The neural process of hazard perception and evaluation for warning signal words: Evidence from event-related potentials

Qingguo Ma\textsuperscript{a,b}, Jing Jin\textsuperscript{a,b}, Lei Wang\textsuperscript{a,b,*}

\textsuperscript{a} School of Management, Zhejiang University, Hangzhou, China
\textsuperscript{b} Neuromanagement Lab, Zhejiang University, Hangzhou, China

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\textbf{A B S T R A C T}

Warning signs have been widely applied to industrial production. As an important component of warning signs, warning signal words were mostly studied by using questionnaire. This study used event-related potentials (ERPs) to explore neural temporal features during the processing of warning signal words in human brain, and found that there were two stages involved in processing warning signal words, providing an electrophysiological evidence for a previous warning information processing model, the Communication-Human Information Processing Model (C-HIP). Previous behavioral studies indicated that the subjective hazard perception of participants facilitates their attention to the warning sign, and people can get hazard information from warning words. Our results provided direct evidence for these conclusions. The present findings of significant differences in subjective hazard perception for warning words among individuals showed the importance and necessity of training for people to get the similar understanding of these words. Our results implicated that the warning words reflecting the same hazard level used in the warning sign should be somewhat changed, at the same time, convey equally or similarly hazardous information, to avoid desensitization and habituation due to overuse of them.

\* Corresponding author at: Neuromanagement Lab, School of Management, Zhejiang University, Zhejiang University, 38# Zheda Road, 310027 Hangzhou, Zhejiang, China. Tel.: +86 571 87167365. E-mail address: wang.lei@zju.edu.cn (L. Wang).

Warning signs which could quickly and effectively convey hazard information were widely applied to various industries, for instance, manufacturing, mining, construction, and so on. A lot of studies [24,30,33] investigated the factors that modulated the effectiveness of a warning sign in the context of information processing theory. Wogalter et al. constructed a theoretical framework, the Communication-Human Information Processing Model (C-HIP), to research how the warning sign does work [33]. This model described five stages of human information processing when facing a warning sign, such as attention, comprehension, attitudes and beliefs, motivation, and behavior. These studies focused on human’s decision-making process with regard to warning signs. Though decision-making involves perceptual and cognitive processes, few studies have fully investigated the subcomponents of cognition underlying the processing of warning information, such as attention, evaluation, and motivation. Thus, this study explores the neurocognitive process associated with the hazard perception and evaluation of warning signal words.

As a component of warning signs, warning signal words play an important role in attracting attention. By using signal words, warning signs can be encoded more easily [34]. Moreover, warning words convey a potential hazard level of a particular warning sign. Three most commonly used warning signal words recommended by the American National Standards Institute (ANSI) Z535.4 were DANGER, WARNING and CAUTION [2]. According to ANSI, these three words indicate three decreasing hazard levels [2]. Chinese National Standards also recommend the usage of several signal words (such as WARNING, DANGER) in safety signs to communicate different levels of hazard [13,14]. Adams et al. found that DANGER was perceived significantly more noticeable than CAUTION [1]. Wogalter and Silver asked participants to rate 84 signal words on the dimensions of strength, severity of injury, likelihood of injury, attention gettingness, the level of care, and understandability [35]. They found strong inter-correlations among these dimensions. Therefore, they proposed a general dimension called “arousal strength”. Recently, there were also some similar studies but using Chinese participants [32,37]. Yu et al. examined the arousal strengths of 16 warning signal words rated by Chinese participants [37]. The result suggested that 15 words among them can be divided into three categories, representing high, moderate, and low hazard levels, according to the arousal strength of the words. This interesting finding indicated that warning signal words provide hazard information and can be categorized into different hazard levels. However, some argued that warning signal words only capture attention but provide little information [10,16]. Therefore, one purpose of this study is to explore
whether signal words can convey the information of hazard level or not.

Until recently, most warning studies adopted the method of subjective measures [16,36,37], in which participants were asked to rate the hazard level of warnings by using Likert scales. Few studies, however, applied the method of physiological response measurement, such as the electroencephalogram (EEG) and event-related potentials (ERPs).

ERPs are a direct measure, with high temporal resolution, of perceptual and cognitive processes to the stimuli [19]. P200 is an early positive ERP component achieving its peak at about 200 ms after the onset of stimuli. It is an attention-related component, reflecting the early rapid automatic activity. Enhanced P200 amplitude suggests the commitment of attention resources to evolutionarily significant stimuli [5,18,29]. Previous studies showed that P200 associated with early detection of threatening stimuli, such as frightful words or images [4,6,22,23]. Correll et al. recorded ERPs when participants played shooting videogame, and revealed larger P200 of armed than unarmed targets [6]. Qin et al. found that P200 was significantly enhanced by words describing risky environmental events relative to safe ones [22]. Late positive potential (LPP) is an ERP component maximal over central-parietal regions occurring between 300 and 700 ms after stimuli onset. LPP indicates the process of subjective evaluation and the activation of motivational systems [8]. Threatening stimuli elicited larger LPP than nonthreatening one [26–28]. Moreover, stimuli of high arousal elicited augmented LPP compared with low arousal stimuli. Schupp et al. categorized emotional pictures used in their study into high and low groups according to arousal ratings, and indicated that high arousal pictures elicited augmented LPPs [25]. Cuthbert et al. suggested that the amplitude of LPP correlates to arousal rating of picture [8]. According to neuropsychological models of attention, there are two sub-systems of attentional network. The anterior system is involved in target detection and the posterior system is involved in orientation to visual locations [7]. It is proposed that anterior cingulate associated with target detection, and that parietal and cingulate areas, especially in right hemisphere, are involved in spatial attentional processes [21]. Previous fMRI study showed that risk rating task activated the medial prefrontal cortex, the inferior frontal gyrus, the cerebellum, and the amygdala [31], and the identification of environmental risks activated the ventral anterior cingulate cortex (vACC) reflected by P200 and posterior cingulate cortex (PCC) reflected by LPP [22]. The authors of [22] suggested that the vACC activation was reflected by P200 and the PCC activation by LPP according to the added ERP experiment. Based on previous researches, this study examined the P200 and the LPP while subjects viewed warning signal words, for the purpose of exploring the neural activities underlying the hazard information processing of these words.

Twenty-three right-handed subjects (10 females), to be called EEG-subjects in this paper, were recruited from Zhejiang University. They were paid for their participation. Subjects were between the ages of 20 and 26 years (mean ± S.D. = 22.7 ± 1.36). All had normal or corrected-to-normal visual acuity, and did not have any history of neurological or mental diseases. Informed consent was obtained from all participants, and this study was approved by the Internal Review Board of Neuronomanagement Lab, Zhejiang University.

The stimuli were 20 warning signal words in Chinese. Each consisted of two Chinese characters. Stimuli selection was according to the recommendation list of the Chinese National Standard [13,14], and the words used by previous studies [16,37]. Based upon the results of these studies, words were classified by arousal strength into two groups with high and low hazard levels, respectively (10 words each group).

We conducted a pilot study to confirm this classification. Thirty subjects who did not take part in the electrophysiological experiment rated the hazard levels of these words using a seven-point Likert scale (1 = very low, 7 = very high). We referred to these subjects as prior-rating subjects. Paired t-test showed significant difference in mean hazard levels between word groups [high level = 5.41, low level = 2.88, t(29) = 17.196, p < 0.001]. The alpha reliability coefficients were 0.861 and 0.844 for word groups with high and low hazard levels, respectively. We referred to this factor of categories as prior-hazard (high vs. low). Words were presented on the computer screen at a distance of 90 cm from subjects with a visual angle of 1.08° × 0.51° (1.7 cm × 0.8 cm, width × height).

Subjects were comfortably seated in a sound-attenuated room with a keypad fixed to a chair arm for them to make responses after they were informed about the experimental procedure. There were totally two blocks of trials in this experiment. At the beginning of each block, an instruction screen indicated the task briefly. Then, a sequence of 40 trials began when subjects pressed a key to inform the system that they were ready. In each trial, a central fixation cross appeared for a duration varying randomly between 800 and 1200 ms, followed by a warning signal word, which was presented at the center of screen for 1500 ms in black color against a grey background. Subjects were asked to judge the perceived hazard level of the word either as low or high whenever they have seen the word. They pressed one of two buttons to indicate high/low level of hazard that they had perceived from the word. The order of signal words was random within a block and each participant received his or her own order of word presentation. The response button corresponding to high- or low-level was counterbalanced across subjects.

EEG was recorded with an electrode cap with 64 Ag/AgCl electrodes mounted according to the extended international 10–20 system, on-line bandpass filtered from 0.05 to 100 Hz, and sampled at 1000 Hz using Neuroscan Synamp2 Amplifier (Scan 4.3.1, Neurosoft Labs, Inc. Sterling, USA). Impedances were maintained below 5 kΩ throughout the experiment. All recordings were referenced to left mastoid.

Stimulus-locked data were segmented into epochs comprised of 200 ms prior to stimulus onset and 1000 ms after the onset. Baseline correction was carried out using the first 200 ms of each channel. Trials with peak-to-peak deflection exceeding ±100 μV were excluded from averaging. Data were digitally filtered with a lowpass filter at 16 Hz. For further analysis, these data were sorted separately based on (1) the prior-hazard levels of words which were classified into high and low hazard groups in above mentioned pilot study and (2) the subject’s responses in ERP experiment. The late criterion of classification was the subjects’ perception and their responses. When subjects perceived high hazard and pressed the corresponding button, the recorded data were classified as the high hazard category, otherwise, the low hazard category. This classification factor was referred to as response-category (high vs. low hazard level).

When data were sorted upon subject’s response, the mean reaction time (RT) for words judged as high hazard level (mean ± S.D. = 686.9 ± 124.45 ms) was significantly shorter than that of words judged as low hazard level (mean ± S.D. = 723.40 ± 107.05 ms), t(22) = -4.249, p < 0.05. When sorted upon the prior-hazard level of these words, the mean RT for the prior high hazard group of words (mean ± S.D. = 692.67 ± 122.16 ms) was also shorter than that for the prior low hazard word group (mean ± S.D. = 712.49 ± 114.27 ms), but the effect failed to reach significant level t(22) = -1.288, p > 0.05 (Fig. 1).

Two ERP components, P200 and LPP, were analyzed. The mean amplitude in the time window of 180–260 ms after the signal words onset was calculated for P200, and the time window of 450–550 ms for LPP. To analyze effects of these components, we selected electrodes (F3, FZ, F4, FC3, FCZ, FC4, C3, CZ, and C4) in the frontal-central
As to P200, when sorted upon subject's response, the 2 (response-category: high vs. low hazard level) × 9 (electrode) repeated-measure ANOVA revealed a significant main effect of response-category [F(1,22) = 11.063, p < 0.005]. The P200 amplitude was enlarged for words judged as high hazard level compared with low. When P200 wave was sorted upon the prior-hazard level, the 2 (prior-hazard category: high vs. low) × 9 (electrode) repeated-measure ANOVA showed no significant main effect for prior-hazard category [F(1,22) = 2.835, p > 0.05], though the grand average amplitude over 9 electrodes of high hazardous words (5.953 μV) was higher than that of low (5.402 μV). Further inspection of each electrode individually revealed that although the mean amplitude of P200 across the 9 electrodes elicited by prior high hazardous words did not differ from that elicited by low, still the mean voltages at FC4 and C4 elicited by prior high level hazard words were significantly larger than that by low, t(22) = 2.145, p < 0.05 and t(22) = 2.702, p < 0.05, respectively, indicating that right hemisphere effect existed to a certain extent.

The similar two ANOVAs for LPP over the 9 electrodes in central-parietal area were also carried out, which produced main effects for both the response-category (high vs. low) of hazard level and the prior-hazard category (high vs. low), F(1,22) = 8.654, p < 0.01 and F(1,22) = 7.682, p < 0.05, respectively. It means that both the words judged as high hazard level by the EEG-subjects in ERP experiment and the words with high hazard level judged by the prior-rating subjects evoked obviously larger LPP (Fig. 2).

As mentioned above, warning signal words elicited apparent P200 and LPP wave. In accordance with previous ERP studies [17,22,29], P200 here indicated the early automatic processing of signal words. It reflected the engagement of attention resources, and associated with the detection of hazard for warning signal words. LPP revealed the late controlled process of more complicated semantic processing of signal words, and reflected the subjective evaluation on these words. We suggested that the processing of warning signal words consists of two stages: the early hazard perception and detection stage, and the later hazard-evaluation process of these words. We referred this “Hazard Perception Two-Stage” process as HPTS model. It is consistent with C-HIP model [33]. After receiving a warning signal word, people notice the word and detect the hazard information it conveyed. This process occurs automatically and rapidly around 200 ms after the word presented. This early stage is represented by P200, and corresponds to the stage of “attention” described in C-HIP model. Then the word is further processed semantically and comprehended. On the basis of one’s previous related experience, people form their attitudes towards the word and assess its hazard level. This cognitive process represented by LPP in our study occurs later and may indicate “comprehension”, “attitudes and beliefs”, and “motivation” in C-HIP model.

Data sorted by subject’s response-category showed significant difference on P200, LPP, and RT between two different hazard perceptions in responses (perceived high hazard vs. perceived low hazard). Subjects responded more quickly to words from which they perceived high hazard, resulting obviously shorter reaction time and distinctly augmented LPP and P200. Edworthy et al. proposed that subjective perceived urgency predicts reaction time [11]. Qin et al. revealed positive correlation between P200/LPP amplitudes and subjective ratings of risky environmental events, indicating that P200 and LPP contributed to subjective ratings of these events [22]. Our result is consistent with these researches. Subjects recruited more attention resources to the words that they subjectively perceived as high hazardous. The previous behavioral research [20] indicated that subjective hazard perception contributes to the noticeability towards warning sign, while our result provided electrophysiological evidence for its suggestion.

Unlike response-category, data sorted by the prior-hazard level (high vs. low) of these signal words revealed no significant difference on P200 and RT. This reflected the discrepancy of cognition on these warning words between the prior-rating subjects and the EEG-subjects. Moreover, perceptions of these warning words were also different from each other among EEG-subjects. Further analysis showed that only 8 words (4 of high hazard level and 4 of low in the prior-hazard categories) were agreed by no less than 20 EEG-subjects. The different result between prior-rating subjects and EEG-subjects may reflect the different characteristic of hazard judgment with and without time pressure. Vorhold et al. proposed that judgments with time pressure prevent subjects from thinking elaborately, thus induce intuitive risk judgments involving both the affect and rationality [31]. We indicate that judgment under limited time may be more susceptible to other factors such as emotion, resulting in even larger differences between subjects. This implies that the factor of time pressure should be taken into account when comparing questionnaire and psychological experiment results. This result was very meaningful for safety management. It showed that any given signal word used in warning sign must be perceived as the same hazard level, at least similar hazard levels, it then takes effect in reality, especially in emergent situation under time pressure. For that, the training for comprehension on warning words does be necessary.

When data was sorted by prior hazard level, the mean amplitude of P200 across 9 electrodes evoked by the words with high prior-hazard did not differ from that evoked by the words with low prior-hazard, but the difference of P200 between prior high and low hazard words was significant at two electrodes of FC4 and C4, showing somewhat right hemisphere effect. Previous studies found that right hemisphere involved more than left hemisphere in processing emotional stimuli, especially in processing negative emotional stimuli [15,29]. Both fMRI and ERP studies have put forward the arguments that hazard rating and identification involves emotional process [22,23,31], the high hazard words in the current experiment might be similar, to a certain extent, to negative stimuli. Then, according to [9], hazard words directly triggered the immediate negative emotion, and showed the right hemisphere effect.

When sorting data by prior-hazard level, differences in amplitude of P200 between high and low prior hazard conditions were only significant at two electrodes in right hemisphere of brain, while those of LPP were significant at almost all 9 electrodes in central-parietal scalp (significant at 6 electrodes, marginally significant at 3), showing that the LPP, as a reflection of evaluation
process on warning signal words, recruited more brain resources compared with P200.

Previous studies showed that high arousal stimuli elicited larger LPP than low arousal ones, reflecting enhanced activation of motivational system in the brain [8,25]. Other physiological indices, such as heart rate and skin conductance, were also larger for high arousal stimuli [3]. In the current study, prior hazard words elicited augmented LPP, indicating that prior high hazard words may have higher strength of negative emotion, resulting in larger LPP. This may imply that warning signal words themselves can convey information of hazard level, not only attract attention.

The difference of LPP between high and low prior hazard words was significant, whereas the difference of RT between those two conditions was insignificant. One possible explanation for the implausible phenomena might be that LPP reflected real evaluation of warning words, while the conveying time (defined as the time of delivering the electrophysiological symbol from brain to the finger to press the response button) were different among different individuals, in other words, the conveying time modulated RT, resulting the insignificant difference of RT between high and low hazard conditions. That is, the direct electrophysiological measurement was better than behavior measurement, such as RT, for understanding the subjects' perception of hazard information.

The current paper suggested that there were two stages in processing the hazardous signal words used in warning sign. The first stage was an early automatic cognitive process of perception for the hazard in warning words, represented by P200; the second was the late controlled process in which the hazard level that the warning words contained was evaluated, represented by LPP. The present findings of significant differences among individuals in subjective hazard perception of warning words showed the importance and necessity of training for receivers to comprehend the words consistently. The results implicated that the warning words which reflect the same hazard level used in warning sign should be somewhat changed, at the same time, convey equally or similarly hazardous information, to avoid desensitization and habituation [12] due to overuse of them.

**Conflict of interest**

There are no conflicts of interest.

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