論文

Examining Cortical Activation for the Primacy of Syntactic over Semantic Processing in Japanese Process: A Study Using Near-Infrared Spectroscopy

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Abstract

In the present study, we examined the primacy of syntactic over semantic processing in the Japanese language, in which grammatical morphology is as prominent as in most of Indo-European languages, but it also possesses symbolic language, similar to Chinese. Three kinds of collocation were created as stimuli: congruous collocations, collocations with semantic violation, and collocations with syntactic violation. Participants were asked to read the stimuli silently and then they judged whether they had seen them or not. Near-infrared spectroscopy was used to measure the regional changes in hemoglobin concentration in the brain of the participants. After analyzing the interplay of cortical activation between syntactic and semantic processing, we found that, during the reading task, when congruous stimuli were presented, activation was observed around the inferior frontal gyrus and the middle temporal gyrus, while when semantically violated stimuli were presented, activation was observed around the inferior frontal gyrus. However, no brain area activation was observed for a syntactic violation condition. These activation patterns suggest that in Japanese, semantic processing is also dependent on the intactness of syntactic information, just as in Indo-European languages. The present study indicates that languages with prominent grammatical morphology exhibit primacy of syntax over semantics, and that near-infrared spectroscopy provides an efficient method of evaluating the primacy of syntactic and semantic processes.

Keyword

syntactic primacy hypothesis, Japanese, near-infrared spectroscopy (NIRS)

脳活動における日本語処理の統語優位性仮説に関する検討
－近赤外分光法（NIRS）を用いて－

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要旨

本研究は，日本語処理において意味処理よりも統語処理が優先されることを検証した。日本語はほとんどのインドヨーロッパ語族の言語と同じように文法的形態が明確であるとともに，非インドヨーロッパ言語の典型である中国語と同じように表意文字を持っている。本研究では，刺激として，正しいコロケーション，意味逸脱コロケーション，統語逸脱コロケーションの３種類を用いた。参加者の課題は，刺激を黙読し，後に再認することであった。課題遂行中の参加者の脳内酸化ヘモグロビン（Oxy-Hb）濃度の変化を近赤外分光法（NIRS）を用いて測定した。統語処理と意味処理を司る脳内部位の活性化状況の相互関係を分析した結果，正しいコロケーションが呈示された時には，左下前頭回と左中側頭回が活性化した。意味逸脱コロケーションが呈示された時には，左下前頭回が活性化した。統語逸脱コロケーションが呈示された時には，どの脳内部位も活性化しなかった。これらの結果によって，ほとんどのインドヨーロッパ語族の言語と同じように，日本語においても統語処理が行われてから意味処理がはじめて行われることが示唆された。本研究は文法的形態が明確な言語は統語処理の優位性を持っている可能性を示した。さらに，NIRSが言語処理の脳内機構を検討する有力な道具として使えることを示唆した。

キーワード

統語処理優位性仮説，日本語，近赤外分光法（NIRS）

Introduction

The comprehension of language in everyday communication involves both the retrieval of single word (i.e., the lexical-semantic processing) and the analyses of the syntactic structure (i.e., the syntactic processing). When it comes to the relationship of the syntax and semantics in sentence processing, whether there is a primacy of syntactic over lexical-semantic processes is a central question (Yu & Zhang, 2008). The interactive models (McClelland & Rumelhart, 1981; Bates & Mac-Whinney, 1987; MacDonald et al., 1994; Marslen-Wislon &Tyler, 1980; Taraban & McClelland, 1988) do not assume such primacy. In contrast, serial, syntax-first models propose such primacy (Frazier & Fodor, 1978; Frazier, 1987; Friederici, 2002). However, no matter the interactive models or the serial models, it is Indo-European languages that are based on.

Recently, researchers from China used Chinese, which is typologically distinct from Indo-European languages, to examine the primacy of syntax over semantics. Different from the previous studies, they found that semantic integration could be attempted even when the processing of syntactic category or syntactic subcategorization frame is unsuccessful. Thus, syntactic processing is not a necessary prerequisite for the initiation of semantic integration in Chinese (Ye et al., 2006; Yu & Zhang, 2008; Liu et al., 2010; Zhang et al., 2013). These studies made the primacy of syntactic over lexical-semantic processes become more controversial.

There is a possibility that the relationship of syntactic processing and semantic processing is different in different kind of languages (Liu et al. 2010; Guo et al. 2009; Yu & Zhang, 2008). In this study, we intended to figure out this question by using Japanese. Japanese is a specific language that both have something in common with Indo-European languages and Chinese. The elements of the sentence can be relatively easily distinguished by particles such as "de", "ni", "wo", "ha" in Japanese, while Indo-European languages such as German and Dutch have morphological markers (such as the third person marked by "s") to label word category. In some extent we can say that grammatical morphology is prominent in both of them. On the other side, both Chinese characters and Japanese characters possess symbolic character, which is to say that we can understand the meaning of the paragraph quickly at the sight of the character. So, theoretically, it is possible that the relationship between syntactic and semantic processing in Japanese is the same with Indo-European languages such as German and Dutch, or with Chinese. By using Japanese, we expect to explore the element which decide the primacy, and the universal properties of language processing.

In this study, we intend to exam the primacy further with collocations in Japanese. Collocation refers to a kind of word combination whose degree of restriction is between free combination and idiom (Nesselhauf, 2003). And as a kind of linguistic unit, collocation is regarded as between the single word and the long sentence. Since most studies have targeted either the single word level (Hagiwara et al., 1999) or the complete sentence level (Hahne & Friederici, 2002; Friederici et al., 2004; Kos et al., 2010), the present study tried to use collocations. Since [v+n] collocation is the most basic type in all of the structure type, we targeted [v+n] collocation in this study.

In this study, we used near-infrared spectroscopy (NIRS), an apparatus measuring regional changes in hemoglobin concentration that yields an index of local activation on the surface of the brain. It is non-invasive, portable, and relatively robust to movement artifacts. Furthermore, the spatial resolution of NIRS is higher than that of ERPs, which is rather sensitive temporally (Mehta & Parasuraman, 2013).

Many studies support the involvement of the left inferior frontal gyrus during syntactic processing and the involvement of the left middle temporal gyrus during lexical-semantic processing (Goldenberg et al., 1987; Caplan et al., 1998; Kuperberg at al., 2000, De´monet et al., 1993; Wise et al., 1991) . Therefore, we predicted cortical activation of the left inferior frontal gyrus during a syntactic violation condition and of the left middle temporal gyrus during a semantic violation condition.

Methods

Participants

Twelve undergraduate and graduate Japanese students from K University, 2 males and 10 females,

Table 1. Examples of the stimuli

Condition	Con	Sem	Syn
Examples	汚れを落とします yogore-o-otoshimasu remove the dirt (acc)	音楽を煮ます onngaku-o-nimasu boil the music (acc)	チームが組みます ti-mu-ga-kumimasu form a team (acc)
	扉を開きます tobira-o hirakimasu open a door (acc)	歯を払います byouki-o okurimasu sent away illness (acc)	卵が産みます tamago-ga umimasu lay an egg (acc)
	ゴミを出します gomi-o dashimasu throw away rubbish (acc)	資料を育ちます shiryo-o sadachimasu bring up material (acc)	雑誌が読みます zasshi-ga yomimasu read a magazine (acc)

Con = congruous, Sem = semantic violation, Syn = syntactic violation.

voluntarily participated in the experiment. The participants were 18 − 26 years of age, right-handed and had normal or corrected-to-normal visual acuity. Informed consent was obtained for all the participants after a brief about the working of NIRS, and the procedure of the study.

Stimuli

We used 135 commonly used Japanese collocations as stimuli, all of which comprised two elements: an object with case particle "o" and a verb. The stimuli were selected from the *Dictionary of Usage of Japanese Basic Verbs* (Koizumi et al., 1989). They were grouped into three conditions by "collocation type" as follows: (1) forty-five sentences in a congruous condition (the original correct collocations); (2) forty-five sentences in a semantic violation condition (the verb was substituted with a semantically unrelated verb) in which the substituted verb raised semantic violation with respect to selectional restriction constraints given the noun before it; and (3) forty-five sentences in a syntactic violation condition (the case particle "o" was substituted with "ga") in which the case particle and the following verb were mismatched with respect to phrase structure constraints. Table 1 shows the examples of these stimuli.

Apparatus and NIRS setting

A personal computer (Dell Studio, XPS1340) was used to control the stimuli presentation. The series of collocations were presented on a 22-inch CRT monitor (Dell, P1230), the display resolution of which was set at 1024 × 768 pixels with a refresh rate of 75 Hz.

A 24-channel NIRS instrument (Hitachi Medical Co., ETG-4000 Optical Topography System), was used for monitoring oxygenated hemoglobin (oxy-Hb) concentration changes with a sampling rate of 10 Hz. The instrument generates near-infrared light of two wavelengths of 695 and 830 nm. Two sets of 3 × 3 array photodiodes, which comprises five light emitters and four detectors side by side at a distance of 3 cm, were placed on the participant's head. We made an effort to cover the participant's inferior frontal gyrus and middle temporal gyrus of both hemispheres. The bottom array of the photodiodes was placed just above the ears, thus in participants' left hemisphere, T3 of the International 10 − 20 system was located between Ch. 3 and Ch. 8, while in their right hemisphere, T4 of the International 10−20 system was located between Ch. 7 and 22 (see Figure 1 for a brief image).

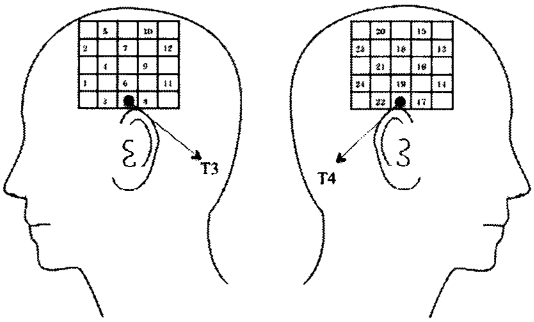

Figure 1. The setting locations of the near-infrared spectroscopy' s probes and channels.

Procedure

The stimuli of the three conditions were randomly allocated into four sessions. For the preparation of the experiment, participants were asked to sit on a comfortable chair 100 cm in front of the monitor using a chin rest. Before the experiment, participants were given a practice session, the stimuli of which did not appear in the experimental session. During experiment, the stimuli were presented visually, one at a time, in the center of the computer display. After 15 s of initial resting time, the instruction for the reading task appeared and was presented for 5 s, and then the experimental session began. One experimental session consisted of two successive tasks, a reading task and a recognition task. The reading task was consisted of six trials, in each of which a stimulus sentence was presented for 2 s followed by a blank interval of 1 s. During the task, participants were asked to read the collocations carefully. After it, the instruction for the recognition task was presented for 5 s, and then the recognition task was followed. The recognition task also consists of six trials, in each of which a probe collocation was presented for 2 s followed by a blank interval of 1 s. Of all the six probe collocations, three were new ones and three were old ones. Participants were asked whether or not these probe collocations had appeared in the previous by pressing the button "d" or "k" as fast and as accurately as possible. After the recognition task, there was 15 s of resting time. The whole procedure took about 45 min to finish, including the rests, initial setting, and removal of the photodiodes.

Data analyses

We calculated the recognition rate (RR-r) and reaction time (RT-r) of the recognition task for each condition.

During the experiment which used NIRS equipment, usually three measurements of hemodynamics will be provided: oxygenate hemoglobin (oxy-Hb), deoxygenated hemoglobin (deoxy-Hb), and total hemoglobin (total-Hb), which is the sum total of oxy-Hb and deoxy-Hb. An increase in oxy-Hb concentration is typically considered as cortical activation. Therefore, we focused on the oxy-Hb change in this study.

To remove measurement artifacts that could have occurred because of body movements as such, the raw oxy-Hb data was digitally low-pass filtered at 0.1 Hz. Using the low-passed raw data, we plotted the trends of oxy-Hb concentration changes over time in each condition. For each of the channels, the oxy-Hb data during the resting time from 5 s prior to the instruction were averaged as the baseline of each trial. In addition, by subtracting the baseline value, we obtained the increment or decrement of oxy-Hb concentration during the task period. A significant change in oxy-Hb concentration was admitted only if there was significant difference

Table 2. The recognition rate of the recognition task, mean reaction time of the recognition task across the three types of stimulus material (SE in parentheses)

	Con	Sem	Syn
RR-r (%)	89 (2.6)	92 (2.3)	89 (2.6)
RT-r (ms)	784 (90.4)	836 (87.2)	772 (88.9)

Con = congruous, Sem = semantic violation, Syn = syntactic violation,
RR-r = recognition rate of the recognition task, RT-r = reaction time of the recognition task.

during the *t*-tests performed against zero for each of the 24 channels.

Results

Behavioral data

Table 2 shows the RT-r and RR-r of the recognition task for the congruous, semantic violation, and syntactic violation conditions. After performing one-way analysis of variance, we found that there was no significant main effect between the three conditions.

NIRS data

The trends in the raw data of the oxy-Hb concentration changes over time in each condition were plotted in Figure 2.

Figure 3 shows the channels with significant activity in the reading task and the recognition task.

In the reading task, channels 1, 3, 4, 6, 7, 8, 9, 12, and 15 were activated in the congruous condition, channels 1, 3, 6, and 8 were activated in the semantic violation condition, but there were no activated channels in the syntactic violation condition. In the recognition task, channels 12 and 23 were activated in the congruous condition; and channels 9, 12, and 18 were activated in the semantic violation condition; whereas no channels were activated in the syntactic violation condition. By comparing the corresponding brain areas, we found that the inferior frontal gyrus and the middle temporal gyrus were activated in the congruous condition, and the inferior frontal gyrus was activated in the semantic violation condition, but no brain area was activated in the syntactic violation condition.

Figure 4 shows the channels for which there was a significant difference between the three conditions in the reading task.

In the reading task, the oxy-Hb concentration change in the congruous condition was significantly larger than that of the syntactic violation condition at channels 1, 3, 4, and 6 (i.e., the brain area corresponding to the left inferior frontal gyrus), while the oxy-Hb concentration change in the semantic violation condition was significantly larger than that of the syntactic violation condition at channels 1 and 3 (i.e., the brain area corresponding to a part of the left inferior frontal gyrus). However, there was no significant difference in oxy-Hb between the channels in the recognition task. This finding indicates that the oxy-Hb concentration change in the left inferior frontal gyrus in the syntactic violation condition was smaller than in the congruous condition and the semantic violation condition in the reading task.

Discussion

We found that most of the oxy-Hb concentration changes were negative during the task periods, reflected as a downward trend in Figure 2. From the behavioral results, which demonstrate

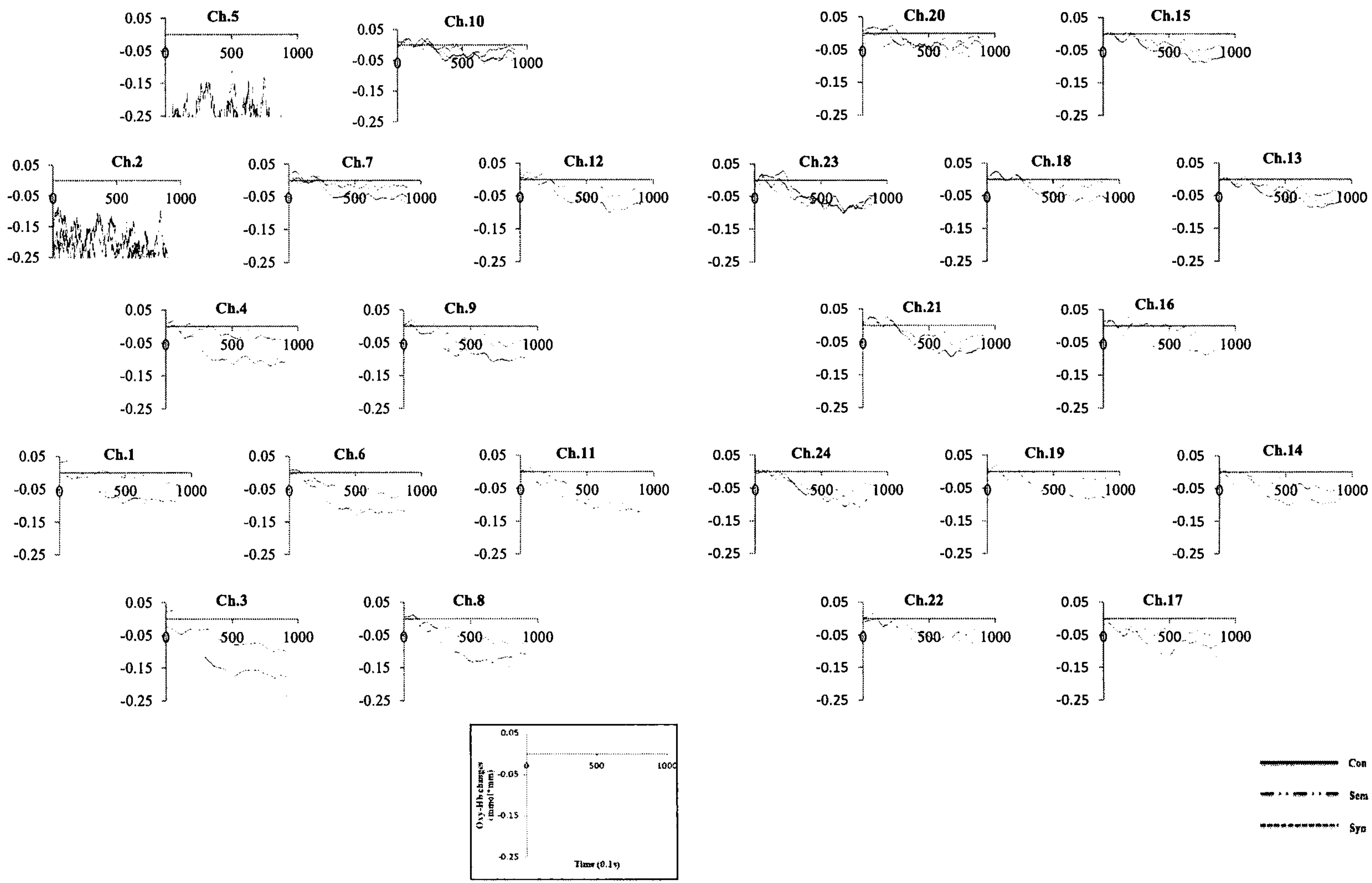

Figure 2. The oxygenated hemoglobin concentration changes (mmol*mm) over time (0.1s) for each channel averaged over all participants. Each inset graph shows the hemoglobin changes in the channels corresponding to Figure 1. Con = congruous, Sem = semantic violation, Syn = syntactic violation.

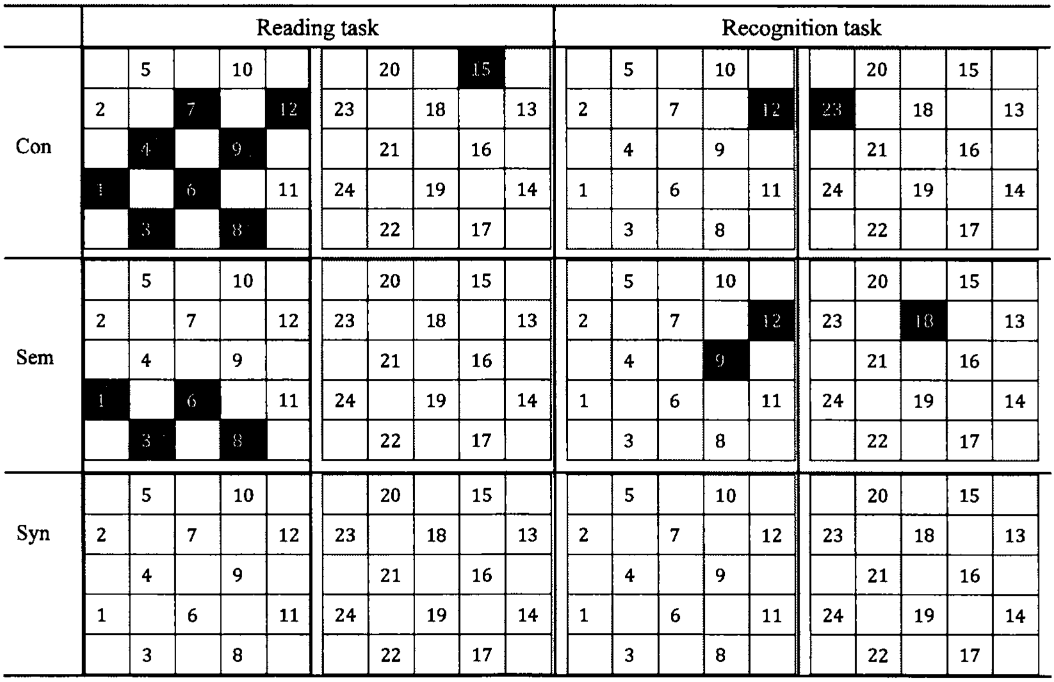

Figure 3. The channels that were significantly (p<.05) activated in each task (shown in black).
Con = congruous, Sem = semantic violation, Syn = syntactic violation.

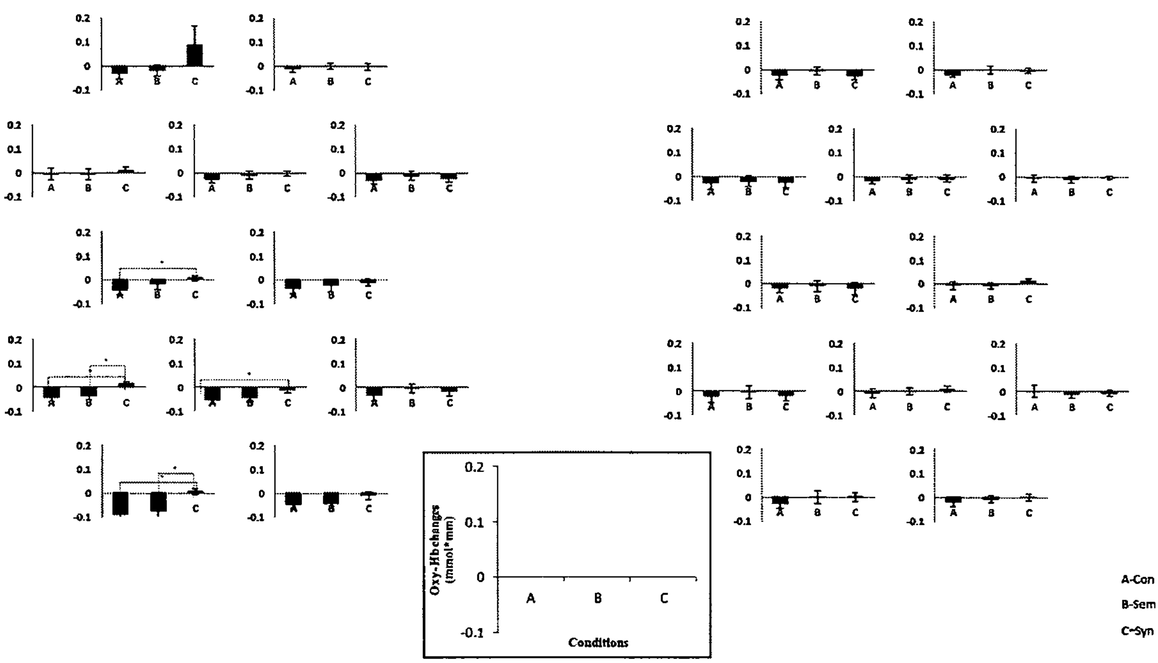

Figure 4. The channels with a significant difference (p<.05) in oxygenated hemoglobin concentration changes (mmol*mm) between the three conditions in the reading task. The setting location of the channels corresponds to Figure 1. Con = congruous, Sem = semantic violation, Syn = syntactic violation.

a high recognition rate and appropriate reaction time in the recognition task, we can conclude that participants concentrated on accomplishing the task during the experimental session. One may expect an increase in blood flow during the tasks to reflect the behavioral patterns. However, the cortical activation measured with NIRS in the present experiment showed decreases rather than increases during the task periods. Aside from some conditions, such as hypoxic-ischemic encephalopathy of newborn infants (e.g., Chen et al., 2002), this kind of decremental change during task periods has also been reported in previous studies using normal healthy people as participants (e.g., Hoshi et al., 1994). It has been proposed that the inactivation appearing in normal healthy participants could be related to the strategy used in performing tasks or the degree of difficulty of the tasks (Hoshi et al., 1994). Regardless of what it was induced by, we can presume that the decreased oxy-Hb states in the present study also indicate cortical activation, at least not in the resting state. Therefore, in this study, we regarded any significant changes of the oxy-Hb concentration, including both increases and decreases, as activations.

During the reading task, the congruous stimuli produced activation in the left inferior frontal gyrus and the middle temporal gyrus, while the semantically violated stimuli yielded activation in the inferior frontal gyrus, and the syntactically violated sentences generated no brain activation. These results indicate that the activation pattern of oxy-Hb changes is related to language processing in the brain. That is, syntactic and semantic processes were involved in the congruous condition, while syntactic processing was involved in the semantic violation condition. However, neither syntactic nor semantic processes were involved in the syntactic violation condition (see Table 3 for a brief image). If the issue of syntactic primacy is not considered, we would expect the left middle temporal gyrus to be activated during the syntactically violated condition, but the fact is that neither the left middle temporal gyrus nor any other gyrus was activated during the syntactically violated condition. This finding implies that the syntactic information, which typically gives rise to the activation of the left frontal gyrus, was hard to process in the syntactic violation condition. The activation pattern in the present study therefore suggests that the failed syntactic processing further blocked the semantic processing, thus the left middle temporal gyrus was not activated. This explanation supports the primacy of syntactic over semantic processing. Moreover, as that the left inferior frontal gyrus is related to syntactic processing, the smaller oxy-Hb concentration change in the left inferior frontal gyrus in the syntactic violation condition, as shown in Figure 4, could indicate unsuccessful processing of syntactic information.

Table 3. The processing involved in each condition

	Syntactic processing	Semantic processing
Con	✓	✓
Sem	✓	×
Syn	×	×

Con = congruous, Sem = semantic violation, Syn = syntactic violation.

This finding is the opposite of that found by Nashiwa and Miyatani (2005, 2006) and Nashiwa et al. (2007). In Nashiwa's experiments, the ERPs of four different types of sentence were observed. The sentences included "Taro-ga ringo-o tabeta; Taro-nom apple-acc ate; Taro ate an apple" (the congruous condition), "Taro-ga reizouko-o tabeta; Taro-nom refrigerator-acc ate; Taro ate a refrigerator" (the semantic violation condition), "Taro-ga rinngo-ni tabeta; Taro-nom apple-dat ate; Taro was eaten by an apple" (the syntactic violation condition), and "Taro-ga reizouko-ni tabeta; Taro-nom refrigerator-dat ate; Taro was eaten by a refrigerator" (the syntactic and semantic violation condition). The results suggested that, when reading Japanese sentences, semantic violation disturbed syntactic processing. As such, syntactic primacy was not supported. In their experiments, sentences were used that had some words in common, so participants could have easily recalled the meaning of the whole sentences according to the first presented condition when one of the three remaining conditions was presented. Although it is not known whether the participants explicitly recognized the sentence based on the characteristics of the stimuli, they could have judged stimuli based on their memory. In contrast, we excluded such a possibility by using three conditions without any words in common. In addition, in Nashiwa's studies, sentences were presented phrase-by-phrase; this mode of presentation could have affected early automatic syntactic processing in particular (Zhang et al., 2006). In the present study, we presented a whole sentence one at a time. This mode of presentation is possible in a NIRS study and may have led to the differing results to Nashiwa and Miyatani (2005, 2006) and Nashiwa et al. (2007).

So far, only a few published studies, such as Kang et al. (1999), Noguchi et al. (2002), and Luke et al. (2002), have investigated the relationship between syntactic processes and semantic processes using collocations. However, they all have some limitations. The verb phrases used in the semantic violation condition (e.g., ate suitcases) of Kang et al. (1999) consisted of verbs and nouns, just the same as normal phrases (e.g., grew plants) , while the stimuli used in the syntactic violation condition (e.g., grew heard) were composed of two verbs. Thus, the brain activity during the syntactic violation condition not necessarily mirrored only the syntactic processing, but could have been caused by the processing of the verbs. The syntactically abnormal condition (e.g., yuki-o tumoru, snow-acc lie, someone lies snow) of Noguchi et al. (2002) could also be semantically violated. Although the semantic anomaly was secondary, the possibility that the participants based their decisions on the anomaly in the sentences could not be ruled out. In Luke et al. (2002) , the stimuli used in the syntactic plausibility judgment task (e.g., likai congcong, quickly left; xiao limaodi, smile politely) consisted of a verb and an adverb, while the stimuli used in the semantic plausibility judgment task (e.g., changle zi, sing-the past tense character, sang a character; shangle men, hurt-the past tense door, hurt a door) was made up of a verb, a marker of the past tense, and a noun. Although we have no idea whether the difference in construction could influence the processing in the brain, it would be easier for us to discuss the results if the construction is the same. Thus, in the present study, we used collocations composed of a verb and noun, and avoided the possibility that the result was caused by using irregular stimuli.

The measurement of ERPs has been a powerful method for addressing the issue of the primacy of syntax, because some distinct ERP responses to syntactic and semantic processes have been amply demonstrated. When ERPs are used to test the primacy of syntax, the basic approach is to investigate whether there is a larger N400 for words constituting a combined violation of syntactic category and semantics compared with correct words or words embodying a syntactic category violation only. If syntactic category processing occurs prior to the semantic processing and the failed syntactic category processing blocks semantic integration, there should be no N400 effect when the combined violation condition is compared with either the correct condition or the syntactic violation only condition. Contrarily, there should be an N400 effect if semantic integration precedes even when syntactic category processing fails (see Zhang, Yu, & Boland, 2010, for more details). The present study has similarities with the ERP studies in that they both used a congruous condition, syntactic violation condition, and semantic violation condition, and analyzed the results by comparing the processes involved. However, a combined violation condition was not used in the present study; we used only three conditions, which is one condition less than the ERP studies, which lightened our load when creating the stimuli. Moreover, because we did not need to present the stimuli for as long as the ERP studies, the participants might not feel as tired as when they take part in experiments using ERPs.

In the recognition task, the active brain area was hard to locate as there were only a few channels activated. Different cognitive processing could have caused the differences between the reading task and the recognition task. That is, as native speakers, participants could correct the violated stimuli into appropriate word combinations even they were not asked to do so. In contrast, participants could easily judge whether they had seen the word combinations or not about half a minute ago (the total time spent in one session was 91 s). Within such a short time, the task was too easy to require and then reproduce the activation of the processing.

In summary, our study provides new findings that are striking in three ways. First, consistent with earlier studies using Indo-European languages, the present study established that there is also a primacy of syntactic processing in Japanese, in contrast to Chinese. Second, a small sentence constituent, such as a collocation, can be used as stimulus material in similar studies. Third, NIRS is also an efficient instrument for exploring the issue of whether syntactic processing has primacy in one language. As discussed in the Introduction, Indo-European languages, such as German and Dutch, are known to have prominent grammatical morphology, which is a feature shared by the Japanese language. Therefore, we have reason to presume that the primacy of syntactic processing is a feature of languages that possess prominent grammatical morphology. This idea is waiting to be verified for more languages.

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