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Semantic processing and emotional evaluation in the traffic sign understanding process: Evidence from an event-related potential study

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ABSTRACT

Traffic signs are used on highways and in urban transportation facilities. As a critical element of driving safety, traffic signs are generally evaluated using questionnaires and by measuring reaction time. This study investigated the cognitive processing of traffic signs by measuring event-related potential (ERP) and explored semantic and emotional processing. A stimulus 1–stimulus 2 paradigm was adopted. Traffic sign–word pairs were organized into semantically congruent and semantically incongruent groups. Larger N400 amplitude and theta activity were simultaneously elicited by semantically incongruent traffic sign–word pairs, which indicated the semantic distance between traffic signs and words. A greater late positive potential was elicited by semantically congruent traffic sign–word pairs, which reflected participants' positive emotional arousal. Additionally, this study measured ERP to assess semantic distance and emotional arousal in the traffic sign understanding process.

1. Introduction

Traffic signs are powerful elements in visual communication because they enable motorists to accomplish safety-critical tasks during driving. They warn and provide information to motorists, facilitating safe driving. While driving, motorists have limited time to check traffic signs; even a 2-s glance from the road can be risky (Yang, Lee, & Yekhshatyan, 2012). However, numerous studies have reported that inadequately understood signs require more cognitive processing, which can cause a delay in responding and contribute to traffic collisions (Klauer, 2006). Therefore, semantic congruence is crucial to understand traffic signs.

Signs convey semantic information through visual language and follow less restrictive rules than do written words (Boff, Kaufman, & Thomas, 1986), which may cause ambiguity and differences in interpretation:

Congruent refers to the fact, for two objects, of matching, agreeing, being appropriate to and being consistent with each other. Incongruent conveys the meaning "illogical", which sometimes also refers to the unexpected or improper/

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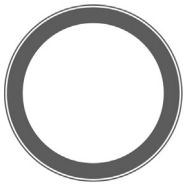
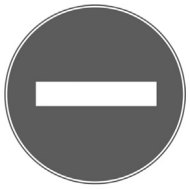
ill-mannered (Fleck-Dousteyssier and Maille, 2011). In this study, semantic congruence is defined as the state in which the information conveyed by traffic signs is consistent with the intended meaning, and vice versa.

Many studies have reported that drivers often misunderstand the intended meaning of signs; some signs were even interpreted to have a meaning contradicting the intended meaning (Shinar and Vogelzang, 2013). Additionally, substantial differences in comprehension were reported for different signs, countries, and driver populations (Shinar, Dewar, Summala, & Zakowska, 2003). Ou and Liu (2012) explored the effect of sign design features and training on cross-culture comprehension and determined that semantic closeness had the greatest positive correlation with comprehension. However, some semantically incongruent signs remain in practical use. For example, Erkut and Hediye (2012) surveyed 1478 participants in Turkey and determined that out of 39 signs, only 12 were identified correctly by $\geq$70% of the participants. In the present study, we determined that although the intended meaning of the first sign in Table 1 is "No passing for all pedestrians and vehicles," it was misunderstood as "Passing allowed" by inexperienced and experienced drivers. Questionnaires and surveys are unsuitable for determining why a semantic distance exists between a sign's intended meaning and its perceived meaning. To resolve this problem, we measured the semantic cognitive processing mechanism of traffic signs (see Table 2).

Event-related potential (ERP) is a brain-evoked potential that is induced by intentional stimulation. It reflects electrophysiological changes that occur in the brain during the cognition process. Luck (2005) recorded the brain potential from the surface of participants' brains while they performed cognitive processing. The ERP method was used to characterize the time-course mechanism that underlies semantic comprehension. The N400 is a language-related component that is best studied and was first reported by Kutas and Hillyard (1980). The N400 is a late negative ERP component that peaks approximately 300–500 ms after the onset of a stimulus (Barrett and Rugg, 1990). Its amplitude is usually the largest over the central and parietal electrode sites, with a slightly larger amplitude over the right hemisphere than over the left hemisphere (Kutas & Dale, 1997). The N400 is typically observed in response to violations of semantic expectancies, and it indexes semantic processing. The N400 is particularly sensitive to semantic incongruence. For example, if the N400 was to process the second word in the following word pairs, then a high N400 amplitude would be elicited by the "tire–sugar" word pair, whereas a low N400 amplitude would be elicited by the "flour–sugar" word pair. The N400 has been observed not only in verbal stimulus studies but also in myriad nonverbal stimulus studies on pictures, icons, and mathematical symbols (Kutas and Federmeier, 2011). N400's amplitude in semantically incongruent contexts is larger than in semantically congruent contexts (Ma, Hu, Xiao, 2016). Hamm, Johnson, and Kirk (2002) measured N400's response to picture stimuli in both congruent and incongruent contexts by using the ERP method and determined that the N400 is responsive to all types of semantic mismatch. Traffic signs are a type of language that conveys information through graphics; thus, the ERP method can be used to determine the semantic congruence of signs and their intended meanings. We hypothesized that a larger N400 would be elicited when the meanings of traffic sign–word pairs were incongruent.

Late positive potential (LPP) is an ERP component that is elicited between 300 and 700 ms after the onset of a stimulus (Cuthbert, Schupp, & Bradley, 2000). The maximal amplitude of the LPP is achieved over the central–parietal regions, and it indicates selective processing of emotional stimuli, reflecting subjective evaluation and activation of brain's motivational systems, which are associated with emotional arousal (Cuthbert et al., 2000; Pastor, Bradley, & Löw, 2008). Konorski (1967) determined that most pleasant affects are associated with the brain's appetitive motivation system, and unpleasant affects are associated with defensive motivation. For example, the LPP reflects the appetitive motivation system and affective arousal. Pastor et al. (2008) assessed ERPs to pleasant, neutral, or unpleasant pictures and determined that emotional

Table 1
Examples of road signs with incongruent messages.

Examples	Intended meaning	Perceived meaning
 Sign color : Red circle on white background.	No passing (for all pedestrians and vehicles)	Passing allowed
 Sign color : White rectangle on red circle.	No entry (for all vehicles)	Slow down/check point