Psychology Research and Behavior Management
Dovepress
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ORIGINAL RESEARCH

Are We Sensitive to Different Types of Safety Signs? Evidence from ERPs

This article was published in the following Dove Press journal:
Psychology Research and Behavior Management

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Purpose: Safety signs are widely used to deliver safety-related information. There are many different types of safety signs. Although previous studies have paid attention to the design and effectiveness of safety signs, little attention has been devoted to investigating how people process the information conveyed by different types of safety signs. Accordingly, the current study is intended to explore the neural mechanisms underlying people's perception of different types of safety signs.

Methods: Three types of safety signs (prohibition, mandatory and warning signs) were used in the study. We employed questionnaire and event-related potentials (ERPs) experiment with an implicit paradigm to probe how people perceive these three types of safety signs.

Results: Behaviorally, warning signs induced a higher level of perceived hazard than prohibition signs and mandatory signs, and prohibition signs induced a higher level of perceived hazard than mandatory signs. At the brain level, prohibition signs and warning signs led to reduced P2 amplitudes compared to mandatory signs. In addition, warning signs elicited larger N2 and N4 amplitudes than prohibition signs and mandatory signs, and prohibition signs elicited larger N2 and N4 amplitudes than mandatory signs, coinciding with the behavioral results.

Conclusion: Different types of safety signs led to significant differences in individuals' hazard perception. Based on the neural results, we suggest that the processing of safety signs consists of two stages: the rapid detection of hazard information (indicated by P2) and the conscious integration of hazard information in working memory (indicated by N2 and N4).

Keywords: safety sign, hazard perception, event-related potentials, P2, N2, N4

Introduction

Safe production methods have been increasingly important in recent years. The frequent occurrence of safety-related accidents poses great harm to human lives and social harmony. For example, some of these accidents may be quite a blow to a family because people involved are a key breadwinner for the family.[1] In an attempt to curb safety accidents, safety signs are used to inform people about potential hazards or prompt people to take reasonable actions. As a security infrastructure, safety signs are widely applied in our daily surroundings, such as in industrial production sites and in commercial and residential buildings.

Given the importance of safety signs in safety management, numerous studies have investigated their design and effectiveness. For example, Wogalter and Silver asked participants to rate 84 warning signal words on a number of dimensions, such as strength, likelihood of injury, severity of injury and attention gettingness, and noted strong inter-correlations among these dimensions. Accordingly, a general

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dimension named "arousal strength" was proposed to measure perceived hazard.[2] A comparative study of three signal words (caution, danger, warning) and four background colors (red, yellow, white, and orange) demonstrated that the hazard levels of different signal words were different, as were the hazard levels of different background colors.[3] Wogalter noted that warnings provided to the subjects before the emergence of danger exerted a significantly stronger influence than warnings provided during the occurrence of the danger, and suggested the addition of signal text, consequences, instructions, etc. to the safety signs to promote warning effectiveness.[4] Additionally, a strand of research has explored the effect of surrounding shapes (e.g., upright triangle, diamond and circle) on hazard perception.[5–7] To systematically elucidate how people process hazard information, a series of theoretical models have been proposed, including the communication theory,[8] communication-human information processing model (C-HIP, which is later refined as a three-stage model consisting of attention, knowledge and compliance),[9,10] and hazard perception two-stage model (HPTS, which is comprised of an early hazard detection stage and a later hazard evaluation stage).[11] Besides, the elaboration likelihood model (ELM), which provides a framework for understanding the fundamental processes that underlie the effectiveness of persuasive communications, is also helpful to understand the effectiveness of hazard communication.[12] According to the ELM, people rely on central cues to form attitudes toward the security messages when the elaboration likelihood is high; otherwise they rely on peripheral cues.[13,14]

Though previous studies have extensively examined how people perceive safety signs, most of them have focused on the subcomponents of safety signs (i.e., signal words, colors, pictorials and surrounding shapes) or a single type of safety signs.[4–7,11] However, little attention has been paid to how people process the hazard information conveyed by different types of safety signs.[15,16] According to the message communicated by safety signs and their functions, they could be broadly classified into prohibition, mandatory, warning, and guide categories:[17] prohibition signs convey messages that prohibit certain conduct; mandatory signs convey rules that people must abide by; warning signs notify people about potential hazards; and guide signs provide information about directions. That is, different types of safety signs play different roles in directing people's behavior. These signs should be able to convey hazard information effectively and cause alarms among audiences in order to avoid accidents in potentially risky environments.[8] Understanding the perceptual and cognitive processing of different types of safety signs is of great importance for improving the effectiveness of safety signs. Consequently, the current study attempts to probe this issue. It is suggested by prior research that the arousal strength of perceived hazard is critical for hazard evaluation and sign effectiveness.[2,6,11,18,19] Hence we suppose that different types of safety signs might result in differential processing primarily due to their differences in the strength of perceived hazard.

Extant research on hazard perception toward safety signs has largely relied on explicit paradigms that directly asked subjects to attend to safety signs (or their subcomponents).[3,7,11,20,21] In real life, however, an individual's attention is not readily directed toward safety signs, which implies that safety signs might be processed implicitly in many cases. As a result, this study adopted an implicit paradigm in which safety signs served as nontarget stimuli and some home products (e.g., desk) served as target stimuli; subjects were instructed to pay attention to the home products throughout the experiment. Such an implicit paradigm not only ensured that the safety signs were processed implicitly, but also allowed us to mask the true purpose of the experiment and avoid a "relevance-for-task" effect.[5,6,22]

Since no behavioral responses were required for the safety signs in the implicit paradigm, neurophysiological measures that were able to capture the neural responses toward safety signs were of paramount importance in this study. ERPs, as direct measures of perceptual and cognitive processing of the stimuli with high temporal resolution, are conducive to understanding how people process hazard information.[6,11] Amplitudes of ERPs components are supposed to signify the degree or intensity of the engagement of cognitive processes, and latencies indicate the time course of stages of information processing. As a result, ERPs approach was utilized to identify the temporal dynamics associated with perception and cognition with respect to safety signs in the current study.[23,24] Until recently, most studies on safety signs have employed surveys or behavioral experiments,[4,7,8,15,16] which failed to clearly characterize the neurocognitive substrates underlying the processing of safety signs.[6,11,25] The present study aims to narrow this gap in the literature. Furthermore, this study served to extend the research by Ma et al on hazard information processing, in which ERPs were applied to recording neural responses.[6]

Ma et al proposed the HPTS model, suggesting that two stages were involved in the processing of warning signal words, i.e., the relatively early hazard perception and detection stage and the later controlled hazard evaluation stage.[11] We would explore whether the HPTS model also applied to this study.

Literature Review

According to the HPTS model, P2, N2 and N4 were of particular interest to us. P2 is a relatively early positive component of ERPs that typically peaks approximately 200 ms after the onset of a stimulus and is well established to reflect the rapid automatic attentional processing of the stimulus.[11,19] Extant literature has shown that P2 is closely associated with the allocation of attentional resources to motivationally and/or emotionally significant stimuli,[26,27] and the detection of hazard stimuli, such as frightful words or images.[19,28-31] Specifically, P2 is related to the early detection of threatening stimuli (words or images) and represents heightened sensitivity that elicits an attentional response toward potentially negative or dangerous events, and this response is generally attributed to the long-term evolutionary desire of human beings to avoid negative consequences.[11,20,26,28-32] Thus, the current study posits that P2 reflects the early automatic detection of hazardous information.

Following the P2 component, a negative wave, known as N2 (or N200), arises in the frontal or central region, with its latency falling between 200–300 ms.[22,33] N2 is suggested to be derived from the frontal area of the brain, such as the anterior cingulate, and reflect conflict processing during cognition and decision making.[34–39] It has also been reported that N2 in the prefrontal region could be induced by nonresponsive stimuli (such as no-go trials) and is sensitive to subjects' perceptual separation of stimuli. For example, in an implicit experiment, Yuan et al reported that the amplitude of N2 induced by extremely negative picture (such as bleeding) was significantly greater than that induced by moderately negative pictures (such as smoking) and neutral pictures (such as chairs).[22] Furthermore, Halgren and Marinkovic and Campanella et al noted that N2 was more sensitive to negative facial stimuli than to positive or neutral facial stimuli.[37,40] This finding was further proven by Cuthbert et al.[41] As Van Veen and Carter suggested, N2 might represent an advanced stage for the processing of dangerous information.[36] In accordance with these studies, we hypothesize that safety signs that convey more hazardous information would elicit a more negative N2 amplitude.

N4 (N400) is a negative-going component of ERPs observed approximately 400 ms after stimulus onset. It is representative of postperceptual, conscious and high-level integration of meaning and context in working memory.[42,43] During the processing of negative stimuli, negative information could lead to memory-related cognitive processes, which might evoke a notable N4 amplitude.[22,42] For example, Williams and Liddell asked participants to discriminate fear vs. neutral stimuli and noted an increased N4 in the fear condition (vs. neutral condition), which suggested the conscious integration of emotional stimuli in working memory.[18] Therefore, in the current study, we postulate that safety signs that communicate more hazardous information would induce a larger N4 amplitude.

In summary, the current study aims to investigate the neurocognitive substrates of how people process different types of safety signs with an implicit paradigm. Before the ERPs experiment, a survey was conducted to examine the strength of perceived hazard of each type of safety signs. Based on the abovementioned literature, we hypothesize that different types of safety signs might be processed differently in the human brain given that they differ in the strength of perceived hazard. More specifically, a smaller P2 amplitude would be elicited by warning signs than by prohibition signs and a smaller P2 amplitude would be elicited by prohibition signs than by mandatory signs. In contrast, the amplitudes of N2 and N4 would be larger for warning signs than for prohibition signs and larger for prohibition signs than for mandatory signs.

Materials and Methods

Subjects

Twenty subjects (10 females) were recruited from Zhejiang University as paid volunteers, with ages ranging from 22–37 years (M ± S.D. = 25.90 ± 4.20). All subjects were healthy, right-handed native speakers, with normal or corrected-to-normal visual acuity, and did not have any history of neurological or mental diseases. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Internal Review Board of the Neuromanagement Lab in Zhejiang University. Written informed consent was obtained from each participant prior to the experiment.

Materials

This study employed an implicit paradigm with a counting task, which has been widely utilized in task-irrelevant

Figure 1 Examples of three types of safety signs: (**A**) A prohibition sign indicating "No putting on spikes"; (**B**) A mandatory sign indicating "Must wear protective shoes"; (**C**) A warning sign indicating "Caution, mechanical injury".

experimental designs and proven to be feasible to investigate automatic information processing driven by stimuli.[6,22,44-46] Twelve pictures of prohibition signs, twelve pictures of mandatory signs and twelve pictures of warning signs were selected according to the recommendation list of the Chinese National Standard[17] as non-target stimuli (see Figure 1 as an example). We did not include guide signs in the present study since they have quite different physical features compared with the other three types of signs. Thus, it resulted in three main conditions, i.e., prohibition signs, mandatory signs and warning signs. Additionally, twelve neutral pictures of home products (e.g., desk) were selected as target stimuli. The participants were required to count the number of home products in the experiment. All pictures were processed to be grayscale images with similar brightness and contrast. Each picture was repeated three times in the experiment; thus there were 144 trials in total, with 36 trials in each condition.

Procedure

Subjects were seated comfortably in a sound-attenuated room with the computer screen positioned approximately 100 cm in front of them. They were asked to read the experiment instructions before the formal experiment started. In the instructions, subjects were told that they would be presented with a number of stimuli in each block and the purpose of the experiment was to see how accurate they could memorize the number of target stimuli (home products). They were also informed that the financial rewards for their participation would be determined by their performance in the experiment. To familiarize the subjects with the experimental procedure, each of them had a practice session with 10 trials.

The formal experiment consisted of three blocks, with 48 pseudorandomized trials in each block. The stimuli were presented at the center of a gray screen by using E-Prime 2.0 (Psychology Software Tools Inc., Pittsburgh, PA, USA). As illustrated in Figure 2, each trial was initiated by a fixation cross presented for 200 ms, which was followed by an interval with a duration varying randomly between 400 and 600 ms. Afterwards, a picture (stimulus) was displayed with a visual angle of

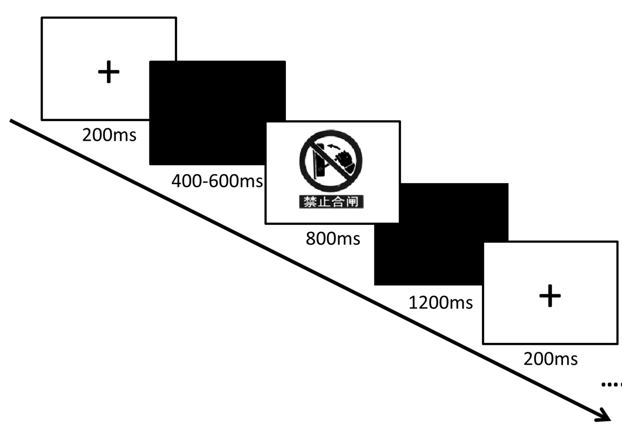

Figure 2 Experimental procedure of a single trial. Subjects were asked to count the number of home products presented in each block in their mind.

3.4°×3.4° for 800 ms. Finally, there was an inter-trial interval (ITI) of 1200 ms before the next trial started. Subjects were instructed to count the number of target stimuli (home products) presented in each block in their minds and to report the number after they completed the block. This task prompted the subjects to concentrate on the target stimuli and made the processing of safety signs task-irrelevant. If a subject reported wrong numbers in more than one block, data from that subject were excluded from further analysis. As a matter of fact, only two subjects made mistakes, with each of them reporting a wrong number in one block. Therefore, the task performance of all subjects was acceptable and each subject was paid for 30 Yuan (about equal to 5 USD at the time of data collection) as a reward after the experiment ended.

Electroencephalogram Data Acquisition and Analysis

The continuous scalp electroencephalogram (EEG) was recorded (bandpass 0.05–100 Hz, sampling rate 500Hz) with a Neuroscan Synamp2 Amplifier (Scan 4.3.1, Neurosoft Labs, Inc.). An electrode cap with 64 Ag/AgCl electrodes mounted according to the extended international 10–20 system was used. A cephalic (forehead) location served as the ground. Channel data were referenced to the left mastoid online and re-referenced to the average of the left and right mastoids offline. The vertical electrooculogram (EOG) was recorded from the left eye by the supra-orbital and infra-orbital electrodes. The horizontal EOG was recorded from electrodes on the outer canthi of both eyes. The impedance of all electrodes was kept below 5 KΩ throughout the experiment.

The EOG artifacts were corrected using the method proposed by Semlitsch, Anderer, Schuster, Presslich[47] The stimulus-locked EEG data were digitally filtered with a bandpass from 0.1 to 30 Hz (24 dB/Octave), segmented into epochs from 200 ms prestimulus to 800 ms poststimulus, and baseline-corrected by the 200 ms prestimulus interval. Trials contaminated by amplifier clipping, bursts of electromyographic activity, or peak-to-peak deflection exceeding ±80 μV were excluded from averaging. Only nontarget stimuli were analyzed in this study. Thus, the EEG segments were averaged separately for prohibition, mandatory and warning signs for each subject.

Based on a visual inspection of the grand averaged waveforms and the extant literature on safety signs, three components of ERPs, P2, N2 and N4, were analyzed. Six electrodes (F3, Fz, F4, FC3, FCz, and FC4) in the frontal and fronto-central regions were selected for P2, N2 and N4 analyses.[11,18,22,33] The mean amplitudes in the time windows of 150–170 ms, 200–250 and 305–365 ms were calculated for P2, N2 and N4 respectively before being submitted to 3 (type: prohibition signs, mandatory signs and warning signs) × 6 (electrode: F3, Fz, F4, FC3, FCz, FC4) repeated measure ANOVAs. The Greenhouse–Geisser correction was applied when necessary (uncorrected *df* and corrected p-values were reported).[48]

Results

Questionnaire Results

A survey was conducted to test whether prohibition, mandatory and warning signs differed in the strength of perceived hazard.[11,21] A hundred and sixty-nine participants who did not take part in the electrophysiological experiment participated in the survey. They were told that the aim of the survey was to understand how people perceived different safety signs and were asked to rate the perceived hazard levels of the safety sign pictures using a seven-point Likert scale (1 = very low, 7 = very high). Among the 169 participants, 51.5% of them were male and 48.5% were female, with age ranges of 16 −20 (8.3%), 21–25 (45.5%), 26–30 (29.6%) and larger than 30 (16.6%). As for education, the majority of participants (65.1%) had earned bachelor's degrees, 30.8% had earned master's or doctoral degrees, whereas 4.1% had high school education. Regarding occupation, 50.3% of them were students and 49.7% were employees. For the perceived hazard levels of the pictures, the alpha reliability coefficients were 0.853, 0.865 and 0.791 for prohibition, mandatory and warning signs, respectively. One-way ANOVA demonstrated a significant difference in the mean hazard levels among prohibition signs (M = 4.632, S.D. = 1.159), mandatory signs (M = 3.686, S.D. = 1.283) and warning signs (M = 5.149, S.D. = 0.992; $F(2, 336) = 146.409$, $p < 0.001$). Pairwise t tests showed that the differences between each two types of safety signs were significant (*ps* < 0.001).

ERPs Results

P2 Analysis

The ERPs grand averaged waveforms at six selected electrodes (F3, Fz, F4, FC3, FCz, and FC4) are displayed in Figure 3. The two-way repeated measure ANOVA on P2 amplitude revealed a significant main effect of type ($F(2, 38) = 13.640$, $p < 0.001$). Pairwise *t*-test results showed that a larger P2 was elicited by mandatory signs (M = 1.457 μV, S.E. = 0.564) than by prohibition signs (M = 0.461 μV, S.E. = 0.572, $p < 0.001$) and warning signs (M = 0.690 μV, S.E. = 0.633, $p < 0.05$). However, there was no significant difference between prohibition signs and warning signs ($p > 0.1$). The main effect of electrode (F (5, 95) = 1.923, $p > 0.1$) and the interaction between type and electrode (F (10, 190) < 1, $p > 0.1$) were not significant.

N2 Analysis

The two-way repeated measure ANOVA on N2 amplitude revealed a significant main effect of type (F (2, 38) =

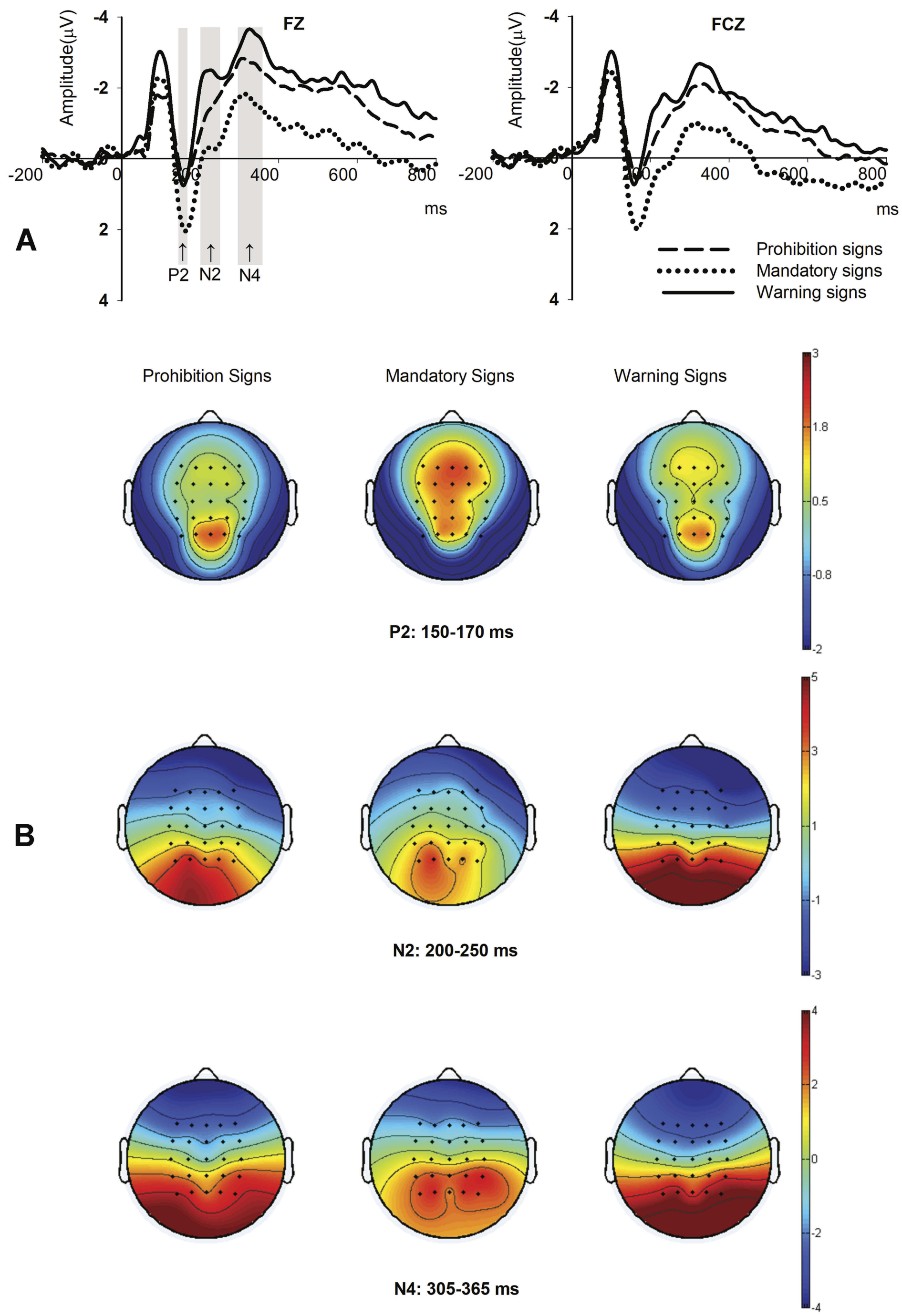

Figure 3 Event-related potentials (ERPs) results. (**A**) The grand averaged waveforms in the frontal and fronto-central sites; (**B**) The topographic maps of P2, N2 and N4 for different types of safety signs. P2 is the second positive component of ERPs; N2 is the second negative component of ERPs; N4 is a negative component of ERPs observed at around 400ms. FZ is a frontal midline scalp electrode and FCZ is a fronto-central midline scalp electrode.

Table 1 Summary of Event-Related Potentials (ERPs) Results

	WS		PS		MS		Pairwise Comparison Results
	M	S.E.	M	S.E.	M	S.E.	
P2	0.690	0.633	0.461	0.572	1.457	0.564	WS < MS*, PS < MS***
N2	−1.829	0.554	−1.082	0.605	−0.312	0.698	WS > PS**, WS > MS***, PS > MS**
N4	−2.418	0.450	−1.972	0.537	−1.238	0.541	WS > PS*, WS > MS***, PS > MS**

Notes: P2 is the second positive component of ERPs; N2 is the second negative component of ERPs; N4 is a negative component of ERPs observed at around 400ms; *p<0.05, **p<0.01, ***p<0.001; The relative magnitudes of an ERPs component in different conditions were determined depending on its polarity.
Abbreviations: WS, warning signs; MS, mandatory signs; PS, prohibition signs.

24.799, $p < 0.001$). Pairwise t tests showed that a larger N2 amplitude was evoked by warning signs (M = −1.829 μV, S.E. = 0.554) than by prohibition signs (M = −1.082 μV, S.E. = 0.605, $p = 0.002$) and mandatory signs (M = −0.312 μV, S.E. = 0.698, $p < 0.001$). Prohibition signs also evoked a larger N2 amplitude than mandatory signs ($p = 0.002$). The main effect of electrode was also significant (F (5, 95) = 5.201, $p = 0.005$). However, the interaction between type and electrode (F(5, 95) <1, $p > 0.1$) did not reach statistical significance.

N4 Analysis

For N4, ANOVA results also showed a significant main effect of type (F (2,38) = 19.039, p < 0.001). Pairwise t tests showed that a more negative N4 amplitude was elicited by warning signs (M = −2.418 μV, S.E. = 0.450) than by prohibition signs (M = −1.972 μV, S.E. = 0.537, $p = 0.040$) and mandatory signs (M = −1.238 μV, S.E. = 0.541, $p < 0.001$). The difference between prohibition signs and mandatory signs was also significant ($p = 0.005$). The main effect of electrode was significant (F (5, 95) = 6.559, p = 0.002), but the interaction between type and electrode was not (F (5, 95) = 1.264, p > 0.1).

To provide an overall picture of the findings, the main ERPs results are summarized in Table 1.

Discussion

In the present study, ERPs were utilized to explore the electrophysiological substrates of how people perceive three types of safety signs (i.e., prohibition, mandatory and warning signs) with an implicit paradigm. Continuous EEG data were recorded while the subjects completed the task. The results showed that three components of ERPs, P2, N2 and N4, could serve as neural indicators of the perceptual and cognitive processing of safety signs. To be specific, compared to mandatory signs, prohibition signs and warning signs resulted in attenuated P2 amplitudes. However, P2 amplitudes did not differ between prohibition and warning signs. In addition, the amplitudes of N2 and N4 elicited by warning signs were significantly larger than those elicited by prohibition signs, which in turn were larger than those elicited by mandatory signs.

Behavioral and Cognitive Mechanism

In light of the previous findings, the processing of safety signs consists of two stages: the rapid automatic detection of hazard information and the conscious integration of hazard information in working memory. Frontal P2 (earlier than 200 ms) activation is associated with the automatic classification of stimuli and early attentional bias that occurs automatically and might represent the rapid detection of typical stimulus features.[20] A number of studies have demonstrated that P2 reflects a rapid and dynamic assessment of the valence of stimuli.[27,29] For instance, Yuan et al observed that extremely negative stimuli led to a smaller P2 than moderately negative and neutral stimuli due to a rapid detection process of salient threatening features.[22] Moreover, in a recent study investigating the hazard perception of the surrounding shapes of warning signs, it was noted that the shape of an upright triangle engendered a smaller P2 amplitude than the shape of a circle because the former shape embodied a higher level of perceived hazard than the latter.[6] In the current study, the subjective ratings collected in the survey demonstrated that warning signs gave rise to a higher level of perceived hazard than prohibition signs and mandatory signs, and prohibition signs engendered a higher level of perceived hazard than mandatory signs. Accordingly, our finding of decreased P2 amplitudes for warning signs and prohibition signs (vs. those for mandatory signs) might suggest an enhanced rapid detection of threatening content, which automatically recruits attentional resources at the relatively early stage. In addition, the enhanced hazard detection might occur subconsciously, and only a fraction of the safety sign features could be detected, as P2 component arose approximately 150 ms after the stimulus onset, which was a relatively early time point.[22] This outcome might explain why P2 amplitudes did not differ between warning signs and prohibition signs.

Apart from P2, notable N2 and N4 (later than 200 ms) activities were observed, which could be considered as the conscious integration of hazard information. N2 might represent a higher level of hazard information processing. As subjects had already paid attention to the content of the safety signs, more stimuli properties were perceived and more potential hazard information was extracted at this stage, which facilitated the brain to integrate the information, leading to the comprehension of the meaning of the different safety signs. Therefore, warning signs and prohibition signs, which did not show any significant difference at the relatively early stage (earlier than 200 ms), led to significantly distinguished brain activities at this processing stage (later than 200 ms). More specifically, a markedly more negative N2 amplitude was evoked by warning signs than by prohibition and mandatory signs. The prohibition signs also triggered a larger N2 amplitude than mandatory signs. This finding was in line with the subjective ratings collected in the survey study.

N4 activities were observed during the 300–500 ms interval in all conditions. An enlarged N4 was evoked by warning signs than by prohibition and mandatory signs. Meanwhile, N4 amplitude evoked by prohibition signs was also larger than that evoked by mandatory signs. N4 in the frontal regions is an endogenous brain parameter sensitive to the valence of face and word stimuli and is suggestive of the postperceptual and conscious integration of meaning and context in working memory.[42,43,49,50] Taking the findings from Williams et al as an example, in which the authors engaged participants in a task to discriminate fear stimuli from neutral stimuli and observed an enlarged N4 in the fear condition (vs. neutral condition), people consciously integrated emotional stimuli in their working memory.[18] Similarly, a more negative slow wave was observed for extremely negative stimuli than moderately negative and neutral stimuli.[22] In accordance with prior literature, we conjecture that the augmented N4 amplitude for warning signs (vs. prohibition and mandatory signs) and for prohibition signs (vs. mandatory signs) possibly indicates the increased activation of prefrontal cortical networks linked to the conceptual knowledge of warning and prohibition signs and the facilitated integration of hazard information in working memory. The conceptual knowledge about the subcomponents contained in safety signs has to be retrieved so that hazard information can be extracted and integrated in working memory.

These two stages are not entirely in support of the HPTS model proposed by Ma et al as the second stage in the HPTS model refers to a relatively late hazard evaluation process indexed by late positive potentials (LPP).[11] We considered two possible explanations for the discrepancy between these two studies. First, they used different paradigms: Ma et al instructed subjects to judge the hazard level of the stimuli explicitly, rendering the processing of hazard information task-relevant;[11] conversely, the present study adopted an implicit paradigm that did not ask the subjects to attend to safety signs, which made the processing of safety signs task-irrelevant and the integration of hazard information in working memory a critical process required to grasp the meaning of safety signs. Second, the two studies differed in experimental stimuli: Ma et al used warning signal words, a subcomponent of safety signs, as stimuli;[11] however, this study used complete safety signs as stimuli, the comprehension of which required conceptual knowledge about each subcomponent and the integration of hazard information.

Theoretical and Practical Implication

Theoretically, the present study provides a new perspective on individuals' processing of different types of safety signs. First, the current study revealed individuals' perception of the complete safety signs both at the behavioral and neural levels. To the best of our knowledge, this is the first study to investigate the neural mechanisms underlying the processing of different types of safety signs by ERPs. Additionally, this study extends the HPTS model proposed by Ma et al that delineates the neural processes of hazard perception and evaluation for warning signal words.[11] The results of the present study suggest that when processing safety sign pictures with an implicit paradigm, individuals' cognitive processes could also be divided into two stages, although the second stage differs from the HPTS model to some extent. Finally, the implicit paradigm used in this study helped us understand how human brain responded to safety signs without explicitly devoting attention to them.

The findings of this study also have practical implications. Occupational health and safety has been a major concern in industrial production,[15,16] especially for countries where the second industry is a pillar industry. The effectiveness of safety signs is crucial, since safety signs are one of the most important safety precaution measures. Unlike previous studies, the present study employed an implicit paradigm that was closer to real life, where people's attention was not readily directed toward safety signs. Consequently, it provides us with insight into the role of safety signs in everyday scenarios, endowing the findings of this study with more practical significance. First, this study suggests that people are able to perceive the potential hazards conveyed by safety signs even if they do not explicitly pay attention to safety signs. Thus, safety signs should be put in place where they are necessary and noticeable so as to increase the likelihood of being processed (explicitly or implicitly) by viewers. Moreover, it is indicated that warning, prohibition and mandatory signs differ from each other in the strength of perceived hazard. This point should be taken into account when designing safety signs to make sure that a specific safety sign communicates an appropriate level of perceived hazard. Last but not least, the design of a safety sign is recommended to be vivid and easily understandable so that the conceptual knowledge about the sign components could be retrieved with ease and the hazard information could be integrated in working memory.

Limitations

There are some limitations that should be acknowledged. First, this study was based upon a broad classification of safety signs (i.e., prohibition, mandatory and warning signs) without considering the application of safety signs in any specific domain. However, safety signs are designed to be applied in diverse domains, such as traffic safety, mine safety, medical and public health safety, and chemical and biological experimental safety. Accordingly, future studies may explore how people perceive the safety signs used in a certain industry or application field, which requires the experimental materials to be more specialized and subjects to be more professional. The results could then make safety signs more targeted for a specific audience and enhance sign effectiveness. In addition, though the present study revealed how people processed the information conveyed by safety signs with an implicit paradigm, it remains unknown if the findings of current study could extend to contexts when people are confronted with dangers. Thus, it is worthy of further research to extend this line of research and figure out people's perception of safety signs in dangerous situations. Third, the majority of the participants in the survey were aged between 20–30 and had college degrees. A more diverse sample is recommended to be included in future research.

Conclusion

Taken together, the current study delved into the neural temporal dynamics associated with processing safety signs. Subjects were engaged in an implicit task with their scalp EEG data recorded. The results showed that significantly smaller P2 amplitudes were elicited by warning signs and prohibition signs than by mandatory signs, but there was no significant difference between the results for warning signs and prohibition signs. Furthermore, warning signs induced more negative N2 and N4 amplitudes than prohibition and mandatory signs, and prohibition signs induced more negative N2 and N4 amplitudes than mandatory signs. These results suggest the rapid automatic detection of hazard information and the conscious integration of hazard information in working memory, respectively.

Acknowledgments

This work was supported by Natural Science Foundation of Guangdong Province (No. 2017A030310466), Humanities and Social Sciences Fund of the Ministry of Education of China (No. 18YJC630034), National Natural Science Foundation of China (No. 71371167), National Project (No. AWS14J011 and No. CICO201903), and Philosophy and Social Sciences Foundation of Guangzhou (No. 2018GZQN33). It was also supported by a grant from Academy of Neuroeconomics and Neuromanagement at Ningbo University. The funders had no role in the study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Disclosure

Dr Jun Bian reports grants from National Natural Science Foundation of China, Natural Science Foundation of Guangdong Province, Humanities and Social Sciences Fund of the Ministry of Education of China, and National Project during the conduct of the study. The authors report no other possible conflicts of interest in this work.

References

1. BA R. Road safety and accident prevention in India. *Ratio*. 2016;28 (28.5):28–5.
2. Wogalter M, Silver N. Arousal strength of signal words. *Forensic Rep*. 1990;3:407–420.
3. Chapanis A. Hazards associated with three signal words and four colours on warning signs. *Ergonomics*. 1994;37(2):265–275. doi:10.1080/00140139408963644
4. Wogalter MS, Laughery KR. Warning! Sign and label effectiveness. *Curr Dir Psychol Sci*. 1996;5(2):33–37. doi:10.1111/1467-8721.ep10772712
5. Zhu LF, Ma QG, Bai XX, Hu LF. Mechanisms behind hazard perception of warning signs: an EEG study. *Transp Res Pt F-Traffic Psychol Behav*. 2020;69:362–374. doi:10.1016/j.trf.2020.02.001
6. Ma QG, Bai XX, Pei GX, Xu ZJ. The hazard perception for the surrounding shape of warning signs: evidence from an event-related potentials study. *Front Neurosci*. 2018;12:8. doi:10.3389/fnins.2018.00824
7. Yu R, Chan AHS, Salvendy G. Chinese perceptions of implied hazard for signal words and surround shapes. *Hum Factor Ergono Man*. 2004;14(1):69–80. doi:10.1002/hfm.10048
8. Laughery KR. Safety communications: warnings. *Appl Ergon*. 2006;37(4):467–478. doi:10.1016/j.apergo.2006.04.020
9. Wogalter MS. Communication-human information processing (C-HIP) model. In: Wogalter MS, ed. *Handbook of Warnings*. Mahwah: Lawrence Erlbaum Associates; 2006:51–61.
10. Laughery KR, Wogalter MS. A three-stage model summarizes product warning and environmental sign research. *Saf Sci*. 2014;61:3–10. doi:10.1016/j.ssci.2011.02.012
11. Ma Q, Jin J, Wang L. The neural process of hazard perception and evaluation for warning signal words: evidence from event-related potentials. *Neurosci Lett*. 2010;483(3):206–210. doi:10.1016/j.neulet.2010.08.009
12. Petty RE, Cacioppo JT. The elaboration likelihood model of persuasion. *Adv Exp Soc Psychol*. 1986;19:123–205.
13. Johnston AC, Warkentin M, Dennis AR, Siponen M. Speak their language: designing effective messages to improve employees' information security decision making. *Decis Sci*. 2019;50(2):245–284. doi:10.1111/deci.12328
14. Lewis I, Watson B, White KM. An examination of message-relevant affect in road safety messages: should road safety advertisements aim to make us feel good or bad? *Transp Res Pt F-Traffic Psychol Behav*. 2008;11(6):403–417. doi:10.1016/j.trf.2008.03.003
15. Chan AHS, Ng AWY. The guessing of mine safety signs meaning: effects of user factors and cognitive sign features. *Int J Occup Saf Ergon*. 2012;18(2):195–208. doi:10.1080/10803548.2012.11076928
16. Chan AHS, Ng AWY. Investigation of guessability of industrial safety signs: effects of prospective-user factors and cognitive sign features. *Int J Ind Ergon*. 2010;40(6):689–697. doi:10.1016/j.ergon.2010.05.002
17. GB2894. *Chinese National Standard: Safety Signs and Guideline for the Use*. Beijing: China Standard Press; 2008.
18. Williams LM, Liddell BJ, Rathjen J, et al. Mapping the time course of nonconscious and conscious perception of fear: an integration of central and peripheral measures. *Hum Brain Mapp*. 2004;21 (2):64–74. doi:10.1002/hbm.10154
19. Ma Q, Fu H, Xu T, et al. The neural process of perception and evaluation for environmental hazards: evidence from event-related potentials. *Neuroreport*. 2014;25(8):607–611. doi:10.1097/WNR.0000000000000147
20. Thorpe S, Fize D, Marlot C. Speed of processing in the human visual system. *Nature*. 1996;381(6582):520–522. doi:10.1038/381520a0
21. Fu H, Qiu W, Ma H, Ma Q, Di Russo F. Neurocognitive mechanisms underlying deceptive hazard evaluation: an event-related potentials investigation. *PLoS One*. 2017;12(8):e0182892. doi:10.1371/journal.pone.0182892
22. Yuan J, Zhang Q, Chen A, et al. Are we sensitive to valence differences in emotionally negative stimuli? Electrophysiological evidence from an ERP study. *Neuropsychologia*. 2007;45(12):2764–2771. doi:10.1016/j.neuropsychologia.2007.04.018
23. Luck SJ, Woodman GF, Vogel EK. Event-related potential studies of attention. *Trends Cogn Sci*. 2000;4(11):432–440. doi:10.1016/S1364-6613(00)01545-X
24. Ma Q, Shi L, Hu L, Liu Q, Yang Z, Wang Q. Neural features of processing the enforcement phrases used during occupational health and safety inspections: an ERP study. *Front Neurosci*. 2016;10. doi:10.3389/fnins.2016.00469
25. Lu G, Hou G. Effects of semantic congruence on sign identification: an ERP study. *Hum Factors*. 2019;0018720819854880.
26. Liu B, Xin S, Jin Z, Hu Y, Li Y. Emotional facilitation effect in the picture–word interference task: an ERP study. *Brain Cogn*. 2010;72 (2):289–299. doi:10.1016/j.bandc.2009.09.013
27. Thomas SJ, Johnstone SJ, Gonsalvez CJ. Event-related potentials during an emotional stroop task. *Int J Psychophysiol*. 2007;63 (3):221–231. doi:10.1016/j.ijpsycho.2006.10.002
28. Carretié L, Mercado F, Tapia M, Hinojosa JA. Emotion, attention, and the 'negativity bias', studied through event-related potentials. *Int J Psychophysiol*. 2001;41(1):75–85. doi:10.1016/S0167-8760(00)00195-1
29. Correll J, Urland GR, Ito TA. Event-related potentials and the decision to shoot: the role of threat perception and cognitive control. *J Exp Soc Psychol*. 2006;42(1):120–128. doi:10.1016/j.jesp.2005.02.006
30. Qin J, Lee TM, Wang F, Mao L, Han S. Neural activities underlying environmental and personal risk identification tasks. *Neurosci Lett*. 2009;455(2):110–115. doi:10.1016/j.neulet.2009.03.008
31. Qin J, Han S. Neurocognitive mechanisms underlying identification of environmental risks. *Neuropsychologia*. 2009;47(2):397–405. doi:10.1016/j.neuropsychologia.2008.09.010
32. Carretié L, Martín-Loeches M, Hinojosa JA, Mercado F. Emotion and attention interaction studied through event-related potentials. *J Cogn Neurosci*. 2001;13(8):1109–1128. doi:10.1162/089892901753294400
33. Pritchard WS, Shappell SA, Brandt ME. Psychophysiology of N200/N400: a review and classification scheme. *Adv Psychophysiology*. 1991;4(43):106.
34. Bekker EM, Kenemans JL, Verbaten MN. Source analysis of the N2 in a cued Go/NoGo task. *Cogn Brain Res*. 2005;22(2):221–231. doi:10.1016/j.cogbrainres.2004.08.011
35. Carter CS, Braver TS, Barch DM, Botvinick MM, Noll D, Cohen JD. Anterior cingulate cortex, error detection, and the online monitoring of performance. *Science*. 1998;280(5364):747–749. doi:10.1126/science.280.5364.747
36. Van Veen V, Carter CS. The anterior cingulate as a conflict monitor: fMRI and ERP studies. *Physiol Behav*. 2002;77(4–5):477–482. doi:10.1016/S0031-9384(02)00930-7
37. Campanella S, Gaspard C, Debatisse D, Bruyer R, Crommelinck M, Guerit J-M. Discrimination of emotional facial expressions in a visual oddball task: an ERP study. *Biol Psychol*. 2002;59(3):171–186. doi:10.1016/S0301-0511(02)00005-4
38. Ma Q, Wang X, Dai S, Shu L. Event-related potential N270 correlates of brand extension. *Neuroreport*. 2007;18(10):1031–1034. doi:10.1097/WNR.0b013e3281667d59
39. Yeung N, Sanfey AG. Independent coding of reward magnitude and valence in the human brain. *J Neurosci*. 2004;24(28):6258–6264. doi:10.1523/JNEUROSCI.4537-03.2004
40. Halgren E, Marinkovic K. *Neurophysiological Networks Integrating Human Emotions*. In: Gazzaniga MS, ed. *The Cognitive Neurosciences*. Cambridge: MIT Press; 1995:1137–1151.
41. Cuthbert BN, Schupp HT, Bradley MM, Birbaumer N, Lang PJ. Brain potentials in affective picture processing: covariation with autonomic arousal and affective report. *Biol Psychol*. 2000;52 (2):95–111. doi:10.1016/S0301-0511(99)00044-7

42. Kiefer M, Spitzer M. Time course of conscious and unconscious semantic brain activation. *Neuroreport*. 2000;11(11):2401–2407. doi:10.1097/00001756-200008030-00013
43. Adolphs R. Neural systems for recognizing emotion. *Curr Opin Neurobiol*. 2002;12(2):169–177. doi:10.1016/S0959-4388(02)00301-X
44. Chen Y, Pan FD, Wang HR, Xiao SB, Zhao L. Electrophysiological correlates of processing own- and other-race faces. *Brain Topogr*. 2013;26(4):606–615. doi:10.1007/s10548-013-0286-x
45. Cano ME, Class QA, Polich J. Affective valence, stimulus attributes, and P300: color vs. black/white and normal vs. scrambled images. *Int J Psychophysiol*. 2009;71(1):17–24. doi:10.1016/j.ijpsycho.2008.07.016
46. Debener S, Makeig S, Delorme A, Engel AK. What is novel in the novelty oddball paradigm? Functional significance of the novelty P3 event-related potential as revealed by independent component analysis. *Cogn Brain Res*. 2005;22(3):309–321. doi:10.1016/j.cogbrainres.2004.09.006
47. Semlitsch HV, Anderer P, Schuster P, Presslich O. A solution for reliable and valid reduction of ocular artifacts, applied to the P300 ERP. *Psychophysiology*. 1986;23(6):695–703. doi:10.1111/j.1469-8986.1986.tb00696.x
48. Greenhouse SW, Geisser S. On methods in the analysis of profile data. *Psychometrika*. 1959;24(2):95–112. doi:10.1007/BF02289823
49. Kuperberg GR. Neural mechanisms of language comprehension: challenges to syntax. *Brain Res*. 2007;1146:23–49. doi:10.1016/j.brainres.2006.12.063
50. Rugg MD, Mark RE, Walla P, Schloerscheidt AM, Birch CS, Allan K. Dissociation of the neural correlates of implicit and explicit memory. *Nature*. 1998;392(6676):595–598. doi:10.1038/33396