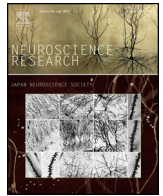




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An event-related potential investigation of sentence processing in adults who stutter

Shinobu Murase^{a,b,*}, Takashi Kawashima^c, Hirotaka Satake^c, Seiichi Era^b

^a Division of Special Needs Education, Faculty of Education, Gifu University, 1-1 Yanagido, Gifu 501-1193, Japan

^b Department of Physiology and Biophysics, Gifu University Graduate School of Medicine, 1-1 Yanagido, Gifu 501-1194, Japan

^c Department of Neurobiology, Gifu University Graduate School of Medicine, 1-1 Yanagido, Gifu 501-1194, Japan

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ABSTRACT

The purpose of this study was to investigate characteristics of the semantic processing of sentences' final verbs in stutters using event-related potential (ERP). ERPs elicited from semantically violating and non-violating verbs in Japanese sentences were compared between 13 adults who stutter (AWS) and 13 adults who do not stutter (AWNS). The stimulus sentences elicited the N400 and the late positive component (LPC) in both groups. The amplitude of the N400, however, was attenuated in AWS. Regarding the LPC, the LPC in the 450–700 ms time window (the early LPC) was evident in both groups, but the LPC in the 700–850 ms time window (the late LPC) was only apparent in AWS. Because AWS judged sentence congruency as accurately as AWNS did, it is assumed that AWS depended more on the LPC for semantic processing, resulting in the enhancement of the late LPC. We speculate that semantic processing of sentences for AWS is more time consuming than that for AWNS.

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1. Introduction

Stuttering is a disorder of speech sound production characterized by sound repetitions, sound prolongations, or silent blocks, mainly at the beginning of words. Although the prevalence of stuttering is approximately 1% in the entire population (Craig et al., 2002), the etiology of stuttering remains unidentified.

It seems evident that stuttering involves the disruption of articulatory movements. The disruption, however, is fluctuating and intermittent. To explain the fluctuation and intermittency, a multifactorial model of etiology has been proposed (Smith and Kelly, 1997; Smith, 1999). The model speculates that multiple factors, including linguistic, cognitive, and emotional, cause the breakdowns in fluent articulatory movements that will result in stuttering. Some studies have shown that stuttering tends to occur with content words rather than with function words (Brown, 1945;

Howell et al., 1999). Other studies have indicated that stuttering occurs with sentences containing less familiar words (Soderberg, 1966; Palen and Peterson, 1982; Hubbard and Prins, 1994). Taken together, stuttering is likely related to the semantic processing of language.

Event-related potential (ERP) is a brain potential fluctuation associated with some physical or mental activities (Picton et al., 2000). Kutas and Hillyard (1980) presented seven-word-sentences word by word visually and found that the last word which was incongruent to the other words in the sentence yielded a large negative deflection at around 400 ms. This component is referred to as the N400. Since its discovery, a substantial amount of studies have explored the characteristics as well as the underlying cognitive and neural functions of the N400 (Kutas and Federmeier, 2011). Linguistically, the N400 is recognized as the major component linked to the semantic processing of language. With regard to experimental conditions, not only sentences but also words or pictures were found to elicit the N400. Both auditory and visual stimuli were also demonstrated to elicit the N400. In addition, abnormalities of language processing in special populations, for example, those suffering from schizophrenia (Matsumoto et al., 2001; Sitnikova et al., 2002; Ruchow et al., 2003), autistic disorder (Pijnacker et al., 2010), or Alzheimer's disease (Revonsuo et al., 1998), have been extensively studied in relation to the N400.

Abbreviations: AWS, adult who stutter; AWNS, adult who do not stutter; LPC, late positive component; ERP, event-related potential; EEG, electroencephalography; EOG, electrooculogram; ANOVA, analysis of variance.

* Corresponding author at: Division of Special Needs Education, Faculty of Education, Gifu University, 1-1 Yanagido, Gifu 501-1193, Japan. Tel.: +81 58 293 2339; fax: +81 58 293 2339.

E-mail addresses: shinobu@gifu-u.ac.jp (S. Murase), tk@gifu-u.ac.jp (T. Kawashima), satake@gifu-u.ac.jp (H. Satake), era@gifu-u.ac.jp (S. Era).

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Several studies have explored semantic processing in adult stutterers using the N400. [Weber-Fox \(2001\)](#) visually presented sentences with violations in semantic expectations (for example, “She looked at the watch to check the rain.”) and recorded ERP from the incongruent words. Although the latency of the N400 was not significantly different between stutterers and non-stutterers, the peak amplitude of the N400 was attenuated in stutterers. Subsequently, [Weber-Fox and Hampton \(2008\)](#) reported that stutterers had an attenuated amplitude of the N400 in the naturally speaking sentences presented by auditory modality. [Maxfield et al. \(2010\)](#) investigated the N400 in adult stutterers with a picture–word priming task. Following the picture labels, auditory probe words which were semantically related or semantically unrelated, were presented to the subjects, and the spatio-temporal principal component analysis was performed to the ERPs obtained from the probe words. Results showed that nonstutterers had attenuated N400 amplitudes for the semantically related probe words, whereas stutterers had enhanced amplitudes. To test the reverse semantic priming effect observed in stutterers, [Maxfield et al. \(2012\)](#) re-examined the semantic priming effect by the modified picture–word priming task where the subjects were instructed to pay attention to the pictures and the auditory probe words. Contrary to their previous results, they found that stutterers had an attenuated N400-like component emerging at around 760 ms after the onset of the stimulus.

The results of the previous studies suggest an atypical semantic processing among stutterers. It should be noted, however, that [Weber-Fox \(2001\)](#) as well as [Weber-Fox and Hampton \(2008\)](#) and [Maxfield et al. \(2012\)](#) have investigated different levels of semantic processing: one at the sentence level and the other at the word level. We consider that a careful examination is required to verify the stutterers’ atypical semantic processing. It is also assumed that a cross-linguistic study will provide us a deeper insight into the probability of an atypical N400 among stutterers.

Recently, a positive deflection at a relatively long latency (between 600 ms and 900 ms) after stimulus onset has been shown to occur in a semantic processing task ([Van Petten and Luka, 2012](#)). This positive component is referred to as the late positive component (LPC) or the semantic P600 in ERP literatures. For example, sentences such as “After an air crash, where should the survivors be buried?” ([Sanford et al., 2011](#)) or “For breakfast, the eggs would only eat toast and jam” ([Kuperberg, 2007](#)) were found to elicit the LPC. The LPC is attributed to either re-analysis of problematic sentences ([Kolk et al., 2003](#); [van Herten et al., 2005](#); [Kuperberg, 2007](#)) or “conflict monitoring,” which is a checking system for possible errors in conflicting information ([van Herten et al., 2006](#); [Vissers et al., 2006](#)).

[Juottonen et al. \(1996\)](#) recorded ERPs for semantically incongruous final words from children and adults and compared the N400 and the LPC between the groups. The N400 was found to be significantly larger in children than in adults, whereas the LPC was apparent in adults but absent in children. The authors speculated that modulation of the LPC was likely a result of cognitive maturity. They also pointed out that other processes essential for semantic integration or concept understanding of stimulus content occur after the N400 time window such as the LPC or semantic P600.

Accordingly, the following speculation can be made: if stutterers have attenuated the N400, they may modulate the LPC to compensate for the semantic processing underlying the N400. To the best of our knowledge, the characteristics of stutterers’ LPC have not been investigated to date. Therefore, in the present study, we will explore the semantic processing of sentences through the N400 and LPC in stutterers.

Table 1
Examples of the stimulus sentences.

	Examples of sentences			
	1st phrase	2nd phrase	3rd phrase	Target phrase
Congruent	ぼくは I	庭に in the garden	木を trees	植える plant
Incongruent	ぼくは I	朝食に at breakfast	卵を eggs	植える plant

The target phrase was always a verb because in Japanese sentences, the verb is always at the end of the sentence. Incongruity occurred between the target verb and any of the preceding phrases in order that the subjects kept attention to all the phrases in the stimulus sentences.

2. Materials and methods

2.1. Subjects

For a subject to be diagnosed as a stutterer, stuttering was defined as disruptions in the fluency of verbal expression characterized by involuntary audible/silent repetitions or prolongations of short speech elements ([Wingate, 1964](#)). A stuttering subject in this study was required to meet the criteria that the frequency of stuttering was above 3% in a conversational speech ([Conture, 1990](#)) with the experimenters and that he/she identified himself/herself as a stutterer. Subjects were 13 adults who stutter (AWS) [one female, 12 males; mean age = 34.4 ± 10.4 years; two left-handed assessed by the H.N. Handedness Inventory ([Hatta, 1996](#))] recruited among members of the self-help organizations for stutterers in Japan. The control subjects were 13 adults who do not stutter (AWNS) matched in age (mean age = 30.9 ± 10.8 years). They, however, were not matched in gender (four females, nine males) and in handedness (all right-handed assessed by the H.N. Handedness Inventory). A speech sample of each AWS was collected, and the occurrence of stuttering was analyzed by the first author, a certified speech-language pathologist in Japan. The percentages of stuttered phrases in each AWS’s conversational speech with the first author ranged from 7% to 27%. All were native Japanese speakers and had normal or corrected-normal vision. None of them had any history of psychiatric and neurological disorders as well as substance abuse or drug use. All subjects had completed at least a high school education, and no one exhibited speech, language and hearing disorders except for stuttering, as well as intellectual disabilities. All subjects were paid and provided written informed consent before participation in the experiment. The study was approved by the ethical committee of Gifu University School of Medicine (#23-70).

2.2. Materials

Stimuli consisted of 75 pairs of four-phrase sentences in Japanese. A pair of sentences included a congruent and an incongruent sentence with an identical target verb at the end. The target verb in the congruent sentence was semantically correct or appropriate in the preceding sentence context, whereas the target verb in the incongruent sentence was semantically incorrect or inappropriate (see [Table 1](#) for examples of stimulus sentences).

2.3. Procedure

Subjects were seated in an electrostatically shielded room, facing a computer screen at a distance of approximately 120 cm. Stimulus sentences were visually presented one phrase at a time on the 16-inch computer screen. The phrases were presented in black Gothic font on a light blue background and were subtended a horizontal visual angle of 5.7° and a vertical angle of 1.4° . [Fig. 1](#) shows the schematic description of stimulus presentation. To maintain

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