RESEARCH PAPER

Visual perception of different wood surfaces: an event-related potentials study

Qian Wan[1,2] · Xiaohe Li[3] · Yachi Zhang[2] · Shasha Song[2] · Qing Ke[2]

Abstract

• *Key message* **Visual perception of the appearances of different wood surfaces is greatly influenced by their features, such as color, grain, and gloss. Among these features, human visual perception of wood grain type occurs through a later and higher-ordered cognitive process than the perception of color or gloss. Dark wood was subjectively preferred to light- or medium-colored wood, and both matte and glossy wood were preferred to semigloss wood.**

• *Context* Understanding how the appearance of wood is processed in visual perception is critical for wood product design and will help improve consumer satisfaction. Unlike traditional subjective evaluation, neuroscientific methods enable a quantitative understanding of the process and are sensitive to the human visual perceptual response to the appearance of wood surfaces.

• *Aims* The objectives of this study were to quantify the visual perception process and to explore the human neural activity elicited by different wood surface appearances.

• *Methods* Three types of wood differing in color (light, medium, and dark) were cut to expose two different grain types (radial and tangential) and finished to three different gloss values (matte, semigloss, and glossy); digital images of these stimuli were shown to the subjects on a screen. A subjective emotion scale was constructed to measure their subjective evaluation, and neural ERP (event-related potential) data reflecting subjects' early visual perception were recorded. Finally, all the data underwent analysis of variance as well as correlation analysis.

• *Results* Regarding early visual perception, the measurements of relevant ERP components showed that subjects perceived the color and gloss of wood more quickly than the grain type, and their perception of wood grain involved a higher-order cognitive process. The match or mismatch between a given stimulus and a subject's visual memory of wood surface appearance could enhance different ERP components, respectively. In addition, subjects had significantly greater appreciation for dark wood than for other colors, and semigloss wood was less favored than matte or glossy wood.

• *Conclusion* This study provides an objective method to measure the visual perceptual processing of wood appearance; this method may help improve the efficiency of material selection for wood product design. Furthermore, the quantification method can be used by designers in measuring their wood products, and the results can be treated as indicators by which to evaluate the appearance of wood.

Keywords Wood surface appearance · Visual perception · Neuroscience · Event-related potentials

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1 Introduction

1.1 Visual perception of wood surfaces

As a highly aesthetically appreciated material, wood has been widely used as material for packaging, furniture, and interior design in our daily life (Manuel et al. 2015). Owing to its beautiful natural surfaces, wood is also considered as a material that can elicit an overall positive impression (Rice et al. 2006). This characteristic of wood is usually associated with aesthetic attributes, its association with well-being, and its eco-friendliness (Nyrud et al. 2008). Previous studies have indicated that the color, finish, texture, and interfaces of materials have significant influences on the design process of products (Hsiao and Ko 2013; Ming et al. 2001; Artacho-Ramírez et al. 2008). Therefore, exploring our visual perception and the process of how we evaluate those features in wood could meaningfully improve the use of wood in product design.

Wood is easily degraded for many factors, such as solar radiation, weathering, the presence of moisture, chemicals, biological agents, and mechanical impacts (Meijer 2001; Williams 2005; Custódio and Eusébio 2006; Bulcke et al. 2008). For centuries, organic coatings have been used on wood surfaces to protect them from degradation and improve their aesthetic qualities, such as colors, surface finishes, gloss values, and textural effects (Scrinzi et al. 2011). Many previous studies have focused on visual preferences for the appearance of humans for wood surfaces (Nakamura et al. 1999; Enar et al. 2009; Ramananantoandro et al. 2013; Manuel et al. 2015). The results showed that the color, grain, and gloss have major influences on the visual aesthetic evaluation of wood surfaces. Wood surfaces can differ dramatically in visual appearance due to the differences among wood species and surface treatments. Surface treatments of wood products have been used so widely that, when we discuss the surface appearance of wood products, we are generally referring to the visual features of the surface after it has been varnished. Thus, evaluating the appearance of wood surfaces with different treatments would be especially meaningful for the wood product industry.

1.2 Limitations in previous studies

Researchers have carried out excellent studies on wood surface visual assessment. One category of persons liked light-colored and uniformly textured wood, while another category appreciated dark wood with an oriented grain (Marchal and Mothe 1994). A study by a different group found that Norwegian consumers preferred uniform texture (Hoibo and Nyrud 2010). Other studies stated that consumers favored slightly dark wood with an oriented grain (Bumgardner et al. 2007; Ramananantoandro et al. 2013). However, most of the previous studies were based on subjective evaluation or did not take all features of the wood surfaces into account.

Although subjective reporting is straightforward, it cannot elicit from subjects an immediate evaluation of the visual appearance of wood without requiring them to interrupt their appraisal and respond behaviorally. Moreover, subjective evaluation alone may not record subjects' real-time affect (Calvert and Brammer 2012; Ding et al. 2017), rendering it difficult to understand the visual perceptual processing of wood appearance. This may be explained by the difficulty that subjects face in explaining their feelings clearly and completely when explicitly asked; their behaviors may be driven by subconscious processes (Calvert and Brammer 2012). Additionally, as the appearance of a wood surface is always evaluated as an indivisible whole, the visual features of wood surfaces (color, grain, and gloss) should be studied comprehensively to reflect real situations in daily life. With the development of neurophysiology and mature of measurement techniques, physiological parameters could be used to investigate the processes of visual perception in a more objective way than before.

1.3 An assessment method based on neuroscience

Some physiological signals that reflect human cognitive processes are associated with the dynamic flow of aesthetic appreciation. Several early studies have measured subjects' perception of products using physiological and neural responses (Khushaba et al. 2013; Chen et al. 2014; Ohira and Hirao 2015). Methods that collect subjects' physiological data accompanied by their emotions can provide real-time information on a series of responses (Ding et al. 2016). In marketing research, physiological measurements such as brain imaging, eye movement, heart rate, blood pressure, and voice pitch analysis have displayed adequate reliability, applicability and validity (Wang and Minor 2010). Human perception is an implicit process that is difficult for the perceiver to describe in words alone, even with rational thinking. Hence, using neural methods could help researchers explore human perceptual processes and complement the traditional subjective reporting method to assess preferences regarding the visual aesthetic properties of wood surfaces.

Event-related potentials (ERPs), recorded by electroencephalography (EEG), are very small voltages generated in the brain in response to specific cognitive events or stimuli (Blackwood and Muir 1990). With high temporal resolution and the ability to be measured noninvasively, ERPs are employed to explore the flow of visual appreciation. ERP measurement, which has the advantages of relatively low cost, can reflect human psychological activity and assess the

topographic distribution of brain activity with millisecond temporal resolution for experimental studies (Pollatos et al. 2005; Morin 2011; Daliri et al. 2013; Luck 2014). Different time "windows" within ERPs can reflect human emotional activity to help clarify the specifics of cognitive function within the brain (Song and Zhao 2012). Further information of EEG and ERPs are available in the Appendix. As it takes approximately 20 ms for information to reach the cortex from a peripheral sense organ, early ERP components mainly reflect neuronal activity in the afferent pathways of the brainstem. In contrast, ERP components appearing after approximately 70 ms often reflect the subject's evaluation of a stimulus (Blackwood and Muir 1990). Some special early cortical visual ERP components can effectively reflect initial sensory processing (Tommaso et al. 2008). For example, N100, peaking at approximately 80–120 ms, is related to physical features detected in the early stage of processing and is sensitive to both affordance (i.e., things are perceived as highly functional) and attractiveness (Righi et al. 2014). N100 is also considered sensitive to the emotional valence of affective pictures (Carretié et al. 2010). Some previous studies showed that the 200–400 ms window is associated with visual perception (De et al. 2008; Handy et al. 2010; Li et al. 2015). N200 (a component with negative amplitude peaking at approximately 200 ms) was demonstrated to reflect initial sensory processing (De et al. 2008). Moreover, the visual N200 ERP (peaking in the time window of 200–350 ms) reflects the perception of beauty (Cela-Conde et al. 2011). P200 (a positive visual evoked potential peaking at approximately 100–200 ms) was associated with rapid and coarse attentional resource allocation in the early-stage evaluation of affective pictures (Carretié et al. 2001; Huang and Luo 2007).

This study aims to explore the visual perception of different wood surface using a neurophysiological method and investigate the neural activity evoked by these stimuli. Our experiment is based on the recording of ERPs that previous studies have found to be relevant to visual processing (N100, N200 and P200). Based on the types of wood materials that are popular in the market, wood samples of three different colors, two different types of grain and three different gloss values were used as stimuli. In order to eliminate the influence of light (angle and intensity) and meet the requirements for repeated measurement in an ERP study (Luck 2014), all the stimuli used in our study are digital simulation models derived from real wood samples. Both ERPs and subjective data were combined to analyze subjects' visual perception of the wood surface appearances after different treatments. We hypothesized that different wood surface appearances could induce different neural activity, reflected by the N100, N200 and P200 ERP components, which could reveal the details of the visual perception for these stimuli.

2 Material and methods

ERP measurements and subjective evaluations were combined to investigate the visual perception of different wood surfaces. After the ERP data were obtained, subjects were asked to complete a predesigned questionnaire reflecting their subjective evaluation of the stimuli (Wan et al. 2019).

2.1 Subjects

Twenty-two healthy right-handed students (11 males and 11 females with a mean age of 23.09 years, SD = 2.86) from Beijing Forestry University were recruited as volunteers. All subjects had normal or corrected-to-normal vision and no history of neurological or psychiatric disorders. All the subjects signed an informed consent document before the experiment and received a gift as compensation after the test.

2.2 Stimuli

Three different types of solid wood were prepared and used in both parts of the study (the ERP section and the questionnaire section); these three materials differed in color (*Fraxinus excelsior* [FE], light; *Tectona grandis* [TG], medium; *Juglans nigra* [JN], dark). All wood samples were produced in an industrial sawmill with raw sawn board dimensions of 150 mm width, 200 mm length, and 25 mm thickness. Each of the three types of wood was cut to expose 2 grains (radial and tangential), and 3 different finishing procedures were used to impart different levels of gloss from low to high (no paint [matte], wax oil paint [semigloss] and water-soluble light paint [glossy]). Thus, the number of samples was 18 (3 colors × 2 grain types × 3 gloss levels). Studies have shown that coatings have some influence on the aesthetic characteristics of wood (Scrinzi et al. 2011). However, it is not feasible to eliminate the effect of coating, which changes the color of the wood surface. This is because the coating is an indispensable step in the manufacture of wood products. In order to minimize the influences of surface treatment on the color of the wood and the appearance of its grain, all wood surface treatments used in our study were clean paintings. Moreover, in order to eliminate the delicate differences in the stimuli, each of these 18 samples had two other replicate samples produced from the same sawn timber under the same conditions. Thus, 54 wood samples (18 original samples and 2 backups for each of these samples) were prepared in this study.

When evaluating the gloss of a piece of material, we see it as a two-dimensional image of light reflection (Nakamura et al. 1999). Therefore, it is important to

ensure uniform environmental lighting during the test. Modeling a design before it is actually produced is a useful way for enterprises to evaluate the design and reduce the production cost. Another reason for the use of visual models is that ERP waveforms need to be extracted from the grand average superposed waveform calculated from many rapidly repeated trials in a short time interval (Luck 2014). These responses are difficult to observe directly when the subjects are shown real samples. Thus, in our study, we used digital models of real wood samples as stimuli and displayed them on a screen to help us control the illumination environment, meet the need for repeated measurements in ERP studies, and simulate the early design process of wood products. Models of the prepared wood samples were built in the 3D studio Max 2014 and rendered by the Vray 3.1 rendering plug-in, and the texture mappings were taken from scanned images of the prepared wood samples. We mirrored the digital textures and tiled them together as a whole picture for evaluation. We used this approach because the textures in wooden products, such as wood furniture, floors, and doors, are mostly repeated patterns that appear continuously. Thus, the repeated textures in the stimuli reflect what is typically encountered in real situations. Thus, a 300 mm × 200 mm image of each processed wood sample was used for the test. A light source was added to the virtual environment to illuminate the surface of each 3D model from an oblique angle (45°, a suitable angle for showing the materials' gloss). After the image models were modeled and rendered, mirrored versions and inverted versions of all images were creased in Photoshop CC to eliminate the impact of the texture and light direction on cognitive judgment. Ultimately, we obtained a total of 216 digital images (18 original samples × 3 backups × 2 mirror images × 2 upside-down images) as stimuli for the experiment. The detailed process of stimulus production is shown in Fig. 1. Finally, all the wood samples are reconstructed in 3D software with a unified lighting environment and display angle (Fig. 2).

2.3 Indexes of subjective evaluation and questionnaire design

According to related research, material properties, potential applications, performance, and environmental protection senses have greatly influenced the evaluation of materials (Karana et al. 2015). Manzini emphasized that the material's functionality was the characteristic most valued by the user (Manzini 1989; Manzini and Petrillo 1991), which indicated that the sense of usability is an important index with which to evaluate materials. He also indicated that material should be socially and culturally acceptable (Manzini 1986). Such an opinion is supported by the present popularity of wood as a material in cultures worldwide. Moreover, when we are evaluating a material, our impression and evaluation are not only influenced by the material itself but also associated with the product
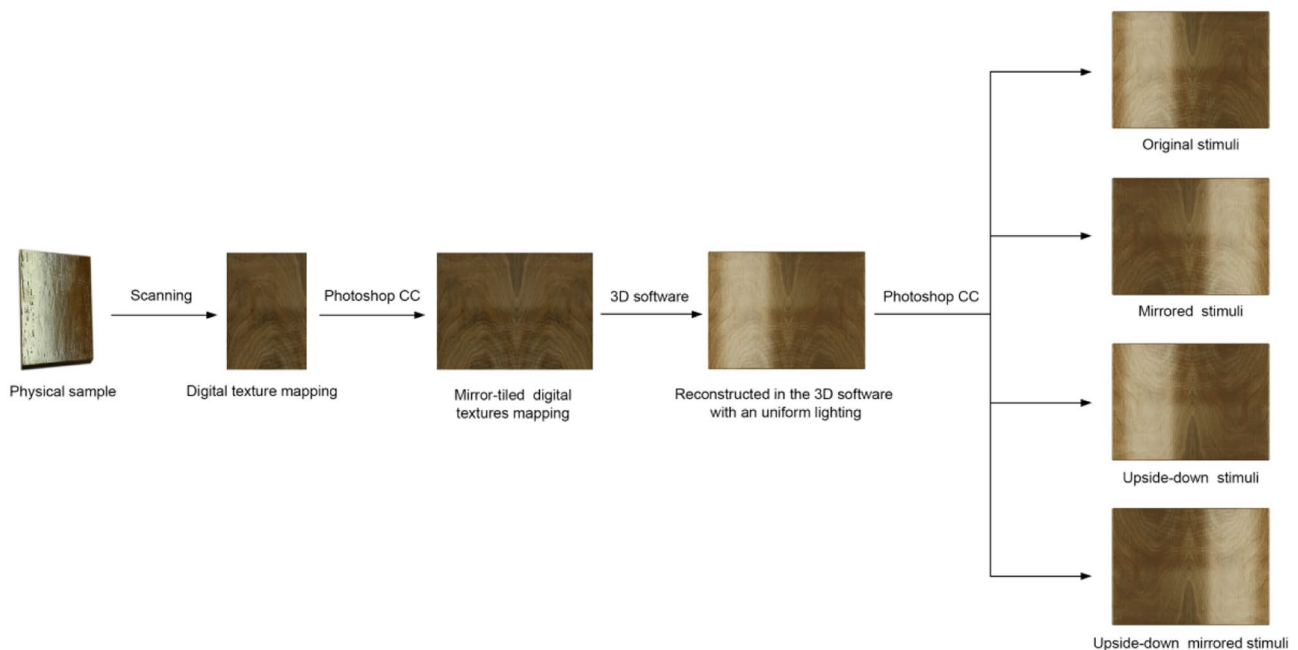

Fig. 1 The detailed process of stimulus expansion production, each of the 54 physical samples was expanded into 4 different stimuli

Fig. 2 Example of 18 difference kinds of wood original samples reconstructed in the 3D software. Including 3 kinds of wood colors (light, medium, and dark color), 2 kinds of grains (radial, tangential), and 3 kinds of glosses (matt, semigloss, and glossy). Each of them has 2 other samples produced from the same sawn timber under the same condition to eliminate the delicate differences of the stimuli in the test

made from the material. Therefore, the economic efficiency of the material, which significantly influences our evaluation of the product, was also chosen as one of the evaluation indexes in the study. Thus, the scale we used in this study includes 5 dimensions to evaluate the subject's visual cognitive preference for the material in design: 1) beauty, 2) usability, 3) environmental friendly, 4) cultural, and 5) economic efficiency.

In order to help subjects evaluate those 5 dimensions of cognitive preference between materials, 30 pairs of Kansei adjective words that describe materials' visual characters were chosen from related papers, magazines, and websites. Then, 70 students (35 males, with a mean age of 23.12 years, SD = 1.93) were asked to rank those Kansei adjective words by different preference. Two of the most selected pairs of Kansei words in each dimension were chosen to reflect the characteristics of that dimension. Finally, 10 pairs of Kansei words were selected for the scale (Table 1). A 7-point Likert scale (1, totally agree with the negative description, to 7, totally agree with the positive description) was used. As each pair of adjective words has a strong tendency to reflect preference, materials with a higher score

mean that subjects have a higher visual preference. Each dimension's score of the materials' visual cognitive preference could be obtained by adding the scores of the two pairs of Kansei adjective words that belong to the dimension. The reliability of the scale was tested with Cronbach's α = 0.93 (Field 2009). All subjective data were analyzed by within-subject repeated-measures analysis of variance (ANOVA), and their correlations with ERP data were analyzed.

2.4 Experimental environment and apparatus

The experiment took place in the brain cognitive laboratory with soft lighting at the College of Material Science and Technology, Beijing Forestry University. The experimental apparatus used was an ESI-46 Leads EEG Neuroscan recording analysis system (Neurosoft Labs Inc), and the electrode location was based on the international 10–20 electrode placement system. This apparatus can collect brainwaves through electrodes (sewn on a cap) located at specific areas of the scalp (Lin et al. 2018). The distribution of these electrodes is shown in Appendix Fig. 11. The stimuli were presented

Aspect	Beauty	Usability	Environmental friendly	Cultural	Economic efficiency
Kansei words	Ugly	Firm	Environmental	Civilized	Rare
	Artistic	Fragile	Infectant	Insolent	Cheap
	Elegant	Easeful	Harmless	Modern	Top grade
	Raffish	Afflictive	Harmful	Uncultured	Low-end

Table 1 Ten pairs of Kansei words chosen in the scale

on a 19-inch LCD (1600×900 pixels, 60 Hz) screen with a white background, and the size of stimuli was adjusted to be clearly observed by the participants (732×549 pixels). The whole task was automatically programmed and presented using E-prime Professional 3.0 (a psychology software tool that provides computerized experimental design, data collection, and millisecond-precision timing).

2.5 Procedure

In order to explore the visual perception of wood appearance with different surface treatments, participants were first asked to comfortably sit in front of the computer screen and focus on the center of the screen. The stimuli were presented on the screen with a distance of approximately 80 cm, and a visual angle about $20.8° \times 15.6°$ (width $\times$ height). The visual angle is the angle a viewed object subtends at the eye (including both the width and the height of the object). A fixed viewing angle meant that the objects could be observed at the same size in the study. Before the formal experiment, the instructions for the test procedure were shown on the screen. After the participant fully understood the testing requirements, the computer screen started to play a countdown clock for 180 s so that the participants could relax. Before each stimulus appeared on the screen, there was a blank page with a "+" symbol located at its center for 1000–1200 ms. After that, all the stimuli occurred randomly for 800 ms presentation duration. In order to improve the signal-to-noise ratio of ERPs (Luck 2014), each of the 216 prepared digital images was repeated 5 times; in other words, each of the 18 original samples, ignoring their repetitions and transformations, appeared 60 times in the test. There were four rest periods, each consisting of a 1-min break. After this test, subjects were asked to complete a questionnaire about their subjective evaluation of the stimuli. The entire experiment lasted approximately 65 min, including electrode placement and instruction, as shown in Fig. 3.

2.6 Electrophysiological (EEG) recording and analysis

Brain electrical activities were recorded by the Neuroscan cap, and the EEG signals were sampled at a rate of 1000 Hz. The reference electrodes were placed on the left and right mastoids. Vertical and horizontal electro-oculograms (EOGs) (see Appendix) were recorded from the left eye supra- and infraorbitally and from the orbits of both eyes, respectively. These data were used to eliminate trials contaminated by blinking, eye movement, or other artifacts. All of the electrodes were maintained below 5 kΩ during the experiment.

The data were analyzed offline using the EEGlab toolbox (EEGlab v12.0.2.4b, Delorme and Makeig 2004; Lin et al. 2018; Martínez-Cancino et al. 2020) under MATLAB R2012a (MathWorks, Natick, MA, USA) to obtain clean ERP data. There are five key steps in the offline data analysis: (1) re-referencing, (2) filtering, (3) segmentation, (4) independent component analysis (ICA), and (5) averaging (Luck 2014). The process and explanation of offline data analysis are shown in Appendix Fig. 12. The raw EEG data was re-referenced to the averaged mastoids and filtered with a 0.1–30 Hz bandpass to optimize ICA decomposition for artifact correction (Luck 2014). These data were narrowed to an epoch from 200 ms before the stimuli onset to 800 ms after the stimuli onset. In addition, each epoch was baseline corrected by using the signal during the 200 ms preceding the onset of the stimuli. Epochs with amplitudes exceeding ± 75 µV were rejected, and epochs containing a single channel that exceeded 4 standard deviations of the channel's mean across epochs were removed to optimize ICA decomposition. Data were then decomposed into temporally independent components using Infomax ICA (Bell and Sejnowski 1995). Artifacts (blinks, eye movement, muscle tension, etc.) were manually identified and subtracted from the data. Trials from 18 kinds of stimuli were selected and averaged separately to obtain the ERPs for each condition. Then, the ERPs were analyzed based on the EEG data using the mean amplitude values
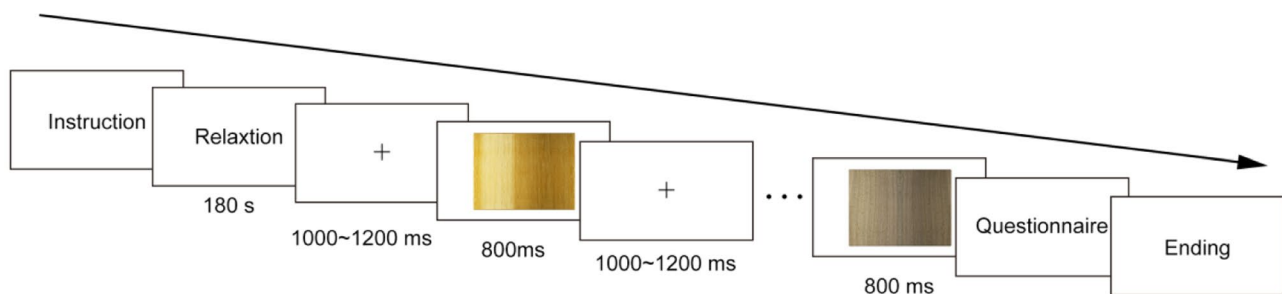

Fig. 3 The process of the test

for a specific set of electrode sites within predefined time windows using EEGlab.

The ERPs were analyzed by within-subject repeated-measures ANOVA, corrected with the Greenhouse–Geisser correction. An α level of 0.05 was set for statistical tests. Electrodes are divided into five subgroups for better analysis of the recording data: a frontal group (F3, FZ, F4), a central group (C3, CZ, C4), a central-parietal group (CP3, CPZ, CP4), a parietal group (P3, PZ, P4), and an occipital group (O1, OZ, O2) (Cona et al. 2015). As different ERPs correspond to different brain locations, the occipital site, which was not related to the chosen ERPs (N100, P200, N200) used in our study was excluded from the analysis. According to related studies (Li et al. 2015; Ding et al. 2017), frontal sites and central sites were chosen for statistical analysis within the time window of 150–200 ms for N100 and 260–340 ms for N200, and the central-parietal site and parietal site were chosen within the time window of 200–260 ms for P200. Within each time window, the average potentials were fed into multifactorial repeated-measures ANOVAs with four factors: color (light-colored FE, medium-colored TG, or dark-colored JN), grain (radial, or tangential), gloss (matte, semimatte, or glossy), and site (frontal, central, central-parietal, or parietal site). Multiple comparisons of means were performed with Tukey's posttests. In addition, the topographic maps for each time window that showed the locations of brain activities were also drawn as reference. The principle of data recording and analysis is shown in Fig. 4.

3 Results

According to the analyses, no interaction effect was found among those features of wood appearance (color, grain, and gloss). Therefore, the results presentation is mainly focused on the main effects of each variable on ERPs.

3.1 ERP analysis in different colors

The grand averaged ERP waveforms for different wood colors are shown in Fig. 5, and scalp topographic maps for each time window are shown in Fig. 6. Mean amplitudes across scalp locations and conditions are reported in Table 2 with two-way ANOVA.

For N100 (150–200 ms), there were main effects of color [$F(2, 42) = 16.839$, $p < 0.001$, $\eta^2 = 0.445$]. Follow-up testing revealed that dark-colored wood elicited a larger N100 than light or medium-colored wood in the frontal ($p < 0.001$, $p < 0.001$) and central ($p = 0.02$, $p < 0.001$) sites. In addition, medium-colored wood
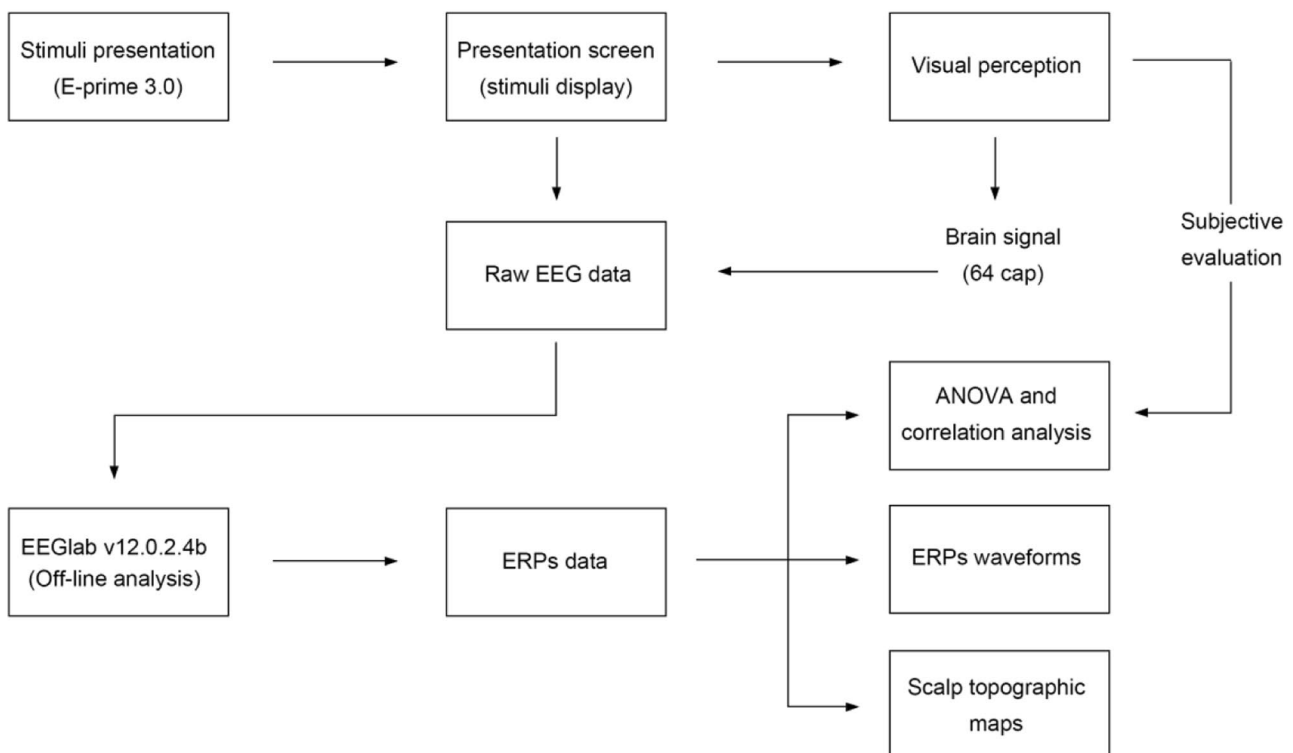

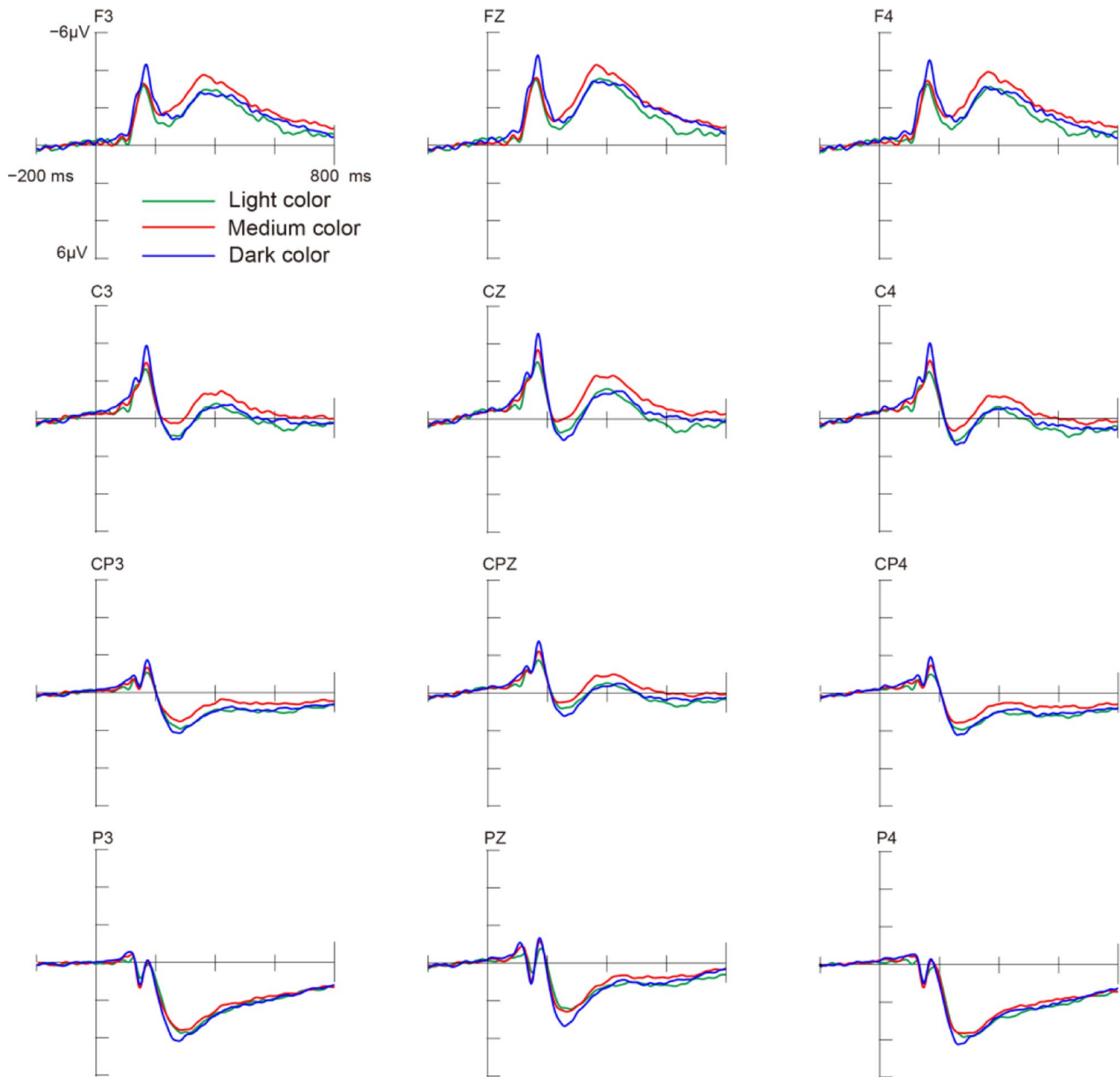**Fig. 4** The principle of data recording and analysis (Ding et al. 2016)

Fig. 5 Grand averaged ERPs for light-colored wood (green), medium-colored wood (red), and dark-colored wood (blue). Time − 200–800 ms, at selected frontal group (F3, FZ, F4), central group (C3, CZ, C4), parietal group (P3, PZ, P4)

elicited a larger N100 than light-colored wood at the central site ($p = 0.009$).

For P200 (200–260 ms), there were main effects of wood color [$F(2, 42) = 8.566$, $p = 0.001$, $\eta^2 = 0.290$]. Dark-colored wood induced a larger P200 than medium-colored wood at the central-parietal ($p = 0.011$) and parietal ($p < 0.001$) sites, but its P200 was larger than that of light-colored wood specifically at the parietal site ($p < 0.001$).

For N200 (260–340 ms), there exist significant main effects of color [$F(2, 42) = 12.897$, $p < 0.001$, $\eta^2 = 0.380$]. The simple

analysis mainly revealed that medium-colored wood elicited a larger N200 than dark- or light-colored wood at both the frontal ($p < 0.001$, $p = 0.003$) and central sites ($p < 0.001$, $p < 0.001$).

3.2 ERP analysis in different grain types

The grand averaged ERP waveforms for different wood grain types are shown in Fig. 7, and topographic maps for each time window are shown in Fig. 8. Moreover, mean
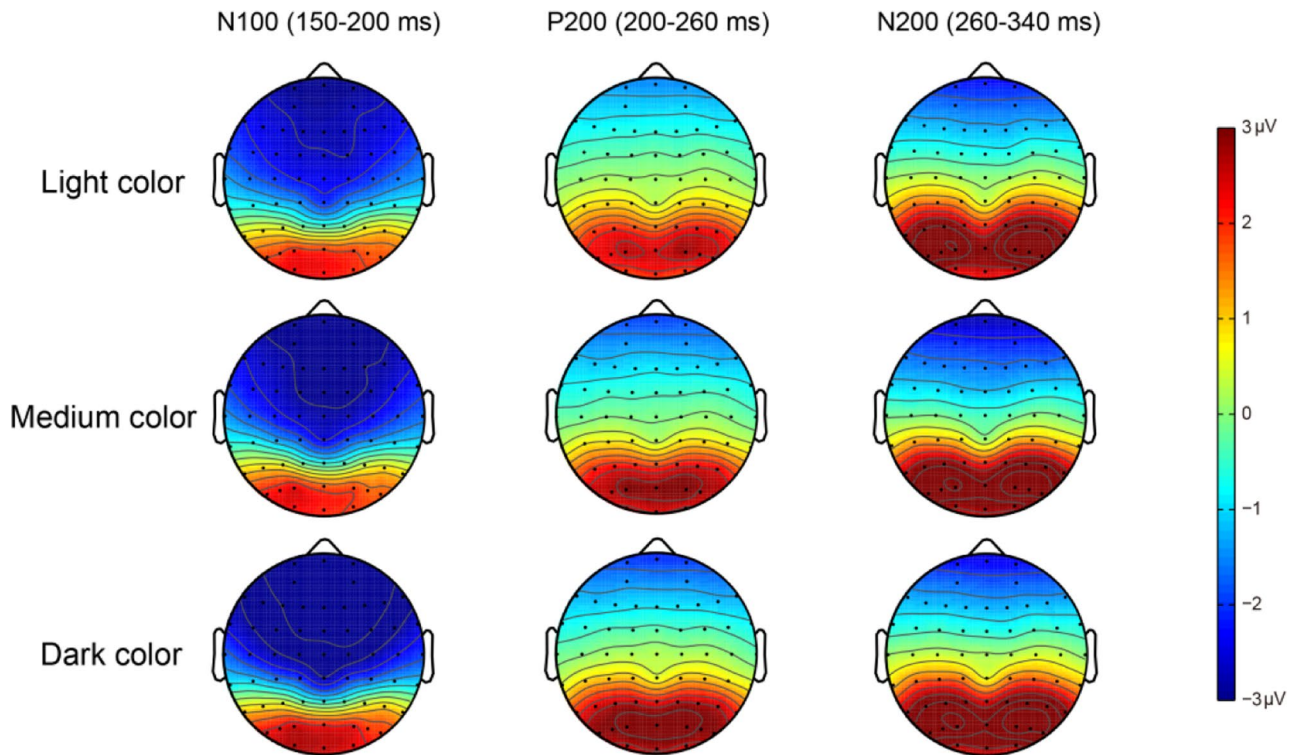
Fig. 6 Grand average topographic map showing ERP components for N100 at 150–200 ms, for P200 at 200–260 and for N200 at 260–340 ms, for three wood colors, light, medium, and dark

amplitudes across scalp locations and conditions are reported in Table 3 with a two-sample paired *t* test.

For N100 (150–200 ms), there was no main effect of grain type [$F(1, 21) = 1.244$, $p = 0.277$, $\eta^2 = 0.056$]. According to the results of the grand average ERP waveforms, a larger N100 was evoked by the radial grain than by the tangential grain, but this difference was not significant.

For P200 within the time window of 200–260 ms, there were main effects of wood grain type [$F(1, 21) = 5.881$, $p = 0.024$, $\eta^2 = 0.219$]. Radial-grain wood elicited larger P200 than tangential-grain wood at both central-parietal ($p = 0.026$) and parietal sites ($p < 0.001$).

For N200 (260–340 ms), no main effect of wood grain [$F(1, 21) = 1.244$, $p = 0.277$, $\eta^2 = 0.056$] was found. The simple analysis mainly revealed that tangential-grain wood elicited larger N200 than radial-grain wood on the central site ($p = 0.012$).

3.3 ERP analysis in different glosses

The grand averaged ERP waveforms for different wood glosses are shown in Fig. 9, and topographic maps for each time window are shown in Fig. 10. Mean amplitudes across scalp locations and conditions are reported in Table 4 with one-way ANOVA.

Table 2 Mean amplitude (µV) of group-averaged ERPs and the results with two-way ANOVA in three conditions by different colors

| ERPs	Location	Light color		Medium color		Dark color		F	p	η^2
		Mean	SD	Mean	SD	Mean	SD			
N100	Frontal	− 2.62	2.12	− 2.89	2.25	− 3.60	2.22	20.411	< 0.001	0.493
	Central	− 2.13	1.73	− 2.49	1.90	− 2.95	1.89	11.811	< 0.001	0.360
P200	Central-parietal	1.25	2.42	1.05	2.48	1.53	2.77	4.275	0.02	0.169
	Parietal	3.22	2.69	3.49	2.90	4.15	3.17	15.441	< 0.001	0.424
N200	Frontal	− 1.91	2.95	− 2.65	3.09	− 1.98	3.40	9.931	< 0.001	0.321
	Central	0.44	2.45	− 0.28	2.42	0.59	2.71	14.749	< 0.001	0.413
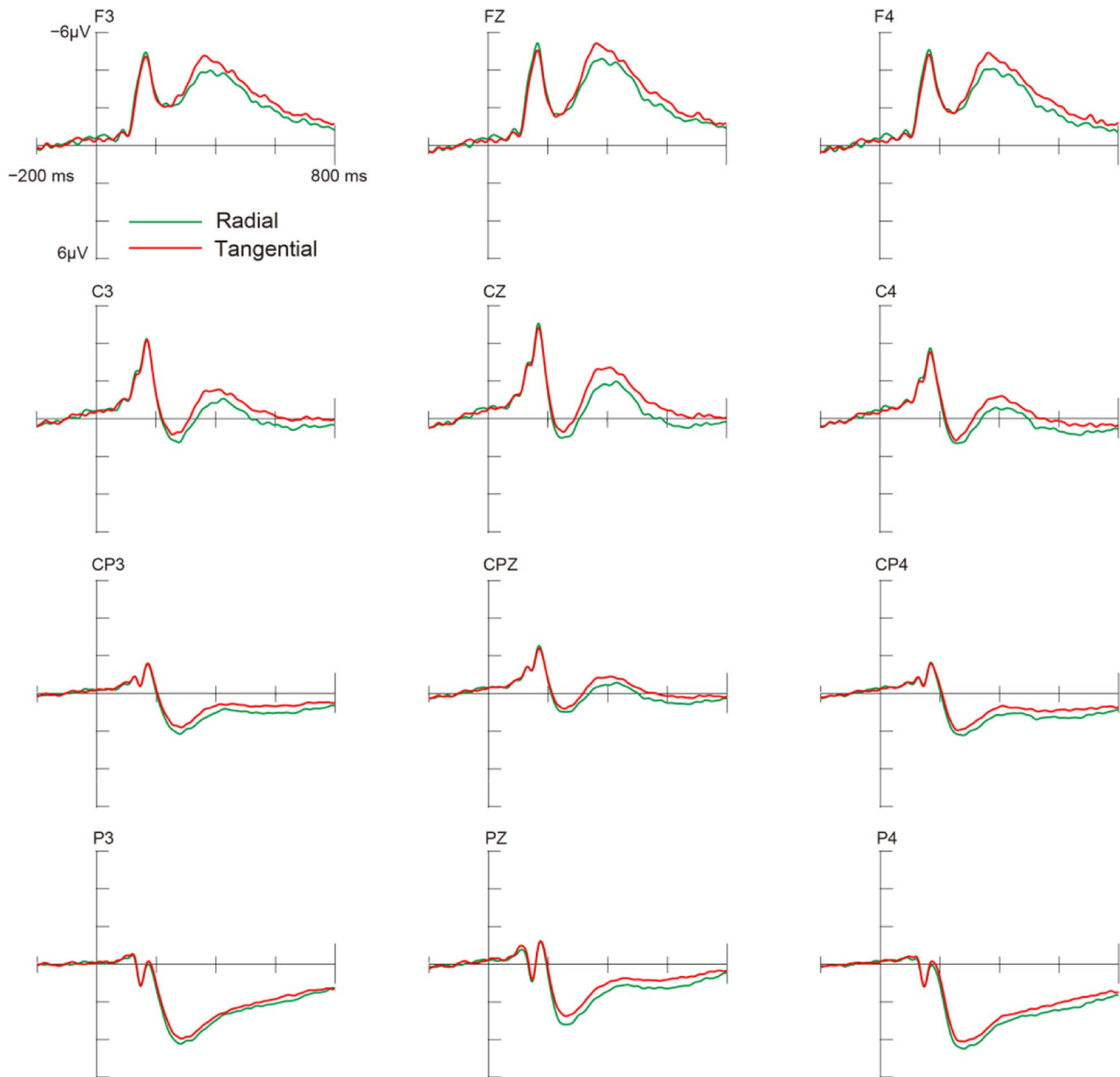
Fig. 7 Grand averaged ERPs for radial wood (green) and tangential wood (red). Time − 200–800 ms, at selected frontal group (F3, FZ, F4), central group (C3, CZ, C4), parietal group (P3, PZ, P4)

For N100 (150–200 ms), the effect of gloss was significant [$F(2, 42) = 3.218$, $p = 0.050$, $\eta^2 = 0.133$]. The simple analysis main revealed that semigloss wood elicited a larger N100 than glossy wood at the frontal ($p = 0.024$) and central ($p = 0.016$) sites and a larger N100 than matte wood at the frontal site ($p = 0.047$).

For P200 within the time window of 200–260 ms, there were main effects of gloss [$F(2, 42) = 5.996$, $p = 0.005$, $\eta^2 = 0.222$]. Results from follow-up testing

revealed that semigloss wood evoked larger P200 than matte wood at both central-parietal ($p = 0.034$) and parietal sites ($p < 0.001$), but its P200 was larger than that of glossy wood only at the parietal site ($p = 0.045$).

For N200 (260–340 ms), there was no main effect of gloss [$F(2, 42) = 0.608$, $p = 0.549$, $\eta^2 = 0.028$]. According to the grand average ERP waveforms, semigloss wood elicited a larger N200 than glossy or matte wood at both the frontal and central sites, but this difference was not significant.

Fig. 8 Grand average topographic map showing ERP components for N100 at 150–200 ms, for P200 at 200–260 and for N200 at 260–340 ms, for two wood grains, radial and tangential
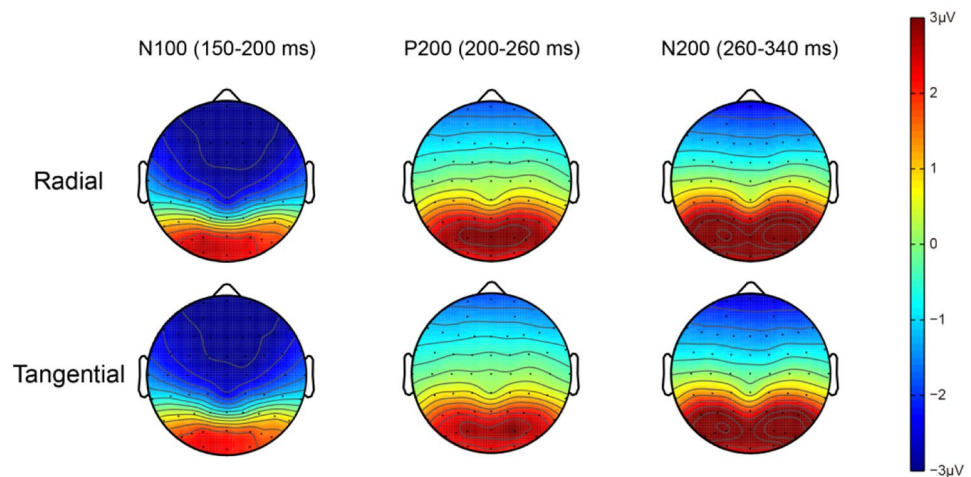
3.4 Results of subjective evaluation

Subjective data were measured to characterize the visual preference of each kind of wood material. The average scores of different wood features are shown in Table 5. The results of one-way ANOVAs showed that there were significant differences on preferences with wood colors [$F(2, 42) = 10.482$, $p < 0.001$, $\eta^2 = 0.333$] and wood glosses [$F(2, 42) = 5.856$, $p = 0.006$, $\eta^2 = 0.218$]. However, there was no main effect of wood grain type ($t = -1.296$, $p = 0.209$). Moreover, the ANOVAs posttest indicated that subjects preferred dark wood to light ($p = 0.009$) or medium-colored wood ($p < 0.001$). Semigloss wood had a significantly lower preference score than glossy ($p = 0.021$) or matte wood ($p = 0.05$). Significant interaction effect of wood appearances (color, grain, and gloss) on subjective preference was found, however, due to the main goal of the current study, this result will be discussed in further researches.

3.5 Correlation analysis between subjective evaluation and ERPs

Table 6 shows the correlation between the subjective evaluation of visual preference and average amplitudes

of ERPs. Frontal and central areas were selected for N100 and N200, and central-parietal and parietal areas were selected for P200. There was a negative correlation between the subjective evaluation of visual preference and the average amplitude of P200, $r = -0.606$, $p = 0.003$. However, no significant correlation was found between the subjective evaluation of visual preference and the average amplitude of N100 or N200.

4 Discussion

Visual N100 is associated with the early phase of visual processing on emotional stimuli (Weinberg and Hajcak 2010), which is also regarded as an index of the allocation of attentional resources of selection and discrimination (Anllovento and Hillyard 1996; Vogel and Luck 2000). Moreover, study have shown that the N100 component responds to the perceptual characteristics of visual stimuli (Tian et al. 2002) and is sensitive to low-level features such as color, luminance and contrast (Anllovento and Hillyard 1996; Vogel and Luck 2000; Bradley et al. 2007). In our experiment, the results showed that the largest N100 amplitudes were evoked by dark and semigloss wood stimuli. However, no significant difference was found within the condition of grain type. This indicated that

Table 3 Mean amplitude (µV) of group-averaged ERPs and the results of a two-sample paired t test in two conditions at different grains

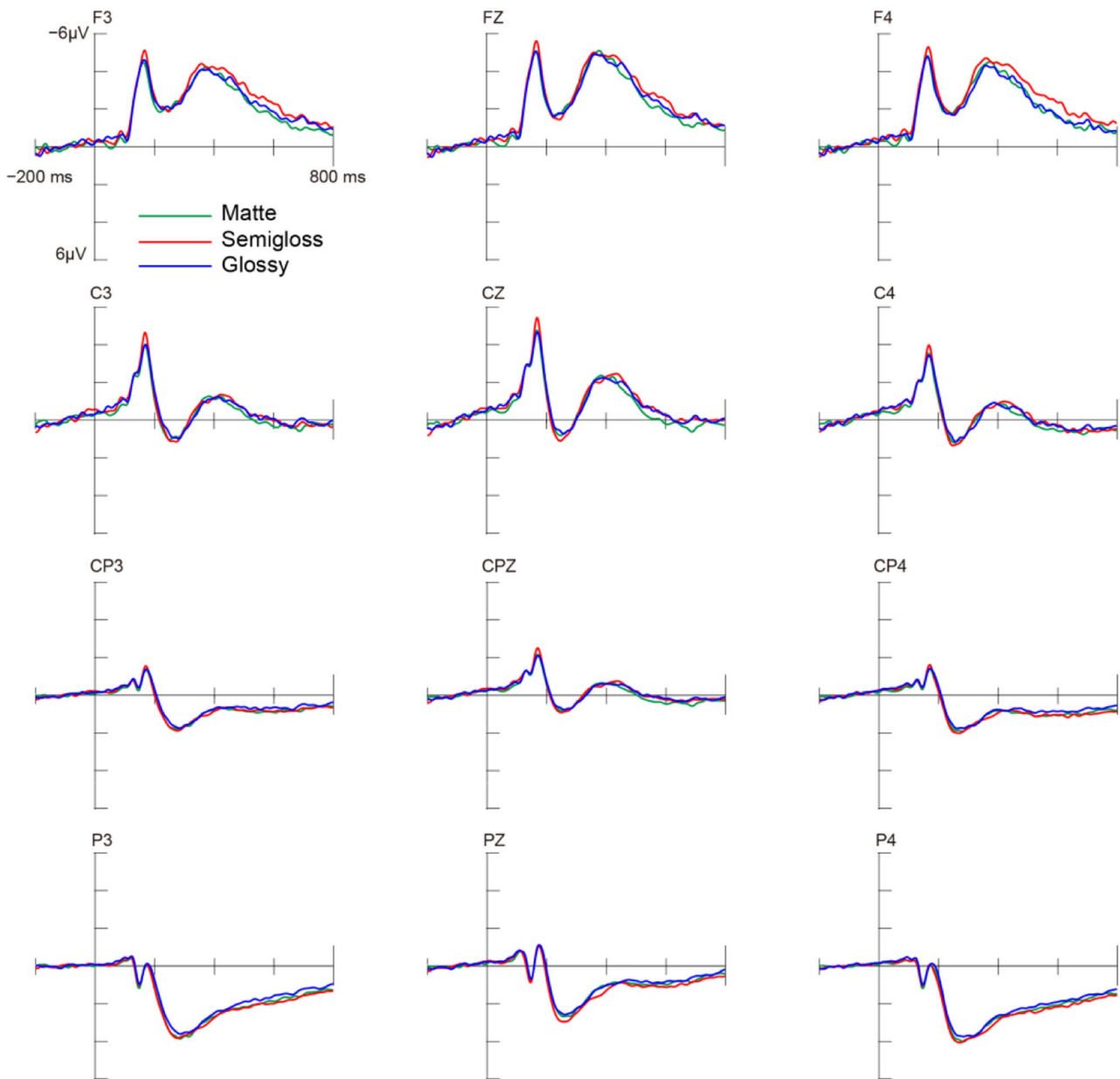| ERPs	Location	Radial		Tangential		T	p
		Mean	SD	Mean	SD		
N100	Frontal	− 3.13	2.17	− 2.95	2.18	− 1.660	0.112
	Central	− 2.55	1.79	− 2.50	1.82	− 0.591	0.628
P200	Central-parietal	1.45	2.60	1.11	2.50	2.403	0.026
	Parietal	3.90	2.96	3.34	2.83	4.497	< 0.001
N200	Frontal	− 2.02	3.17	− 2.35	3.13	1.983	0.061
	Central	0.46	2.56	0.02	2.50	2.763	0.012

Fig. 9 Grand averaged ERPs for matte wood (green), semigloss wood (red) and glossy wood (blue). Time -200–800 ms, at selected frontal group (F3, FZ, F4), central group (C3, CZ, C4), parietal group (P3, PZ, P4)

differences in color and gloss of wood surface appearance might attract attention more quickly than wood grain during the very first presentation of a sample. Textures on the wood surface are a type of detailed, complex natural pattern. This would cause a longer observation and processing time for subjects in cognition procedure, which also implies that the evaluation of wood grain could be a higher-order cognitive process than the evaluation of color or gloss, requiring a longer processing time before the differences can be detected.

P200 has been shown to be associated with higher-level perceptual and attentional processing of visual stimuli (Luck and Hillyard 1994; Hajcak et al. 2012) and reflects the beginning of the initial assessment (Wang et al. 2012). Moreover, Di Russo's study has shown that P200 in 200–300 ms reflects the early visual discrimination of stimuli (Russo et al. 2006), and another study suggested that P200 in 240–260 ms may reflect the activation of different visual pathways (O'Donnel et al. 1997). The results of our experiment showed that all three conditions
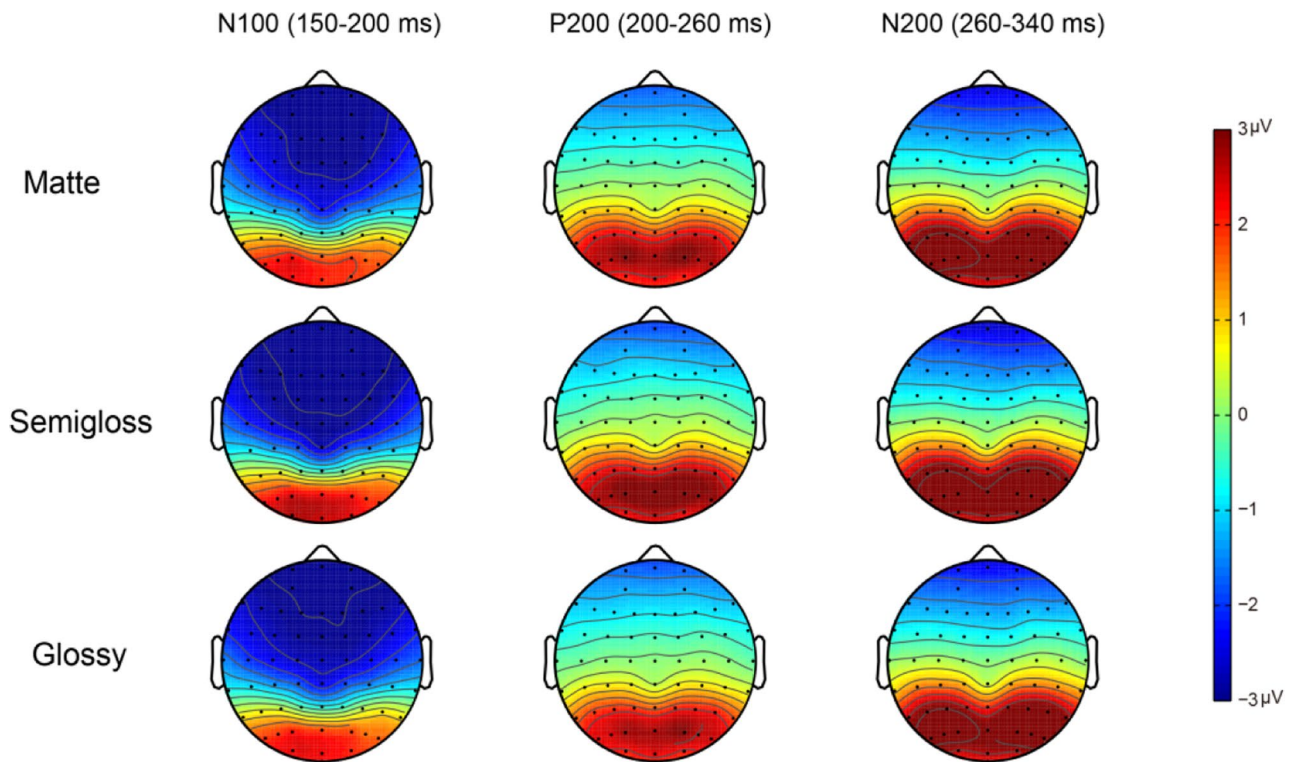
Fig. 10 Grand average topographic map showing ERP components for N100 at 150–200 ms, for P200 at 200–260 and for N200 at 260–340 ms, for three wood glosses, matte, semigloss, and glossy

exhibited a main effect difference in P200, where the dark color, semigloss, and radial-grain wood elicited larger P200 amplitudes. This phenomenon supported the idea, discussed above, that the evaluation of wood grain is a higher-order cognitive process that can be detected by the P200 component. Furthermore, previous studies showed that P200 was also able to reflect the matching between the sensory input and the representation stored in memory (Phillips and Takeda 2009; Schendan and Lucia 2009). Since wood with a dark color (such as JN) or exclusively radial grain is rarely encountered in daily life (compared with a medium-colored or tangential grain), this mismatch of our sensory of wood appearance in memory may lead to a change in P200.

On the other hand, P200 is associated with early automatic emotion processing (Spreckelmeyer et al. 2006), where P200 prominent at frontal sites is viewed as an index reflecting the process of cognitive classification (Ma et al. 2015). In the literature, studies revealed that changes in ERPs could be elicited by positive or negative stimuli (Ding et al. 2017; Feng et al. 2014). Studies also suggested that P200 over central-parietal or occipital sites reflected greater automatic mobilization of attention resources to negative stimuli (Huang and Luo 2006; Carretié et al. 2011). A study from Wang et al. showed that beautiful pendants (positive stimuli) can lead to a lower P200 (Wang et al. 2012), and other studies suggested that negative stimuli evoked a larger P200 (Olofsson and Polich 2007; Carretié et al. 2011; Delplanque et al. 2004).

Table 4 Mean amplitude (µV) of group-averaged ERPs and the results with two-way ANOVA in three conditions at different glosses

ERPs	Location	Matte		Semigloss		Glossy		F	p	η^2
		Mean	SD	Mean	SD	Mean	SD			
N100	Frontal	− 2.99	2.20	− 3.25	2.24	− 2.89	2.16	3.427	0.042	0.140
	Central	− 2.50	1.71	− 2.70	1.91	− 2.37	1.87	2.554	0.090	1.108
P200	Central-Parietal	1.06	2.42	1.43	2.66	1.34	2.58	3.148	0.053	0.130
	Parietal	3.29	2.78	3.93	2.97	3.64	2.98	9.326	< 0.001	0.308
N200	Frontal	1.83	2.21	1.88	2.50	1.87	2.25	0.056	0.946	0.003
	Central	4.73	2.88	5.02	3.01	4.94	2.94	2.702	0.079	0.114

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Table 5 Subjective scores of different wood features

Variable		Total	
		Mean	SD
Color	Light color	47.30	8.07
	Medium color	44.11	10.95
	Dark color	52.83	9.77
Grain	Radial	47.57	8.47
	Tangential	48.59	8.22
Gloss	Matte	49.08	8.01
	Semigloss	45.80	9.50
	Glossy	49.35	8.61

These studies revealed the difference in P200 variety when participants were evaluating absolutely positive and negative stimuli simultaneously in one experiment. However, during our test, we did not define any stimulus as a positive or negative stimulus, and the subjective evaluation was processed after the fact. Therefore, we cannot discuss how positive or negative wood appearance influences ERPs, and this is not the purpose of our study. Participants' preference for positive or negative wood stimuli is a relative concept in our test and thus may lead to a mismatched result compared with previous studies. This may explain why dark color wood evoked a larger P200 with a higher subjective evaluation and semigloss wood evoked a larger P200 with a lower subjective evaluation. Although the evaluation of liking or disliking in our study was implicit, the average amplitude of P200 had a negative correlation with the subjective evaluation. This result confirmed that pictures with a negative subjective evaluation could elicit a larger P200 than positively evaluated pictures.

Previous studies regarded N200 as an index related to automatic stimulus identification and closely associated with the cognitive process of perception, selective attention, increased attention, recognition, and categorization (Patel and Azzam 2005; Folstein and Van Petten 2010; Luck 2012). Moreover, N200 has been detected when human search stimuli are stored in visual working memory (Roberto et al. 2010), which is deemed an endogenous ERP component influenced by the physical features of the stimuli (Folstein and Van Petten 2010). In daily life, medium-colored (such as TG) and wood images with a tangential grain are more common than dark, light, or radial-grain wood. Wood

surfaces with a medium color and tangential grain are more similar to the impression of wood in our memory. Thus, it is possible that subjects were more familiar with these wood appearances, which attracted more attention resources. An enhanced N200 elicited in the frontocentral area indicates that more attention has been allocated to the corresponding stimuli (Folstein and Van Petten 2010). This may explain the result that the wood with a medium color and tangential grain evoked a larger N200 in our study.

There are several limitations in our study. First, the subjects in our study were all young students. The cognitive process may differ across different subject groups with different backgrounds. Since enterprises are interested in satisfying the needs of diverse consumer groups in reality, more subjects with diverse demographic backgrounds (age, income level, education level, and ethnicity) should be recruited and investigated. Second, the ERPs we chose were early visual evaluation indexes that may not fully reflect the effect on subjective evaluation, especially when the affective differences among these stimuli are small. Thus, the relationship between the very later ERP components, such as P300 or the LPP (late positive potential), and the subjective evaluation of wood appearance needs further investigation.

5 Conclusion

We investigated subjects' response to a variety of wood surface appearances by using ERP measures. Although we commonly believed that wood appearance is evaluated as an inseparable whole, the ERP results in our study showed that the visual cognitive process of inspection on color and gloss features started earlier than that on grain. The visual cognitive process of wood grain is a higher-order process compared with the process of color and gloss features. Furthermore, the mismatch in our sensory memory of wood appearance may evoke a larger P200, and familiarity with wood appearance may evoke a larger N200. Subjects prefer dark color wood over light and medium color wood. Also, in the experiment, subjects preferred semigloss wood over matte and glossy wood.

Current work proposes a more efficient way of investigating wood appearance and the feasibility of ERPs for measuring the perceptual processing of wood materials' visual features. In addition, this method can be applied in other materials' visual appearance assessment. Thus, the results from current work imply the possibility of taking advantage of the neurological approach for industries to improve the quality of their product.

Table 6 Correlation coefficients for subjective evaluation versus ERPs

Correlation	N100	P200	N200
Visual preference	− 0.216	− 0.606**	− 0.174

**p < 0.01

Appendix

Explanation of terms related to neuroscience

EEG: An electroencephalogram (EEG) records a type of spontaneous electric potential of the human brain. EEG signals are usually recorded by electrodes on the scalp and change with people's movements and mental activities.

ERPs: Event-related potentials (ERPs), extracted from EEG, are very small voltages generated in response to specific cognitive events or stimuli in the brain. ERP contains three key parameters: (1) amplitude, (2) latency, and (3) distribution over the scalp (Daliri et al. 2013). The average amplitude of ERPs is analyzed within the corresponding time window and used to calculate the difference between conditions. The latency, which is usually expressed in milliseconds, shows the time interval from stimuli onset to the occurrence of the ERPs peak. The scalp distribution of ERP represents which brain areas are working when stimulus is showed. Then, these three key parameters in ERPs can reflect people's psychological activities (Luck 2014). Usually, the ERPs are distinguished as negative and positive amplitudes, which are represented by the letter "N" or "P"

(Luck 2014). Meanwhile, the millisecond time of peak latency is marked after the letter to represent a complete ERP component. Frontal N100, for example, means a negative potential with peak latency, approximately 100 ms after stimuli are displayed and distributed on the frontal scalp.

EOGs. Electro-oculograms (EOGs) are a technique for measuring the corneo-retinal standing potential that exists between the front and the back of the human eye. The resulting signal is called the electro-oculogram. Vertical electro-oculogram (VEOG) and horizontal electro-oculogram (HEOG) recorded during an ERP study were used to eliminate the influence of eye activity on the signals.

Fig. 11 Distribution of electrodes based on the international 10–20 system. Notes: Central (C); frontal (F); temporal (T); occipital (O); parietal (P); frontal pole (Fp); anterior frontal (AF); frontal temporal (FT); frontal central (FC); temporal parietal (TP); central parietal (CP); parietal occipital (PO); scalp midline electrodes (z); even numbers (2–10): right hemisphere, numbers increase from midline z; odd numbers (1–9): left hemisphere, numbers increase from midline z; vertical electro-oculogram (VEOG); horizontal electro-oculogram (HEOG)
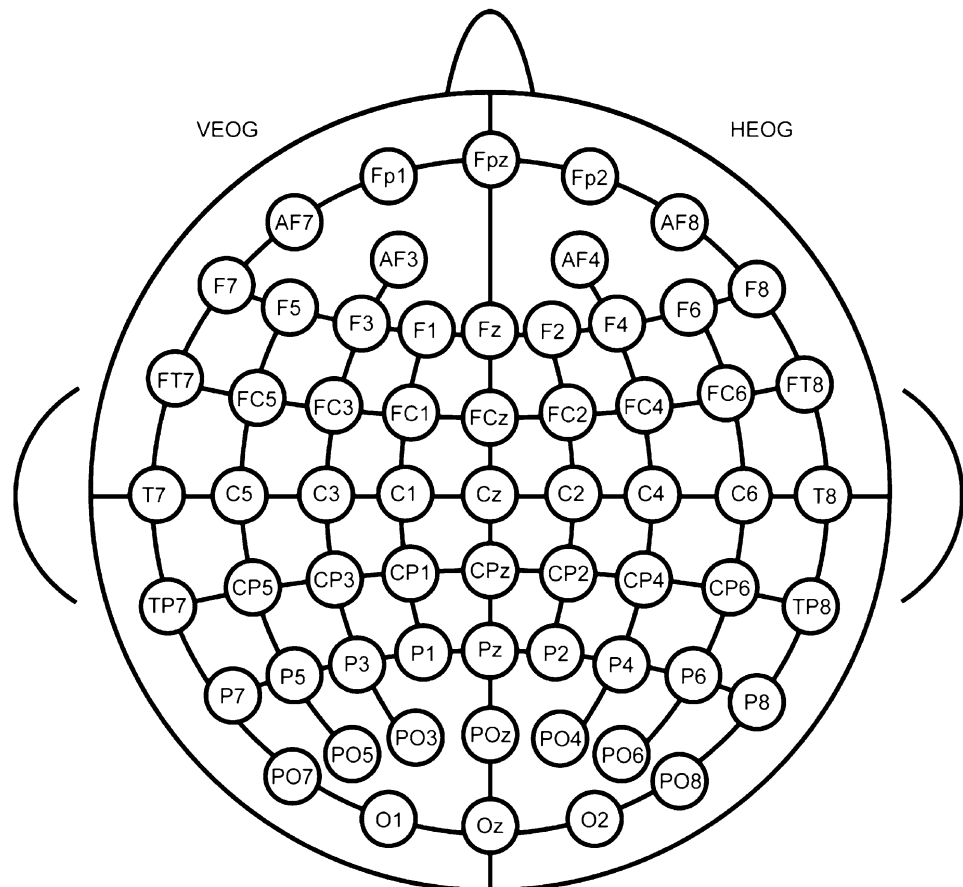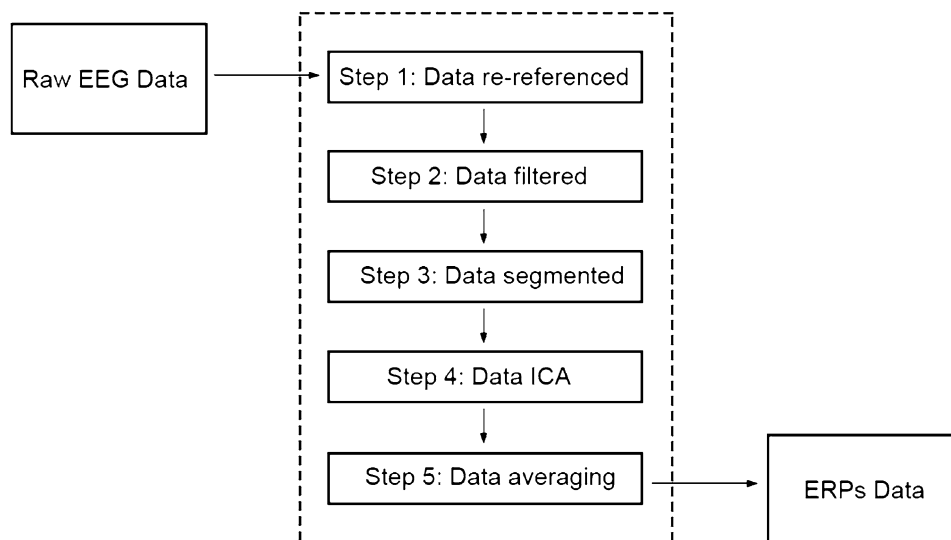
Fig. 12 The process and explanation of offline data analysis. Notes: *Step 1 Data re-referencing*: Since the EEG recorder records the potential difference between the two electrode points, a relatively neutral electrode point (like mastoids) needs to be set as reference electrode to make the recorded voltage have a uniform standard (Luck 2014); *Step 2 Data filtering*: The frequency range of most relevant components in the ERP waveform is between 0.01–30 Hz (Luck 2014). However, the raw EEG data include a lower frequency signal (slow voltage changes caused by nonneural activity, such as skin electrical signals) and a higher frequency signal (some unexpected high frequency noise, such equipment noise and muscle electrical signals). Therefore, a bandpass is used to filter out the signal noise in the analysis. According to early studies (Addante et al. 2012), we used 0.1–30 Hz as the bandpass in our study; *Step 3 Data segmentation*: This step is to obtain the latency amplitude of interest under each condition, the segmented data is called "epoch" in an ERP study; *Step 4 ICA*: In this step, EEG signals are transformed into a space of independent source components, and some artifacts, such as blinks, eye movement and muscle tension, are manually identified and subtracted from the data (Changquan et al. 2018; Zhang et al. 2015); *Step 5 Data averaging*: The EEG signal collected in a single trial in the test is considered to be composed of ERP waveforms and random noise. Therefore, the ERP waveforms can be extracted by superposition averaged from repeated trials (Luck 2014). Thus, the same kind of stimuli should be evaluated many times in an ERP study

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Declaration on ethics The authors declare that they obtained the approval of "Ethic and Animal Welfare Committee of Beijing Forestry University" for conducting the present study based on Interviews/surveys. In addition, the authors declare that they obtained the informed consent from human participants involved in this study.

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