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Anterior N2 Predicts Subsequent Viewing Time and Interest Rating for Novel Drawings

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Abstract

Event-related brain potentials (ERPs) in response to novel pictures and subsequent visual exploration were examined. Eighteen undergraduates viewed 120 novel drawings as long as they wished. ERPs were calculated separately for drawings that were viewed longer or shorter than the median viewing time of each participant. The drawings viewed longer elicited a larger anterior negativity (N2) peaking at 245 ms than the shorter viewed drawings. This effect disappeared and the overall amplitude of the N2 decreased when the same set of drawings was presented again in a subsequent interest-rating session. Drawings rated as more interesting elicited a larger N2 than did drawings rated as less interesting. This study demonstrates a type of anterior N2 that is sensitive to stimulus unfamiliarity or difficulty in encoding, which reflects a conflict between stimulus input and existing knowledge and prompts further recognition processes and visual exploration.

Key words: curiosity, interest, exploratory behavior, event-related potentials, novelty, conflict, unfamiliarity, picture

Introduction

Exploring novel stimuli is an intrinsically motivated behavior of human beings and animals that facilitates adaptation to the environment (Hunt, 1965; Keller, Schneider, & Henderson, 1994). Novel objects are looked at longer than familiar objects (Berlyne, 1958; Leckart, 1966), and the duration of visual exploration is correlated positively with subjective feeling of interest (Silvia, 2006). Visual exploration is thought to be initiated by the detection of incongruity or conflict between the organism and the environment (Berlyne, 1960; Hunt, 1965; Sokolov, 1963). When a deviant event occurs, the organism orients to the event or modulates its sensory organs for taking in more information. This orienting response leads to increased allocation of attentional resources to the event, which enables further cognitive processing, response execution, and memory updating (Kahneman, 1973; Öhman, 1979; Spinks & Siddle, 1983). Event-related potentials (ERPs) have been used to investigate the central mechanism of orienting responses (Loveless, 1983; Näätänen & Gaillard, 1983). The high temporal resolution of ERPs allows for the separation of stages of information processing that cannot be achieved by the autonomic measures such as electrodermal and cardiovascular responses, which were originally used in the study of orienting responses (Sokolov, 1963). It remains unclear, however, whether there is any ERP component that correlates with subsequent visual exploration, which often lasts for several seconds. Few studies have dealt with this question directly.

Daffner et al. (1998, 2000c) recorded ERPs elicited by line drawings during a target detection (*oddball*) task in which participants were allowed to look at each stimulus as long as they wished and gave a motor response for the target. Three types of stimuli were presented: frequent repetitive background stimuli, infrequent target stimuli, and infrequent non-repetitive deviant stimuli. ERP waveforms were calculated separately for novel drawings whose viewing times were longer or shorter than the 50th percentile of each participant. The peak-to-peak amplitude of the N2-P3 waves occurring 200-500 ms after the stimulus onset was larger for the drawings that were viewed longer. Since this effect was not significant for the baseline-to-peak P3 amplitude (Daffner et al., 2000c, Note 4), it appeared to be due to the change in the N2 amplitude rather than the P3 amplitude. In a subsequent study, Daffner et al. (2000b) suggested that the N2 and P3 might have different functional characteristics. The N2 is sensitive to deviation from the long-term context and less affected by the frequency or task relevance of an eliciting stimulus, whereas the P3 is sensitive to deviation from the immediate context held in working memory and more affected by stimulus probability. They called the N2, which had an anterior scalp distribution, the “visual novelty N2.” Daffner et al. (2000b) suggested that this visual novelty N2 might be an index of stimulus unfamiliarity or unusualness (i.e., a factor that depends on the past experience of a participant) rather than stimulus complexity (i.e., a factor that depends on physical attributes of a stimulus).

The purpose of the present study was to replicate and extend the findings about the relation between ERPs and subsequent viewing times for novel drawings. The experimental protocols were modified in two aspects. First, a free viewing task rather than a target detection task was used. All trials contained novel drawings and the participants’ task was only to view each drawing as long as they wished. There were no target or distracter stimuli. Second, the same set of drawings was presented again in a second session to examine the repetition effect of novel drawings on the anterior N2. In the second session, participants were asked to rate their subjective interest in each drawing. If the anterior N2 reflects stimulus unfamiliarity, two predictions can be made. First, drawings that were viewed for a longer time would elicit a larger anterior N2 than those viewed shorter, since less familiar stimuli would be looked at longer. Second, N2 amplitude would be smaller in the second presentation of the same novel stimuli, since the visual exploration at Session 1 would reduce the unfamiliarity of the stimuli. In addition to this main purpose, a supplemental analysis was conducted in search of ERP components that correlate with subjective interest ratings. ERPs at Session 2 were also calculated separately based on the interest ratings made by each participant. A previous study showed that the amplitude of the P3 (P300) was higher for pictures that were rated as more interesting compared to pictures that were rated as less interesting (Hömberg, Grünewald, & Netz, 1984).

Method

Participants. Eighteen undergraduates with normal or corrected-to-normal vision participated in the study (12 women and 6 men, 20–22 years old). Two were weakly left-handed and the rest were right-handed, as assessed by the Edinburgh Inventory (Oldfield, 1971). All participants gave written informed consent.

Stimuli. 123 black-and-white pictures were drawn by one of the authors (YS). Figure 1 shows some examples of the pictures.[1] Each picture was digitized into 256 × 256 pixels using a scanner, and presented on a 17-inch cathode ray tube display of a computerized tachistoscope (IS702, Iwatsu-Isec, Japan). The visual angle was 3.8 degrees both horizontally and vertically. The viewing distance was 150 cm.

Procedure. The experiment was performed in a dimly lit, sound-attenuated room, where participants sat in a comfortable chair. Two experimental sessions were conducted. At Session 1, participants were asked to look at the drawings at their own pace. Each drawing appeared immediately after the participants pressed a trigger key using the right index finger and disappeared when they pressed the same key again. The viewing time was measured in milliseconds as the interval between the key presses. Participants were instructed that they would be asked about their impressions of the drawings after this session but did not have to memorize them because no memory test would follow. Here we used a vague word “impressions” instead of “interest” to prevent participants from making conscious evaluations of drawings in terms of interest. At Session 2, the same drawings were presented in a different order at a fixed duration of 2 s. The method of stimulus presentation was the same as at Session 1 except the stimulus disappeared automatically. Participants were asked to rate how interesting they felt each drawing was by pressing one of the five keys corresponding to 1 (*very uninteresting*) to 5 (*very interesting*) after the drawing disappeared. Each session consisted of 3 practice trials and 120 experimental trials, which were divided into three blocks containing 40 trials each. Each drawing was presented only once at each session. A break of a few minutes was inserted between blocks and sessions. Participants were asked not to look away from the drawing whenever it was on the screen.

Electrophysiological recording. An electroencephalogram (EEG) was recorded at 19 electrode sites (Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, and O2) according to the 10-20 system using an Electrocap with tin electrodes. The ground electrode was fixed on the forehead (AFz). An electrooculogram (EOG) was recorded bipolarly with electrodes placed at the outer canthus and 2 cm above the left eye. Electrode impedances were kept below 5 kΩ. The EEG and EOG were amplified by an NEC San-ei 6R12 amplifier (gain: 20,000, bandpass filter: 0.05–30 Hz, 6 dB/octave cutoff) and digitized at a sampling rate of 200 Hz. EEG data were re-referenced to mathematically averaged earlobes (A1-A2) offline.

Data reduction. For each participant, the 120 drawings were sorted by the viewing times at Session 1. Excluding the trials with extremely short viewing times (< 1 s, 0.8 % of the total trials), the drawings were divided into two groups for each participant: the drawings whose viewing times were above the median (hereafter called the *long* set) and those below the median (the *short* set). Viewing times were analyzed after logarithmic transformation, because they were positively skewed. A Pearson’s correlation coefficient between viewing time and interest rating was calculated for each participant.

Based on the viewing times at Session 1, ERP waveforms were calculated separately for the long and short sets for Sessions 1 and 2. The averaging period was 1,000 ms starting 200 ms before the onset of the drawings. Trials in which the EEG or EOG exceeded ±100 μV were excluded automatically from averaging. Trials with small saccades and muscular artifacts were also excluded by visual inspection. All averaged waveforms were aligned to the mean amplitude of the 200-ms prestimulus period. At Session 2, ERP waveforms were also calculated separately for the drawings that were rated as interesting (4 or 5 on a scale of 1 to 5) or uninteresting (1 and 2). The data of one participant were excluded from this analysis because the number of trials to be averaged was insufficient (10). The mean amplitudes of 130-195, 200-295, 300-395, and 400-795 ms were measured for the P2, N2, N3, and positive slow wave (PSW), respectively.

Statistical analysis. Repeated measures analyses of variance (ANOVAs) were performed on the data. Whenever appropriate, degrees of freedom were corrected using the Greenhouse-Geisser procedure. A Session (1 vs. 2) × Viewing Time (long vs. short) × Site (19 electrodes) ANOVA was performed for each amplitude measure. When there was an interaction between viewing time and site, the simple main effect of viewing time was tested at each site. For supplemental analyses, an Interest (interesting vs. uninteresting) × Site (19 electrodes) ANOVA was performed for each amplitude measure at Session 2. The significance level was set at .05 for all analyses. Effect sizes are shown using partial η^2 (η_p^2) for ANOVAs and Cohen's *d* for *t* tests.

To estimate cortical current sources of the ERPs associated with the differences in viewing time, the low resolution brain electromagnetic tomography (LORETA) algorithm was used (Pascual-Marqui, Esslen, Kochi, & Lehmann, 2002). Subject-wise normalized LORETA images were compared between the long and short sets of drawings with voxel-by-voxel paired *t* tests using the statistical nonparametric mapping method (Nichols & Holmes, 2002).

Results

The mean viewing time was 4,469 ms ranging from 1,686 to 12,861 ms across participants. No significant differences in mean viewing times were found across the three blocks (4,546, 4,356, and 4,507 ms for Blocks 1, 2, and 3; $F < 1$). The mean viewing times of the long and short sets were 5,781 and 3,455 ms, respectively, $t(17) = 13.23$, $p < .001$ (two-tailed), $d = 0.865$. The drawings viewed longer were rated more interesting than the drawings viewed shorter. The mean rating scores were 3.3 (*SD* 0.38) and 2.8 (*SD* 0.46) for the long and short sets, respectively, $t(17) = 3.85$, $p = .001$ (two-tailed), $d = 1.252$. The correlation between viewing time and interest rating was significant but rather low, $r = +.28$ (mean value calculated after Fisher's *Z* transformation, $p < .01$, $df = 118$), varying from +.69 to –.23 across participants. Table 1 shows a contingency table between viewing time and interest rating. A Viewing Time (long vs. short) × Interest Rating (interesting vs. uninteresting) ANOVA showed a significant interaction, $F(1, 17) = 8.60$, $p = .001$, $\eta_p^2 = .460$. Post hoc *t* tests showed that the longer viewed drawings were rated as interesting more frequently than the shorter viewed drawings, and the shorter viewed drawings were rated as uninteresting more frequently than the longer viewed drawings, *p*s < .01. However, there were also a considerable number of long-uninteresting and short-interesting combinations, which is consistent with the low correlation coefficient between viewing time and interest rating mentioned above.

ERPs associated with shorter and longer viewing times

Figure 2 shows the grand mean ERP waveforms for the drawings that were viewed longer or shorter than the median.[2] Figures 3 and 4 show the mean amplitudes at three midline sites and the scalp topographic maps of ERP components, respectively. Both sets of drawings elicited a P2 with a central dominant distribution peaking at 160 ms after the stimulus onset. The amplitude of the P2 was larger for the short than for the long set at both sessions. A Session × Viewing Time × Site ANOVA showed a significant main effect of viewing time, $F(1, 17) = 12.00$, $p = .003$, $\eta_p^2 = .414$, without significant interactions with session, *p*s > .20. The Viewing Time × Site interaction was not significant, $F(18, 306) = 2.28$, $p = .106$, $\varepsilon = .133$, $\eta_p^2 = .118$.

The P2 was followed by an anterior negative wave with two peaks: the former had a peak of 245 ms (labeled “N2”) and the latter had a peak of 330 ms (labeled “N3”). Scalp topographic maps (Figure 4) show that the N2 and N3 were negative over anterior sites but the polarity was reversed at temporal sites. At Session 1, the N2 showed a larger amplitude for the long than for the short set. However, the difference disappeared and the overall amplitude decreased at Session 2. The N3, on the other hand, showed no clear amplitude differences between the long and short sets. The overall amplitude of the N3 also decreased at Session 2.

For the N2 amplitude, the Viewing Time × Site and Session × Site interactions were marginally significant, *F*s(18, 306) = 2.39 and 2.89, *p*s = .089 and .080, εs = .146 and .093, η_p^2s = .123 and .145. Tests of simple main effects showed that the N2 amplitude decreased from Session 1 to Session 2 over the central and right frontal sites (Fz, F4, and F8; *p*s < .05). At Session 1, a Viewing Time × Site ANOVA showed a significant interaction, *F*(18, 306) = 3.65, *p* = .014, ε = .191, η_p^2 = .177, although the main effect of viewing time was not significant, *F*(1, 17) = 3.33, *p* = .086, η_p^2 = .164. Tests of simple main effects showed that the N2 amplitude was larger for the long than for the short set over the frontocentral sites (F3, Fz, F4, C3, Cz, and C4; *p*s < .05). At Session 2, however, no significant main or interaction effects of viewing time were found, *F*s < 1. For the N3 amplitude, the Session × Site interaction was significant, *F*(18, 306) = 4.47, *p* = .025, ε = .096, η_p^2 = .208. Tests of simple main effects showed that the N3 amplitude decreased from Session 1 to Session 2 over the frontal sites (Fp2, F7, F3, Fz, F4, and F8; *p*s < .05). No significant main or interaction effects of viewing time were found.

Following the N3, a positive slow wave (PSW) with a parietal distribution appeared in the waveforms. No significant effects of viewing time or session were found for this positivity.

LORETA images of the anterior N2 at the peak latency of the grand mean waveforms (245 ms) were compared between the long and short sets of drawings. The resultant *t*-value images are shown in Figure 4. Red areas indicate the voxels showing a stronger activation for the long than for the short sets. The largest difference between the LORETA images was located in the dorsal part of the anterior cingulate gyrus, $t(17) = 3.90$, $p = .08$, parametric $p = .001$ (two-tailed). The second largest difference was found in the superior frontal gyrus, $t(17) = 3.56$, $p > .1$. It should be noted that the LORETA image before comparison showed the strongest activation over bilateral temporal lobes, but the difference between the long and short sets appeared in the anterior cingulate cortex (ACC).

ERPs for interesting and uninteresting drawings

Figure 5 shows the ERP waveforms at Session 2 calculated separately for drawings that were rated as interesting or uninteresting. The N2 wave was larger for interesting drawings than for uninteresting drawings, while ERP waveforms in other latency ranges did not show clear differences. Figure 3 shows mean amplitudes of each ERP component at midline sites. An Interest × Site ANOVA showed that the main effect of interest was significant only for the N2, $F(1, 16) = 10.29$, $p = .005$, $\eta_p^2 = .391$. The interaction with site was not significant, $F(18, 288) = 1.64$, $p = .186$, $\varepsilon = .190$, $\eta_p^2 = .093$. The ANOVAs for the P2, N3, and PSW did not show significant main or interaction effects. The scalp topography of the differences in the N2 amplitudes between interesting and uninteresting drawings is shown in Figure 4. The differences appeared over more central sites than the N2 differences between the long and short sets at Session 1, where the differences appeared over frontocentral sites. However, this visual impression was not supported statistically.[3] The LORETA analysis was applied to the interest-related N2 differences, but no voxel showed significant differences, $p > .40$.

Discussion

Novel drawings that were viewed longer elicited a larger anterior N2 than those viewed shorter. When the same drawings were presented again in a subsequent interest-rating session, the effect of viewing time on N2 amplitude disappeared and the overall amplitude was reduced. P2 amplitude also varied with viewing time, but this effect did not differ significantly between sessions. At Session 2, drawings that were rated as more interesting elicited a larger N2 than drawings rated as less interesting.

ERP waveforms recorded in this study showed a positive slope over prefrontal sites. A similar anterior positive slope sometimes appears in ERP waveforms elicited by pictures (e.g., Schendan & Kutas, 2003; Van Petten, Senkfor, & Newberg, 2000). Because trials including saccades were excluded from ERP averaging, this slope may reflect slow eye movements and/or prefrontal brain activity. In either case, since this slope appeared similarly for both conditions, it did not obscure the ERP differences in question.

ERPs correlated with visual exploration

The present study replicated the previous finding that N2 amplitude was larger for the drawings that were subsequently viewed longer (Daffner et al., 1998, 2000c). This effect appeared over the frontocentral sites, although the potential in ERP waveforms before comparison showed a scalp topography that was negative over anterior sites and positive over temporal sites. This result suggests that several generators were activated concurrently in this period. Hereafter, we use the term “anterior N2” to specifically refer to the frontocentral component of the potential occurring in this latency range (200–295 ms). The anterior N2 effect disappeared at Session 2, where all drawings were assumed to be familiar because of the free visual exploration at Session 1. The rather low correlation coefficient between viewing time at Session 1 and interest rating at Session 2 (r = .28) is probably because the visual exploration reduced stimulus unfamiliarity, which is strongly related to interest (Berlyne, 1960; Silvia, 2006). This result indicates that the anterior N2 was sensitive to the participant's past experience (i.e., stimulus unfamiliarity) rather than the physical attributes of the stimulus (i.e., stimulus complexity). Although stimulus complexity remained constant across sessions, the repeated presentation led to the amplitude reduction of the anterior N2. Another possible reason for the N2 reduction is the differences in task requirements. Although the method of initiating a stimulus was identical, the stimulus lasted until a participant pressed the key again (Session 1) or disappeared automatically after 2 s (Session 2). Moreover, the mental sets for free viewing and interest rating might be different. A further study using an identical task at both sessions is needed to examine the possible effect of task requirements on the anterior N2.

N2 (or N200) is a generic term for a negative wave occurring 200−300 ms after stimulus onset and has been classified into several subtypes (Näätänen & Picton, 1986; Pritchard, Shappell, & Brandt, 1991). Although the properties of N2 are better understood for the auditory modality (e.g., Näätänen, 1992), we focus here on the findings for the visual modality. The visual N2 can be divided into at least two categories according to scalp topography: posterior-lateral N2 and anterior N2 (Breton, Ritter, Simson, & Vaughan, 1988). The anterior N2 usually occurs later than the posterior-lateral N2 (Luck & Hillyard, 1994a; Renault & Lesévre, 1978, 1979). The posterior-lateral N2 group includes the N2 elicited by an infrequent event in an attended channel (Na or N2a; Renault & Lesévre, 1978, 1979), the N2 elicited by a target stimulus in a classification task (classification N2 or N2c; Ritter, Simson, & Vaughan, 1983; Ritter, Simson, Vaughan, & Macht, 1982), and the N2 elicited by a task-relevant stimulus in the presence of simultaneous distracter items with a larger amplitude over sites contralateral to the stimulus position (N2pc; Luck & Hillyard, 1994a, 1994b). A negative wave called “NA” that occurs in a similar latency range but precedes the N2 (N2c) also shows a posterior-lateral scalp distribution (Ritter et al., 1982, 1983). These N2s are assumed to be generated in cortical visual areas and specific to the visual modality. On the other hand, the anterior N2 has not been categorized clearly. The N2b (or attentional N2) was a typical anterior N2 (Pritchard et al., 1991). It is often elicited by infrequent task-relevant stimuli in an attended channel (Renault & Lesévre, 1978, 1979). The anterior N2 in the present study appears to be different from the N2b, because it was elicited by every stimulus. Other studies have shown that a similar frontal negativity was elicited by pop-out stimuli presented in an attended channel (Luck & Hillyard, 1994a), by unidentifiable color patterns (Courchesne, Hillyard, & Galambos, 1975), or by variable target stimuli (Breton et al., 1988). Some researchers called it “N300” and argued that it was specific to nonverbal figural stimuli (Barrett & Rugg, 1990; Holcomb & McPherson, 1994; McPherson & Holcomb, 1999).

Another type of anterior N2 that has been studied extensively is the Nogo N2 (Jodo & Kayama, 1992), which is recorded when a response is needed to be suppressed. Although the Nogo N2 was originally thought to reflect response inhibition processes, recent findings suggest it may instead reflect a conflict between execution and inhibition of an action (Falkenstein, 2006; Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003). A similar N2 has been shown to be increased when the strength of conflicting action imperatives was augmented by increasing perceptual similarity between the stimuli that required different responses (Azizian, Freitas, Parvaz, & Squires, 2006).

Cortical current source estimation using the LORETA algorithm suggested the dorsal part of the ACC as a possible source of the anterior N2 related to the difference in viewing time. Since the estimation was based on a relatively small number of electrodes and only a marginally significant effect was obtained, this finding needs replication using high-density EEG recordings as well as functional imaging techniques. However, this estimation seems reasonable because visual exploration should require activation of the ACC, whose function is the initiation and monitoring of goal-directed behaviors (Bush, Luu, & Posner, 2000; Devinsky, Morrell, & Vogt, 1995). Moreover, one of the sources of the Nogo N2 is also estimated to be the ACC (Bokura, Yamaguchi, & Kobayashi, 2001; Nieuwenhuis et al., 2003). It is not surprising to see ACC activation that is related to subsequent behavior in this latency range. Recent studies with an ultra-rapid visual categorization task using complex photographs suggested that ERP differences associated with specific stimulus categories (such as animals and vehicles) started as early as about 80 ms after stimulus onset and those associated with the participant’s behavior started from at least 150 ms poststimulus (Delorme, Rousselet, Mace, & Fabre-Thorpe, 2004; Thorpe, Fize, & Marlot, 1996; VanRullen & Thorpe, 2001). These results suggest that not only low-level features of a stimulus but also part of the information about stimulus content are already available at the onset of the N2.

Daffner et al. (2000b) suggest that the anterior N2 may be elicited when early perceptual analysis reveals that the stimulus is not easily recognizable and requires further processing. One possible interpretation is that a conflict between stimulus input and past experience may be reflected in the anterior N2 in the present study. A stimulus input that is congruent with existing knowledge can be easily recognized, whereas an incongruent input requires further processing. Most theories of visual exploration and interest assume that a conflict or incongruity between incoming information and existing knowledge is a key element of visual exploration and interest (Berlyne, 1960; Hunt, 1965). Actual behavior and feeling may be modified by other elements such as an appraisal of one's coping potential (e.g., one may avoid objects that are too complex or too unfamiliar to understand), but an appraisal of novelty, broadly defined, is one of the first judgments in the appraisal sequence that leads to exploration and interest (Silvia, 2005). The anterior N2 may reflect this first step of processing. As a conflict in the motor domain is reflected in the Nogo N2, a conflict between visual input and stored representation might also involve a similar activity in the ACC.

The amplitude of P2 also varied with subsequent viewing time, but the effect of viewing time on P2 amplitude did not change significantly between sessions. The P2 difference between the long and short sets is consistent with the results of Daffner et al. (2000c), although they did not mention it explicitly. Close inspection of Figure 5 in their paper revealed that the ERP waveforms elicited by the stimuli viewed for shorter or longer times diverged from each other as early as 150 ms near the onset of P2, which is quite similar to the finding of the present study. In both studies, a larger P2 was elicited by the pictures with shorter viewing times. In the present study, the stimuli were presented immediately after a participant's button press. As a result, movement-related potentials, especially the post-motor P2 (Vaughan, Costa, & Ritter, 1968), may have overlapped in this latency range. However, this possible contamination can be ignored because the method of stimulus presentation was identical at both sessions and we dealt with only the differences between the long and short sets. It is known that the amplitude of P2 is related to endogenous factors such as the intensity and interstimulus interval of the eliciting stimuli, although little is known about the functional significance of the P2 (Crowley & Colrain, 2004). Several studies have shown that the amplitude of the P2 elicited in the visual modality is affected by attention. For example, it was larger when the eliciting word was subsequently recognized correctly (Smith, 1993), when memorization of a spatial position was required (Gevins et al., 1996), or when infrequent novel visual stimuli were presented (Knight, 1997). These results suggest that a neural system underlying the P2 is related to the allocation of attentional resources to the eliciting event. However, in the present study, the P2 did not differ between sessions, so it may be related to differences in physical attributes.

ERP differences correlated with viewing time did not appear after the N2. The amplitude of the N3 was not affected by viewing time or by interest rating. The N3 in this study may be the N400, which has been reported in picture naming/identification tasks (Holcomb & McPherson, 1994; McPherson & Holcomb, 1999; Stuss, Picton, & Cerri, 1986; Stuss, Picton, Cerri, Leech, & Stethem, 1992). The reduction of this potential at Session 2 is consistent with the repetition effect of novel figures on ERPs, in which ERP waveforms become more positive in the second rather than in the first presentation, usually after 250−300 ms poststimulus (Cycowicz & Friedman, 1999; Mecklinger, 2000; Van Petten et al., 2000; but see the opposite result, Rugg, Soardi, & Doyle, 1995, Experiment 1).

A positive slow wave appeared in the waveform, but its amplitude did not show any significant effects of viewing time and session. It is unclear whether this component corresponds to the P3 in previous studies, because the experimental design of this study is not suitable for P3 elicitation, which requires contextual deviance. Daffner et al.

(2000b) suggested that the N2 and the P3 (P3a, novelty P3) have different functional characteristics. The elicitation of the P3a in previous studies appeared to be due to the rare occurrence of novel stimuli in the experimental context (Daffner et al., 1998, 2000c). In the present study, every trial contained novel drawings so there was no need for redirection of attention. The anterior N2 might reflect a process for detecting deviance from past experience and signaling for further processing, whereas the P3a might be sensitive to contextual deviance and reflect a redirection of attention to task-irrelevant infrequent events rather than the processing of novelty per se (Katayama & Polich, 1998; Polich, 2003). Because this design minimized the potential impact of contextual deviance, the present results do not give any conclusion about the relationship between the P3 and visual exploration. It is possible that both unfamiliarity and contextual deviance may play a role in determining subsequent viewing time. It has been suggested that older adults tend to generate a relatively small N2 to novel visual stimuli and the amplitude of the P3, not the N2, predicts subsequent viewing time (Daffner et al., 2006). Moreover, patients with prefrontal lesions show a relatively intact N2, but a reduced visual exploration for novel pictures (Daffner et al., 2000a, 2003). These findings suggest that the anterior N2 is not the only determinant of subsequent viewing time.[4]

ERPs correlated with subjective interest rating

Although a previous study showed that the amplitude of the P3 varied with subjective interest ratings (Hömberg et al., 1984), this study showed a difference in N2 amplitudes. The enhancement of P3 amplitude is often seen when using arousing emotional pictures (e.g., Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Schupp et al., 2000) and is assumed to reflect enhanced processing of motivationally relevant stimuli in a circuit of visual cortical structures (Sabatinelli, Lang, Keil, & Bradley, 2006). The absence of P3 differences in this study may be due to the low emotional values of the drawings. The scalp topography of the N2 differences related to the interest ratings appeared to be slightly different (i.e., more broadly and centrally distributed) from the scalp topography of the N2 differences related to viewing times. The statistical analysis failed to reveal the subtle topographic differences, possibly because of the increased noise level in subtraction waveforms. The LORETA algorithm also failed to estimate the source of the interest-related N2 differences.

Because this N2 effect was not expected and its topographic nature was unclear, only an ad hoc speculation can be made. One possibility is that the N2 reflects the residual unfamiliarity of stimuli at Session 2. Another possibility is that the N2 associated with interest rating is different from the N2 associated with viewing time, and reflects stimulus complexity rather than stimulus unfamiliarity. Relevant to the latter position, Daffner et al. (2000b) reported that a repetitive complex background stimulus elicited a larger N2 than did a simple but unique deviant stimulus even after more than one hundred repetitions. This result seems more consistent with the interpretation that the anterior N2 is sensitive to stimulus complexity rather than stimulus unfamiliarity, since an unusual background stimulus should become familiar after repetitions. This inconsistency could be reconciled by assuming that the anterior N2 is not a unitary component. Daffner et al. (2000b) stated that the difference between the N2 elicited by repetitive unusual background stimuli and the N2 elicited by simple deviant stimuli was best seen at Cz, which is consistent with the N2 differences related to interest ratings at Session 2. In contrast, ERP differences related to viewing time at Session 1 as well as the amplitude reduction from Session 1 to Session 2 appeared over more frontal sites. There might be two types of anterior N2s: frontal N2 and central N2. The former might be sensitive to stimulus unfamiliarity, whereas the latter might be sensitive to stimulus complexity. This speculation needs further research using dense electrode recordings along with elaborated experimental manipulations.

Conclusion

The findings of the present study suggest that brain activities occurring within 150-300 ms after stimulus onset are correlated with subsequent visual exploration and subjective interest rating for novel pictures. A possible cortical current source of this potential was estimated in the anterior cingulate cortex. In accordance with Daffner et al.'s (2000b) proposal of the visual novelty N2, this study demonstrates a type of anterior N2 that is sensitive to stimulus unfamiliarity or difficulty in encoding, which reflects a conflict between stimulus input and existing knowledge and prompts further recognition processes that may lead to visual exploration.

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References

Azizian, A., Freitas, A. L., Parvaz, M. A., & Squires, N. K. (2006). Beware misleading cues: Perceptual similarity modulates the N2/P3 complex. *Psychophysiology*, *43*, 253-260.

Barrett, S. E., & Rugg, M. D. (1990). Event-related potentials and the semantic matching of pictures. *Brain and Cognition*, *14*, 201-212.

Berlyne, D. E. (1958). The influence of complexity and novelty in visual figures on orienting responses. *Journal of Experimental Psychology*, *55*, 289-296.

Berlyne, D. E. (1960). *Conflict, arousal, and curiosity*. New York: McGraw-Hill

Bokura, H., Yamaguchi, S., & Kobayashi, S. (2001). Electrophysiological correlates for response inhibition in a Go/NoGo task. *Clinical Neurophysiology*, *112*, 2224-2232.

Breton, F., Ritter, W., Simson, R., & Vaughan, H. G., Jr. (1988). The N2 component elicited by stimulus matches and multiple targets. *Biological Psychology*, *27*, 23-44.

Bush, G., Luu, P., & Posner, M. I. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends in Cognitive Sciences*, *4*, 215-222.

Courchesne, E., Hillyard, S. A., & Galambos, R. (1975). Stimulus novelty, task relevance and the visual evoked potential in man. *Electroencephalography and Clinical Neurophysiology*, *39*, 131-143.

Crowley, K. E., & Colrain, I. M. (2004). A review of the evidence for P2 being an independent component process: Age, sleep and modality. *Clinical Neurophysiology*, *115*, 732-744.

Cuthbert, B. N., Schupp, H. T., Bradley, M. M., Birbaumer, N., & Lang, P. J. (2000). Brain potentials in affective picture processing: Covariation with autonomic arousal and affective report. *Biological Psychology*, *52*, 95-111.

Cycowicz, Y. M., & Friedman, D. (1999). ERP recordings during a picture fragment completion task: Effects of memory instructions. *Brain Research Cognitive Brain Research*, *8*, 271-288.

Daffner, K. R., Mesulam, M. M., Scinto, L. F. M., Acar, D., Calvo, V., Faust, R., Chabrerie, A., Kennedy, B., & Holcomb, P. (2000a). The central role of the prefrontal cortex in directing attention to novel events. *Brain*, *123*, 927-939.

Daffner, K. R., Mesulam, M. M., Scinto, L. F. M., Calvo, V., Faust, R., & Holcomb, P. J. (2000b). An electrophysiological index of stimulus unfamiliarity. *Psychophysiology*, *37*, 737-747.

Daffner, K. R., Mesulam, M. M., Scinto, L. F. M., Cohen, L. G., Kennedy, B. P., West, W. C., & Holcomb, P. J. (1998). Regulation of attention to novel stimuli by frontal lobes: An event-related potential study. *Neuroreport*, *9*, 787-791.

Daffner, K. R., Ryan, K. K., Williams, D. M., Budson, A. E., Rentz, D. M., Wolk, D. A., & Holcomb, P. J. (2006). Increased responsiveness to novelty is associated with successful cognitive aging. *Journal of Cognitive Neuroscience*, *18*, 1759-1773.

Daffner, K. R., Scinto, L. F. M., Calvo, V., Faust, R., Mesulam, M. M., West, W. C., & Holcomb, P. J. (2000c). The influence of stimulus deviance on electrophysiologic and behavioral responses to novel events. *Journal of Cognitive Neuroscience*, *12*, 393-406.

Daffner, K. R., Scinto, L. F., Weitzman, A. M., Faust, R., Rentz, D. M., Budson, A. E., & Holcomb, P. J. (2003). Frontal and parietal components of a cerebral network mediating voluntary attention to novel events. *Journal of Cognitive Neuroscience*, *15*, 294-313.

Delorme, A., Rousselet, G. A., Mace, M. J., & Fabre-Thorpe, M. (2004). Interaction of top-down and bottom-up processing in the fast visual analysis of natural scenes. *Brain Research Cognitive Brain Research*, *19*, 103-113.

Devinsky, O., Morrell, M. J., & Vogt, B. A. (1995). Contributions of anterior cingulate cortex to behavior. *Brain*, *118*, 279-306.

Falkenstein, M. (2006). Inhibition, conflict and the Nogo-N2. *Clinical Neurophysiology*, *117*, 1638-1640.

Gevins, A., Smith, M. E., Le, J., Leong, H., Bennett, J., Martin, N., McEvoy, L., Du, R., & Whitfield, S. (1996). High resolution evoked potential imaging of the cortical dynamics of human working memory. *Electroencephalography and Clinical Neurophysiology*, *98*, 327-348.

Holcomb, P. J., & McPherson, W. B. (1994). Event-related brain potentials reflect semantic priming in an object decision task. *Brain and Cognition*, *24*, 259-276.

Hömberg, V., Grünewald, G., & Netz, J. (1984). Category scaling of the interest value of complex visual stimuli and late positive components of the evoked potential. *Annals of the New York Academy of Sciences*, *425*, 216-222.

Hunt, J. M. (1965). Intrinsic motivation and its role in psychological development. In D. Levine (Ed.), *Nebraska symposium on motivation* (vol. 13, pp. 189-282). Lincoln: University of Nebraska Press.

Jodo, E., & Kayama, Y. (1992). Relation of a negative ERP component to response inhibition in a Go/No-go task. *Electroencephalography and Clinical Neurophysiology*, *82*, 477-482.

Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, NJ: Prentice-Hall

Katayama, J., & Polich, J. (1998). Stimulus context determines P3a and P3b. *Psychophysiology*, *35*, 23-33.

Keller, H., Schneider, K., & Henderson, B. (1994). *Curiosity and exploration*. Berlin: Springer-Verlag.

Knight, R. T. (1997). Distributed cortical network for visual attention. *Journal of Cognitive Neuroscience*, *9*, 75-91.

Leckart, B. T. (1966). Looking time: The effects of stimulus complexity and familiarity. *Perception and Psychophysics*, *1*, 142-144.

Loveless, N. (1983). The orienting response and evoked potentials in man. In D. Siddle (Ed.), *Orienting and habituation: Perspectives in human research* (pp. 71-108). New York: John Wiley & Sons.

Luck, S. J., & Hillyard, S. A. (1994a). Electrophysiological correlates of feature analysis during visual search. *Psychophysiology*, *31*, 291-308.

Luck, S. J., & Hillyard, S. A. (1994b). Spatial filtering during visual search: Evidence from human electrophysiology. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 1000-1014.

McCarthy, G., & Wood, C. C. (1985). Scalp distributions of event-related potentials: An ambiguity associated with analysis of variance models. *Electroencephalography and Clinical Neurophysiology*, *62*, 203-208.

McPherson, W. B., & Holcomb, P. J. (1999). An electrophysiological investigation of semantic priming with pictures of real objects. *Psychophysiology*, *36*, 53-65.

Mecklinger, A. (2000). Interfacing mind and brain: A neurocognitive model of recognition memory. *Psychophysiology*, *37*, 565-582.

Näätänen, R. (1992). *Attention and brain function*. Hillsdale, NJ: Lawrence Erlbaum

Näätänen, R., & Gaillard, A. W. K. (1983). The orienting reflex and the N2 deflection of the event-related potential (ERP). In A. W. K. Gaillard, & W. Ritter (Eds.), *Tutorials in event related potential research: Endogenous components* (pp. 119-141). Amsterdam: North-Holland.

Näätänen, R., & Picton, T. W. (1986). N2 and automatic versus controlled processes. In W. C. McCallum, R. Zappoli, & F. Denoth (Eds.), *Cerebral psychophysiology: Studies in event-related potentials (EEG Suppl. 38)* (pp. 169-186). Amsterdam: Elsevier.

Nichols, T. E., & Holmes, A. P. (2002). Nonparametric permutation tests for functional neuroimaging: A primer with examples. *Human Brain Mapping*, *15*, 1-25.

Nieuwenhuis, S., Yeung, N., van den Wildenberg, W., & Ridderinkhof, K. R. (2003). Electrophysiological correlates of anterior cingulate function in a go/no-go task: Effects of response conflict and trial type frequency. *Cognitive, Affective, and Behavioral Neuroscience*, *3*, 17-26.

Öhman, A. (1979). The orienting response, attention and learning: An information-processing perspective. In H. D. Kimmel, E. H. van Olst, & J. F. Orlebeke (Eds.), *The orienting reflex in humans* (pp. 443-471). Hillsdale, NJ: Lawrence Erlbaum Associate.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia*, *9*, 97-113.

Pascual-Marqui, R. D., Esslen, M., Kochi, K., & Lehmann, D. (2002). Functional imaging with low resolution brain electromagnetic tomography (LORETA):

Review, new comparisons, and new validation. *Japanese Journal of Clinical Neurophysiology*, *30*, 81-94.

Polich, J. (2003). Theoretical overview of P3a and P3b. In J. Polich (Ed.), *Detection of change: event-related potential and fMRI findings* (pp. 83-98). Boston: Kluwer Academic.

Pritchard, W. S., Shappell, S. A., & Brandt, M. E. (1991). Psychophysiology of N200/N400: A review and classification scheme. In J. R. Jennings, P. K. Ackles, & M. G. H. Coles (Eds.), *Advances in Psychophysiology* (Vol. 4, pp. 43-106). London: Jessica Kingsley.

Renault, B., & Lesévre, N. (1978). Topographical study of the emitted potential obtained after the omission of an expected visual stimulus. In D. A. Otto (Ed.), *Multidisciplinary perspectives in event-related brain potential research* (pp. 202-208). Washington, DC: U.S. Government Printing Office.

Renault, B., & Lesévre, N. (1979). A trial-by-trial study of the visual omission response in reaction time situations. In D. Lehmann, & E. Callaway (Eds.), *Human evoked potentials* (pp. 317-330). New York: Plenum Press.

Ritter, W., Simson, R., & Vaughan, H. G., Jr. (1983). Event-related potential correlates of two stages of information processing in physical and semantic discrimination tasks. *Psychophysiology*, *20*, 168-179.

Ritter, W., Simson, R., Vaughan, H. G., Jr., & Macht, M. (1982). Manipulation of event-related potential manifestations of information processing stages. *Science*, *218*, 909-911.

Rugg, M. D., Soardi, M., & Doyle, M. C. (1995). Modulation of event-related potentials by the repetition of drawings of novel objects. *Brain Research Cognitive Brain Research*, *3*, 17-24.

Sabatinelli, D., Lang, P. J., Keil, A., & Bradley, M. M. (2006). Emotional Perception: Correlation of Functional MRI and Event-Related Potentials. *Cerebral Cortex*,

Schendan, H. E., & Kutas, M. (2003). Time course of processes and representations supporting visual object identification and memory. *Journal of Cognitive Neuroscience*, *15*, 111-135.

Schupp, H. T., Cuthbert, B. N., Bradley, M. M., Cacioppo, J. T., Ito, T., & Lang, P. J. (2000). Affective picture processing: The late positive potential is modulated by motivational relevance. *Psychophysiology*, *37*, 257-267.

Silvia, P. J. (2005). What is interesting? Exploring the appraisal structure of interest. *Emotion*, *5*, 89-102.

Silvia, P. J. (2006). *Exploring the psychology of interest*. New York: Oxford University Press

Smith, M. E. (1993). Neurophysiological manifestations of recollective experience during recognition memory judgments. *Journal of Cognitive Neuroscience*, *5*, 1-13.

Sokolov, E. N. (1963). *Perception and the conditioned reflex*. New York: Pergamon Press.

Spinks, J. A., & Siddle, D. (1983). The functional significance of the orienting response. In D. Siddle (Ed.), *Orienting and habituation: Perspectives in human research* (pp. 237-314). New York: John Wiley & Sons.

Stuss, D. T., Picton, T. W., & Cerri, A. M. (1986). Searching for the names of pictures: An event-related potential study. *Psychophysiology*, *23*, 215-223.

Stuss, D. T., Picton, T. W., Cerri, A. M., Leech, E. E., & Stethem, L. L. (1992). Perceptual closure and object identification: Electrophysiological responses to incomplete pictures. *Brain and Cognition*, *19*, 253-266.

Thorpe, S. J., Fize, D., & Marlot, C. (1996). Speed of processing in the human visual system. *Nature*, *381*, 520-522.

Van Petten, C., Senkfor, A. J., & Newberg, W. M. (2000). Memory for drawings in locations: Spatial source memory and event-related potentials. *Psychophysiology*, *37*, 551-564.

VanRullen, R., & Thorpe, S. J. (2001). The time course of visual processing: From early perception to decision-making. *Journal of Cognitive Neuroscience*, *13*, 454-461.

Vaughan, H. G., Jr., Costa, L. D., & Ritter, W. (1968). Topography of the human motor potential. *Electroencephalography and Clinical Neurophysiology*, *25*, 1-10.

Footnotes

[1] The complete set of drawings is available from the corresponding author by request.

[2] A supplemental analysis showed no systematic differences in ERP waveforms across three blocks, which is consistent with the result that viewing times did not differ significantly across three blocks.

[3] The N2 differences between long and short sets and the N2 differences between interesting and uninteresting sets were compared using a Task (free viewing vs. interest rating) × Site (19) ANOVA on amplitude data that were normalized by vector length (McCarthy & Wood, 1985). No significant interaction effect was found, $F(18, 288) = 1.32$, $p = .278$, $\varepsilon = .185$, $\eta_p^2 = .076$.

[4] The correlation coefficient between the average N2 amplitude and the average viewing time calculated for each participant was not significant, *r*s = .36 and .37 at Fz and Cz, respectively, *p*s > .1, $df = 16$. The positive correlation suggests that participants who showed a larger (less positive) N2 tended to have a shorter viewing time on average, which is just opposite to what one expects from the result of intraindividual analysis. Therefore, the present finding about the relationship between the anterior N2 and subsequent viewing time cannot be applied to interindividual differences.

Table 1. Contingency table between viewing time at Session 1 and interest rating at Session 2 (*N* = 18)

	Interest rating					Interesting	Uninteresting
	5	4	3	2	1	(5+4)	(2+1)
Long	9.4 ± 1.2	15.2 ± 1.1	11.4 ± 1.1	9.5 ± 0.8	4.4 ± 0.8	24.6 ± 1.7	13.9 ± 1.3
Short	3.9 ± 0.8	12.4 ± 1.4	12.2 ± 1.3	12.3 ± 1.0	9.2 ± 1.6	16.3 ± 1.9	21.5 ± 1.7
Total	13.3 ± 1.5	27.6 ± 2.2	23.6 ± 2.2	21.8 ±1.5	13.6 ± 2.0	41.0 ± 2.9	35.4 ± 2.3

Note. Means ± standard errors of frequency (%) are shown.

Figure Captions

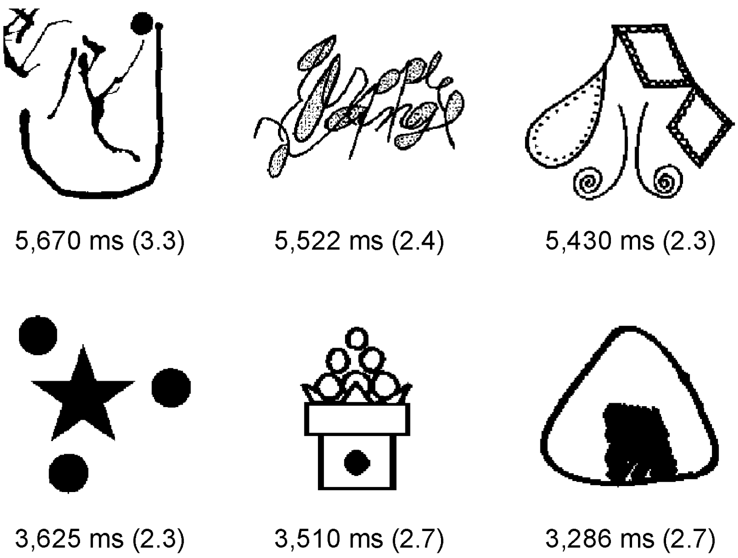
Figure 1. Examples of the drawings used in the study. The upper and lower drawings were viewed relatively longer and shorter by most participants, respectively. Mean viewing times and interest ratings (1: very uninteresting − 5: very interesting) averaged across participants are shown for illustrative purposes, although the sorting was actually done according to each participant's data.

Figure 2. Grand mean ERP waveforms at Sessions 1 and 2 ($N = 18$). The drawings were divided into the long and short sets according to the median viewing time of each participant at Session 1. Open and solid triangles indicate the P2 and N2, respectively.

Figure. 3. Mean amplitudes of ERP components elicited by drawings that were viewed for longer or shorter times at Session 1, and for the drawings that were rated as interesting or uninteresting at Session 2. Bars indicate standard errors of means. Results of paired t tests at respective sites are also shown.

Figure 4. Scalp topographical maps of ERP components. The maps were drawn by using the average reference. The difference between adjacent contours is 0.6 μV. The upper right figure shows the LORETA t-value images showing cortical areas with different levels of activation between drawings viewed longer or shorter at Session 1. The image was taken at the peak latency of the anterior N2 measured in the grand mean waveforms (245 ms). Red areas indicate the voxels showing a stronger activation for the drawings subsequently viewed longer than those viewed shorter.

Figure 5. Grand mean ERP waveforms at Session 2 for drawings rated as interesting or uninteresting (*N* = 17). The solid triangle indicates the N2.



5,670 ms (3.3) 5,522 ms (2.4) 5,430 ms (2.3)

3,625 ms (2.3) 3,510 ms (2.7) 3,286 ms (2.7)

Figure 1

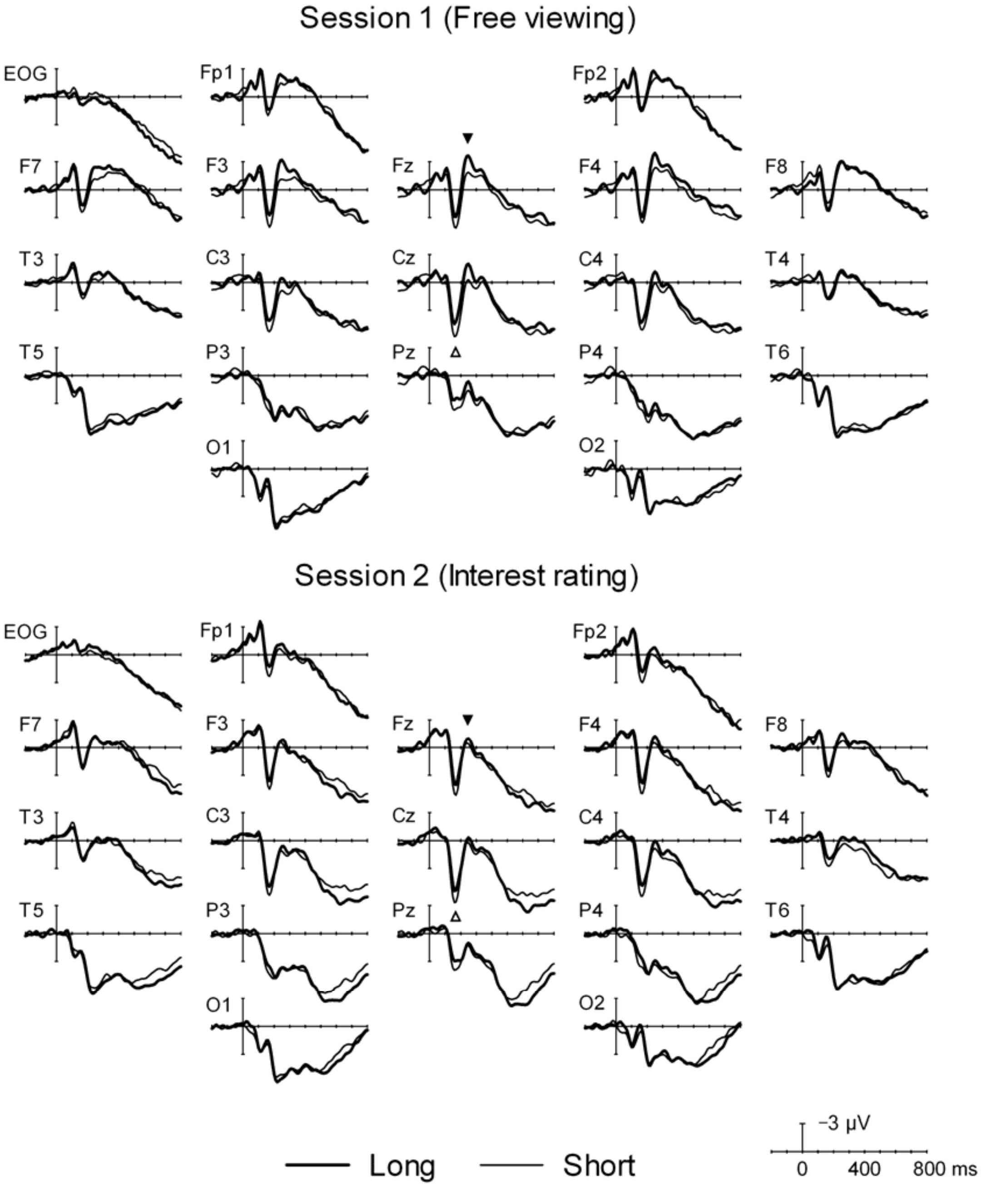

Session 1 (Free viewing)
EOG
Fp1
Fp2
F7
F3
Fz
F4
F8
T3
C3
Cz
C4
T4
T5
P3
Pz
P4
T6
O1
O2
Session 2 (Interest rating)
EOG
Fp1
Fp2
F7
F3
Fz
F4
F8
T3
C3
Cz
C4
T4
T5
P3
Pz
P4
T6
O1
O2
Long
Short
−3 μV
0
400
800 ms

Figure 2

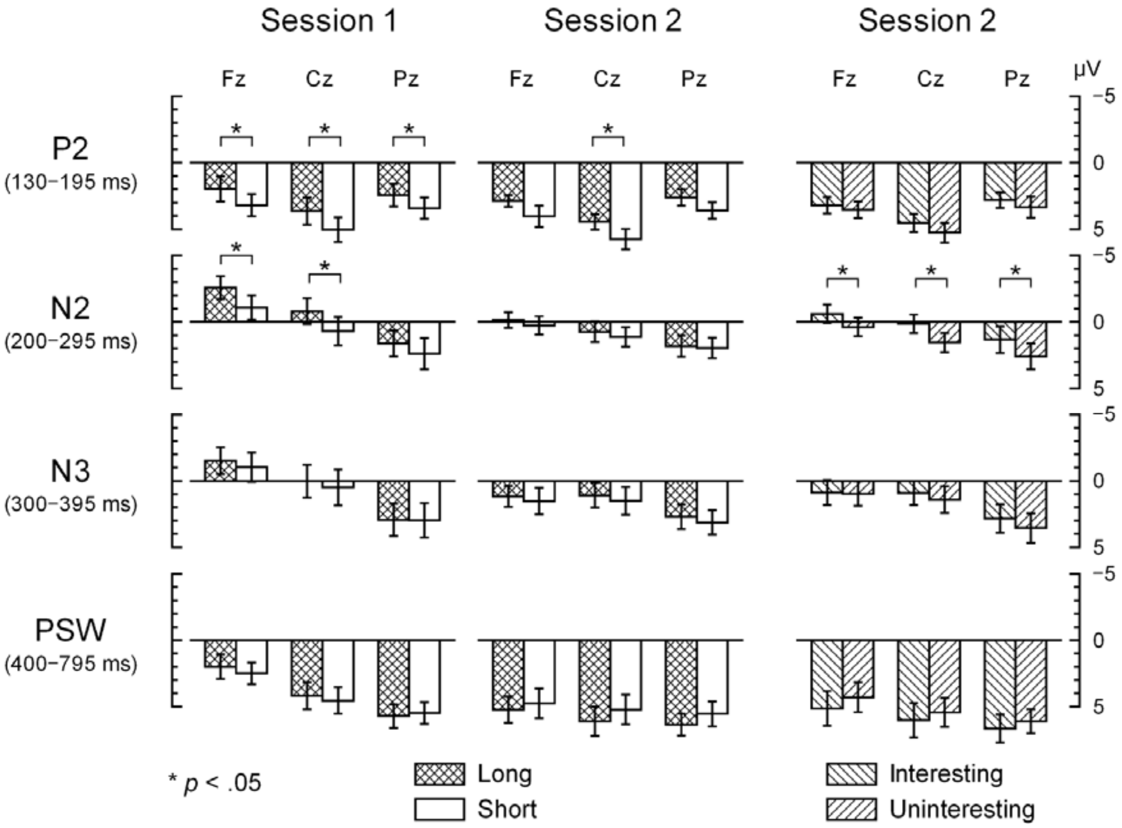

Session 1
Session 2
Session 2
Fz
Cz
Pz
μV
−5
0
5
P2
(130–195 ms)
N2
(200–295 ms)
N3
(300–395 ms)
PSW
(400–795 ms)
*
* p < .05
Long
Short
Interesting
Uninteresting

Figure 3

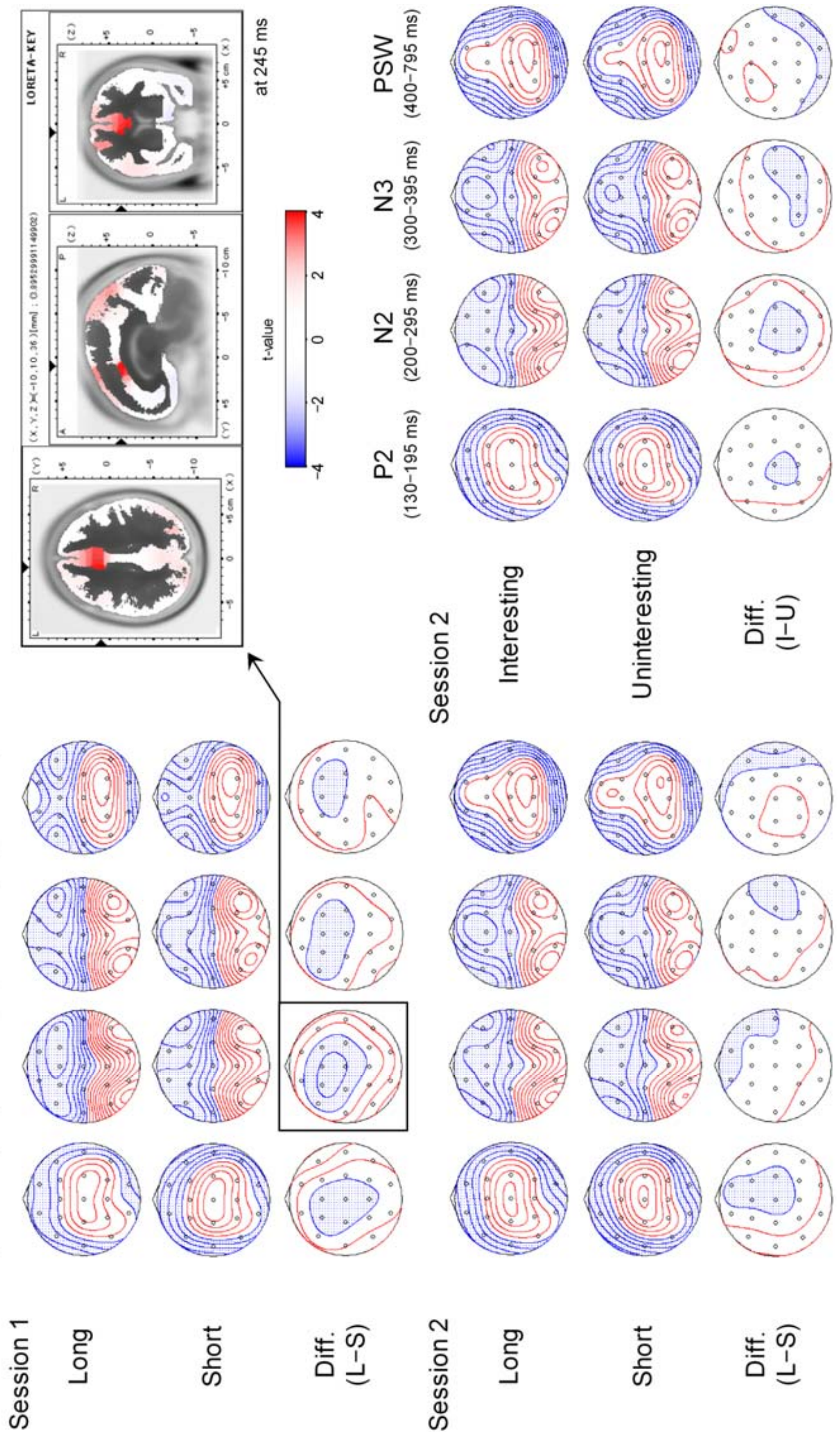

Session 1
Long
Short
Diff. (L−S)
Session 2
Long
Short
Diff. (L−S)
P2 (130–195 ms)
N2 (200–295 ms)
N3 (300–395 ms)
PSW (400–795 ms)
Session 2
Interesting
Uninteresting
Diff. (I−U)
LORETA-KEY
at 245 ms
t-value
4
2
0
−2
−4

Figure 4

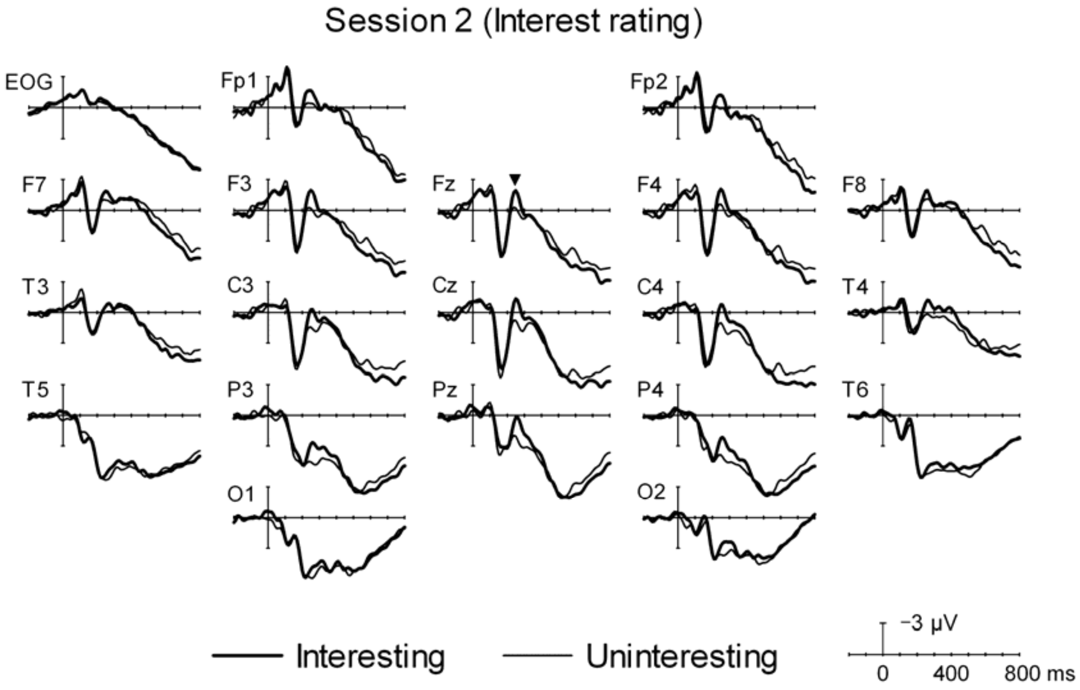

Session 2 (Interest rating)
EOG
Fp1
Fp2
F7
F3
Fz
F4
F8
T3
C3
Cz
C4
T4
T5
P3
Pz
P4
T6
O1
O2
Interesting
Uninteresting
−3 μV
0
400
800 ms

Figure 5