78, SE = .56$), signed and provided written informed consent forms approved by the Institutional Review Board of Gangnam Severance Hospital, Yonsei University College of Medicine. All participants had normal or corrected-to-normal vision and no hearing and color-vision impairments, and none of them reported brain lesions and previous history of neurological or psychiatric disorders including any current use of psychotropic medications. Out of 40 enrolled participants, 38 were right-handed (95 %), 1 was
ambidextrous (2.5 %), and 1 was left-handed (2.5 %), as identified by the Edinburgh Handedness Inventory [25].

**Visual stimuli**

As presented in Figure 1A, a “restorative” nature 360° VE (retrieved from https://www.youtube.com/watch?v=PVaHQADhXgg) consists of a variety of seaside, grassland, and hill locations abroad. To confirm that the nature VE (with soft fascination) are more restorative than entertainment VEs (with hard fascination), three different fireworks VEs (see Figure 1B), as one of the most world-famous, attention-drawing entertaining events, were additionally collected with the nature VE from Google’s YouTube: fireworks 1 (retrieved from https://www.youtube.com/watch?v=WDGxepzOILE&t=18s), fireworks 2 (retrieved from https://www.youtube.com/watch?v=G2KqHBPMYzM&t=153s), and fireworks 3 (retrieved from https://www.youtube.com/watch?v=qEgL8umN1w4&t=13s). In line with the finding that the only initial 5-min dose of a total of 10-min exposure to nature images yielded significantly different physiological responses [15], all the 4K 360° VR videos were edited to the same running time of 5 min 53 sec with the same resolution of 3840 × 1920 pixels.

**Apparatus**

In this experiment, auditory stimuli were delivered to participants via MDR 1A headphones (Sony, Tokyo, Japan) on an OptiPlex 7040 Mini Tower PC (Dell, Round Rock, TX, USA) while focusing their attention on the given VR tasks. The experimental paradigm was programmed and presented using E-Prime v.2.0 software (PST: Psychology Software Tools Inc., Pittsburgh, PA, USA) with PST’s E-Prime Extensions for Net Station (EENS) v.2.0. EEG data were recorded and analyzed with the GES 400 system (EGI: Electrical Geodesics Inc., Eugene, OR, USA): a Net Amps 400 amplifier, a 64-channel HydroCel™ Geodesic Sensor Net (HCGSN), and Net Station v.5.4 software (i.e., Net Station Acquisition/Review/Tools) run by an Apple’s MacBook Pro (Apple Inc., Cupertino, CA, USA).
A mobile VR system (LG Electronics, Seoul, South Korea) consisted of a LG G5 smartphone and LG 360 VR glasses (960 × 720 pixels at 639 ppi per eye) only compatible with each other. In terms of comfort and wearability, the LG 360 VR (164.1 × 185.6 × 45.9 mm; 134.3 g) were more appropriate to be employed in this experimental setting than the Samsung Gear VR released in 2015 (201.9 × 116.4 × 92.6 mm; 318 g headset only) whose total weight was increased up to approximately 480 g including the weight of a smartphone. The LG’s VR glasses did not press down heavily on the electrodes posited around a forehead, eyes, and ears during pilot tests. In order for 360° VR videos to be optimally displayed on VR glasses across each participant’s vision, all participants were guided to manually adjust focal length and inter-pupillary distance (i.e., IPD: the distance between the center of the pupils of the two eyes). After calibrating the VR glasses, they were taught how to control the VR display and how to find, play, and view 360° VR videos in its user interface.

**Experimental paradigm and visual task**

The current ERP study employed a two-tone auditory “passive” oddball paradigm in which frequent standard and infrequent deviant tones were presented on the probability of 75% (180 trials) and 25% (60 trials), respectively. Particularly, the 750-Hz standard and 1000-Hz deviant tones were randomly presented at 75 dB sound pressure level (SPL) for 100 ms, and the inter-stimulus interval (ISI) varied randomly between 1000 and 1300 ms. Accordingly, the experimental paradigm was designed not to exceed a maximum of 5 min 30 sec for preventing VR stimuli from ending before the auditory oddball paradigm completely ended.

While viewing silent 360° VR videos on a revolving chair, participants were not allowed to intentionally detect sound changes and identify the rare deviants from the frequent standards, thereby focusing only on the given visual tasks and ignoring all the visual-task irrelevant sounds and even any sudden noises in an EEG recording room. The presentation order of three fireworks VEs was randomly assigned, and the last was a nature VE.
Self-report measures

In the context of 360° VR environment, whether people’s restorative experience in nature VE were threatened by the simulator sickness will be determined. The Simulator Sickness Questionnaire (SSQ) [26] consists of a total of 16 items which measure the severity of three different groups of negative physical symptoms affected by the experience of mechanical simulators: nausea (7 items), oculomotor (7 items), and disorientation (7 items). All items are anchored from 0 (none) to 3 (severe). Following the recommendation of Kennedy, Lane [26], the SSQ was first administered to participants before performing VR tasks to rule out the possibility of already present symptoms and to measure the baseline physical condition (pre-exposure SSQ), and was then implemented immediately after viewing each 360° VE (post-exposure SSQ). In the current study, the Korean version of the SSQ was adopted from Min, Jeon [27].

According to Hartig, Kaiser [16], the current version of the PRS is composed of 26 items that measure the following five restorative factors: being away (5 items), fascination (8 items with 2 reversed items), coherence (all 4 reversed items), compatibility (5 items), and legibility (4 items). The PRS scale was administered to indicate how well the statements described participants’ restorative experience in different VEs using a 7-point scale (0 = not at all, 6 = completely) immediately after actively viewing each VE. To compute the total PRS score, the six items written in the negative direction were reversely coded, and then all the scores for 5 restorative factors were summed. In this study, the Korean version of the PRS scale was adopted from Yoo, Yeoun [28].

Electrophysiological data recording and analysis

During EEG recording, the analog signals were referenced to a single vertex electrode (Cz), filtered with a 0.01–400 Hz bandpass filter, and digitized at a sampling rate of 1,000 samples per second online. The impedance for all wet electrodes were kept below 30 kΩ in that the recommended threshold limit is 50 kΩ to ensure an optimal signal-to-noise ratio for the high-input EGI amplifier system [29].
For pre-processing EEG signals, all datasets were re-filtered with a 0.3–30 Hz band-pass filter off-line and segmented into epochs ranging from 100 ms before and 500 ms after the onset of each of the two stimulus conditions: (1) standard and (2) deviant. As a result of a timing test to assure the accuracy of auditory stimulus presentation in E-Prime and EENS, the data were offset by the average offset value of 16 ms. Following the automated algorithm of EGI’s Net Station Tools, such artifacts as eye-blinks, eye-movements, and bad channels were detected. If bad for greater than 20 percent of segments, the channel was marked bad for all segments. Based on the bad segment specification, segments were marked bad if they contained (1) more than 10 bad channels (Max–Min > 150 μV for the entire segments, with a moving average of 80 ms), (2) eye-blinks (Max–Min > 100 μV with a moving average of 80 ms), and (3) eye-movements (Max–Min > 55 μV with a moving average of 80 ms). Bad channel replacement was then performed. The data were averaged for individual participants and baseline-corrected from -100 ms to 100 ms, and then all participants’ data were grand-averaged. After that, all channels were re-referenced to average reference off-line.

Finally, the deviant–standard difference waves were computed to identify the presence of the MMN/P3a complex component. For a further statistical analysis, the values of adaptive mean of the aMMN and P3a amplitudes at the FCz electrode site were extracted from the difference waveforms within the following time windows: (1) aMMN: 150–250 ms and (2) P3a: 220–280 ms.

**Results**

**Manipulation check**

For a manipulation check, a one-way repeated measures analysis of variance (RM-ANOVA) was conducted to explore the effect of type of VE (i.e., VE with soft or hard fascination) on the perception of environmental restorativeness. There was a significant effect of VE type, $F (3, 117) = 27.18, P < .001$, $\eta_p^2 = .41$. All three Bonferroni-adjusted post-hoc comparisons in the PRS scores between one
nature VE and each of the three fireworks VEs were significantly different: (1) nature ($M = 101.25$, $SE = 3.91$) vs. fireworks 1 ($M = 69.97$, $SE = 3.57$), $P < .001$; (2) nature vs. fireworks 2 ($M = 77.15$, $SE = 3.93$), $P < .001$; (3) nature vs. fireworks 3 ($M = 81.08$, $SE = 3.85$), $P < .001$ (see Figure 1A and 1B). It was finally revealed that the soft-fascinating nature VE was perceived as more restorative than the averaged hard-fascinating fireworks VE ($M = 76.03$, $SE = 3.28$), $t (39) = 7.26$, $P < .001$, Cohen’s $d = .78$.

In an ERP analysis of amplitude modulation in the MMN/P3a complex, a significant difference in the P3a amplitude with exposure to the two different VEs was observed [$t (39) = -2.05$, $P = .048$, $d = .35$], not in the aMMN amplitude [$t (39) = .59$, $P = .56$]. During exposure to the soft-fascinating VE ($M = 1.67$, $SE = .30$), the significantly increased P3a amplitude in response to unexpected and distracting stimuli was elicited, compared to that of the hard-fascinating VE ($M = .91$, $SE = .17$) (see Figure 2A). However, no significant difference in the latency of the MMN/P3a complex was found between the two VEs [aMMN: $t (39) = -1.23$, $P = .23$; P3a: $t (39) = -.61$, $P = .54$].

In this respect, the nature VE stimuli were successfully manipulated to elicit participants’ restorative responses, both from subjective and neurophysiological measures. Furthermore, the possibility that the aMMN would not depend on attention was also found, and it is more likely that the amplitude of the MMN/P3a complex will be a potential candidate for reflecting involuntary attention restoration than that of the latency.

**Simulator sickness as a control variable**

To clarify the genuine restorative effect of exposure to virtual nature, a one-way RM-ANOVA for the self-ratings of simulator sickness before and after VR tasks was performed. As no significant difference in all five SSQ scores was found [$F (4, 156) = 2.42$, $P = .065$], it was confirmed that participants’ physical conditions did not vary with VR exposure time and stimuli.
Effect of group difference in perceived restorativeness on MMN/P3a complex modulation

To investigate the effect of individuals’ restorative experience during exposure to virtual nature on the MMN/P3a complex amplitudes, 40 participants were defined by a median split on the perceived restorativeness scale (median PRS score = 103) and divided into either a low restorative [If PRS ≤ 103, N = 21; M = 82.62, SE = 3.65] or a high restorative [If 103 < PRS, N = 19; M = 121.84, SE = 2.88] group.

The differences in the MMN/P3a complex amplitude between the two restorative groups were compared using an independent samples t-test. Whereas the group difference in individuals’ restorative experience failed to induce significantly different aMMN amplitudes [t (38) = .91, P = .37], the high restorative group (M = .92, SE = .30) showed significantly lower P3a amplitudes than the low restorative group (M = 2.36, SE = .46) when viewing a soft-fascinating nature VE [t (38) = 2.57, P = .02, d = .59] (see Figure 2B). Consistent with the result of the manipulation check, the latency of the MMN/P3a complex did not significantly differ between the two groups: (1) aMMN: t (38) = - 1.47, P = .15; (2) P3a: t (38) = - .31, P = .76.

As the ERP reflection of normal functioning of the cognitive system and involuntary attention restoration, the fronto-central N1/aMMN and P3a components were prominently produced by frequency deviant detection while viewing 360° virtual nature. Particularly, the high restorative group exhibited more attenuated fronto-central P3a activity than the low restorative group in the topographical distributions, consistent with a decreased involvement of frontal cortex in response to auditory distractors during meditation (see Figure 3A). Figure 3B demonstrates ERP time courses of the two groups with different levels of restorative experience at the FCz electrode site.
Correlations between individual’s PRS scores and P3a amplitudes

A correlation analysis was further carried out to examine the relationship between self-reported PRS scores and P3a amplitudes over the three fronto-central midline electrode sites: Fz, FCz, and Cz. Following the interpretation of Cohen’s guideline [30], a moderate, but significantly negative correlation between the explicit and implicit measures was revealed only at the FCz site ($r = -0.38, P = 0.02$; see Figure 2C), not at the Fz ($r = -0.11, P = 0.50$) and Cz ($r = -0.28, P = 0.08$) sites.

Discussion

The aim of this study based on the ART is to determine whether the amplitude of the MMN/P3a complex can be a distinct ERP biomarker of involuntary attention restoration during exposure to 360° virtual nature in healthy young adults with different levels of restorative experience. Unlike previously published aMMN or P3a studies, the current study placed more focus on a neurophysiological “handover” from pre-attentive information processing (i.e., aMMN) to subsequent attention orienting processing (i.e., P3a) as indexed by the MMN/P3a complex, not separately. The findings of this study will extend those of previous ART and ERP studies in the real world into the virtual world. Moreover, theoretical and empirical implications from this study will support the development and assessment of restorative VR contents by allowing various stakeholders such as designers, researchers, and clinicians to investigate the restorative responses which potential users have given to active relaxation in restorative VEs, particularly at the “involuntary” attentional level (not limited to the “voluntary” attentional level as reported in the previous studies).

As shown in the results of the manipulation check and the hypothesis testing, no significant differences in the aMMN amplitudes were found between the two restorative groups as well as between the two fascinating VE conditions, which corresponds to the pre-attentive nature of the aMMN beyond the attention debate in the real world [20] and the given task that participants had to focus only on conducting visual tasks and ignore any environmental sounds. In other words, the
automatic change detection is not only one of the most important cognitive functions for human survival from a revolutionary perspective, but normal functioning of the cognitive system is also characterized by maintaining a sound balance between goal-directed behavior and involuntary orientation [31, 32]. Despite no significant changes in the aMMN amplitudes during exposure to virtual nature, the robustness of the aMMN amplitudes proves that those who participated in this study are qualified as healthy subjects. Mental fatigue during or after prolonged periods of cognitive tasks impairs pre-attentive auditory processing, as revealed by that aMMN amplitudes at fronto-central electrode sites can be significantly decreased for mental fatigue [33]. These impairments in pre-attentive processing of auditory change detection also appear in clinical populations, such as patients with schizophrenia [34, 35], ADD/ADHD [36], or major depressive disorder [37]. Given the possible link between decreased exposure to nature and increased occurrence of mental disorders [6-8], it is still important to clarify the role of the aMMN amplitude in different groups from people vulnerable to mental fatigue or at high-risk for any mental disorders to patients with acute or chronic mental disorders in future direction.

Based on only a few ART studies that focused more on the concept of “fascination” [1, 5, 38], the current study compared the restorative effect of entertaining events to that of natural events for the manipulation check. Consistent with the ART [1], the “non- or less restorative” urban fireworks VEs with hard fascination consumed relatively more involuntary attentional resources with leaving very little space for mental reflection than the “restorative” soft-fascinating nature VEs which elicited significantly increased P3a amplitudes and PRS scores. As hypothesized, the P3a amplitude was differently affected by individuals’ restorative experience during exposure to the nature VE, supporting the restorative effect of virtual nature as indicated by the negative correlation between self-reported PRS scores and P3a amplitudes as well as the attenuated P3a amplitudes in the high restorative group. As the P3a is an index for frontal neural activity generated by stimulus-driven attention mechanisms [19], a trend for clear P3a amplitude reduction can be inferred to be consistent with decreased attentional engagement by the frontal cortex in response to unexpected and distracting stimuli during meditation practice, as shown by Cahn and Polich [18]. In line with the finding of
Pierson, Le Houezec [39], it is more likely that participants reporting greater restorative depth are those who can find it easier to enter a state of deep quiescence due to their low sensation-seeking trait to positively correlate with the frontal P3a amplitude. More importantly, meditation not only reflects first person experiences that cannot be easily shared [40] but also facilitates attention control mechanisms [41, 42]. If the restorative effect of virtual nature experience shows a similar trend in that of meditation practice with the aim of decreasing emotional and cognitive reactivity, individuals’ different restorative experience in the nature VE could play a key role in renewing their capacity of attention control without an attempt to intentionally regulate attention [1, 4]. To shed a light on the similarities in the two relaxation techniques, whether the decreased automated reactivity and inhibited evaluative processing of the task-irrelevant attention-demanding auditory stimuli are consistently observed needs to be further determined in the future studies.

Although meditation is well-known as an effective relaxation technique with both short-term and long-term effects on attentional function [18, 43-45], there is a limitation that mental and attentional fatigue might be tough to meditate without any guidance or help from professionals. As some people might prefer non-guided meditation or free-style relaxation to guided meditation, a self-chosen 360° VR nature therapy within a limited short time might be a more appealing alternative than a virtually guided scenario-based VR meditation. The mobile VR system encourages mentally fatigued workers and students to be away from the real world full of stressful factors immediately after wearing VR glasses with a feeling of being there. People with disabilities, elderly people, and inpatients can easily utilize the VR nature therapy in home and ward environments, allowing those vulnerable to simulator sickness to control the 360° VEs only with subtle head movements or even without wearing the VR glasses and to independently act in the virtual world. Taken together, it is expected that this VR nature therapy can act as a self-help, self-administered treatment for mental and attentional fatigue in everyday life.
Conclusions

To conclude, the 360° VR nature exposure therapy can help individuals suffering from mental fatigue effectively to manage their attentional resources with a minimum of effort by only about 5 min of exposure to virtual nature for restoring involuntary attention without being threatened by simulator sickness. As far as individuals’ restorative experience is concerned, the amplitude of the fronto-central MMN/P3a complex can be potentially employed as a distinct ERP biomarker of involuntary attention restoration during virtual nature experience in healthy young adults.

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Conflicts of interest

None declared.

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