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Semantic Involvement in the Lexical and Sentence Processing of Japanese Kanji

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Unlike the letters in an alphabetical writing system, each single kanji in the Japanese writing system contains semantic value. This feature of kanji has made many researchers claim that semantic processing is a primal process in kanji word recognition (e.g., Goryo, 1987; Nomura, 1978, 1979; Saito, 1981; Sasanuma, 1974; Sasanuma & Fujimura, 1972; Sasanuma & Monoi, 1975). A Japanese sentence consists of both kanji and kana scripts (see details in Kess & Miyamoto, 1999; Leong & Tamaoka, 1995; Tamaoka, 1991; Tamaoka, & Hatsuzuka, 1997, 1998; Tamaoka, Hatsuzuka, Kess, & Bogdan, 1998; Tamaoka & Miyaoka, submitted). The kana script represents phonological units of morae while the kanji script often pertains to morphemic aspects. If the overall meaning of a sentence involves recognition of each word regardless of the script it is in, then, the semantic processing at the sentence level may differ from the processing of a single kanji-compound word. In contrast, it may be that the semantic processing of kanji compound words at the word level is the same at the sentence level since kanji clearly stand out when embedded in the kana script. Thus, the present study examined how semantics are involved in the processing of both the word and sentence level.

One method of examining word recognition in sentences is by using a proofreading task. Shimomura and Yokosawa (1991) studied the processing of two-kanji constituents in Japanese using proofreading experiments. They used pseudo-homophones and nonwords as stimuli. For example, the two-kanji compound pseudo-homophone of 美熱 /bi netu/ was created from the real word 微熱 /bi netu/ meaning 'slight fever'. Participants were asked to detect miscombination of kanji in sentences on a computer display. When the miscombination was a two-kanji compound pseudo-homophone (e.g., 美熱), detection time of participants was shorter than when the miscombination was a two-kanji compound nonword (e. g., 横熱, possibly pronounced as /oR netu/). This result suggests that participants used phonological information in proofreading. However, no significant difference was found between pseudo-homophones and nonwords with regards to accuracy rates (i.e., how well their miscombinations were detected). Shimomura and Yokosawa (1995) also investigated effects of orthographic similarity by the way of a proofreading task. Orthographic similarity between incorrect (e. g., 徴熱) and correct characters (e. g., 微熱) revealed that miscombinations having features nearly identical to proper kanji resulted in lower detection rates than the control stimuli.

The main question of the present study was whether processing two-kanji compound words, individually, differs from processing the same words when embedded in sentences. To answer this question, three different experiments were used: (1) a lexical decision task for two-kanji compound words in Experiment 1, (2) a proofreading task (detection of miscombinations) for the same two-kanji compound words at the sentence level in Experiment 2, and (3) a semantic decision task for sentences with the same two kanji compound words in Experiment 3.

EXPERIMENT 1

Lexical Decision Task

This experiment examined the effects of semantic similarity during lexical decision of two-kanji compound words. In Experiment 1, semantically similar nonwords constructed of two kanji were used. For example, 余額 was created from the real word 残額 , meaning ‘the balance of money left over’. Both 余 and 残 have the meaning ‘left over’. A control nonword 乱額 was created by changing one kanji in the semantically similar nonword. The kanji 乱 means ‘disorder’, so 乱額 became a semantically dissimilar nonword. If semantic processing of single kanji is involved in the lexical decision of two-kanji compound words, semantically similar nonwords would be rejected slower and less accurately than dissimilar nonwords.

Method

Participants. Twenty-four graduate and undergraduate students at Hiroshima University participated in the experiment. Average age of participants was 23 years and 10 months. All participants were native Japanese speakers.

Stimuli. In the lexical decision task for correct ‘No’ responses, semantically similar and dissimilar nonwords were formed by changing one of the two kanji used in already-existing 27 compound words. For example, a semantically similar nonword ‘整並’ was created from the already-existing word '整列' meaning 'stand in a line', by keeping a kanji '整' and by replacing ‘並’ by ‘列’, of both which mean 'a line'. Likewise, a semantically dissimilar nonwords ‘整渋’ was created by replacing the same kanji by semantically unrelated kanji ‘渋’ meaning 'sober'. The details of stimuli are listed in Appendix.

As shown in Table 1, two types of nonwords were matched across 13 possible factors (these data taken from Tamaoka, Kirsner, Yanase, Miyaoka & Kawakami, 2001, submitted). The first factor was the school grade in which the kanji is taught. The second factor was the number of strokes in each kanji. The frequency of occurrence of kanji in print was controlled accounting for the third, fourth, and fifth factors. The sixth factor was the accumulative kanji neighborhood size of the left-hand side of two-kanji compound words. The term ‘kanji neighborhood size’ refers to the number of combinations one kanji can have with another to create two-kanji compound words. The accumulative neighborhood size and the total of both sides together were also controlled (the seventh, and eighth factors). The ninth factor was radical frequency. Single kanji are often composed of two or more constituents: a radical and secondary elements. Radical frequency indicates how many of the 1,945 basic kanji share the same radicals. The 10th factor was the number of constituents. A single kanji’s pronunciation is often shared by multiple kanji. The 12th factor was the number of kanji homophones. The last two factors concerned phonological effects of kanji readings. On-reading frequency was calculated by summing up the frequency of occurrence for On-readings of each kanji using the kanji frequency index of 1976 provided by the National Language Research Institute. In the same way, total accumulative frequency of occurrence was calculated for each kanji using both On- and Kun-readings. There were no significant differences between semantically similar nonwords and dissimilar nonwords across all these 13 factors.

Insert Table 1 about here

The aforementioned 27 existing words were also used as correct 'Yes' responses. In addition, existing 9 filler words were also selected. The stimuli were divided into three counterbalanced lists of 9 existing words, 9 semantically similar nonwords and 9 semantically dissimilar nonwords. The additional 9 filler words were the same in each list. Thus, a total of 18 real words and 18 nonwords assigned to three groups of participants. Because each participant viewed only one list, no one saw the same kanji twice.

Procedure. Real words as well as nonwords were randomly presented to participants in the center of a computer screen (Toshiba, J-3100 Plasma display) 600 ms after the appearance of an eye fixation point marked by an asterisk '*'. Participants were instructed to respond as quickly and as accurately as possible in deciding if the item was a correct Japanese two-kanji compound word. Twenty-four practice trials were given to participants prior to commencement of the actual testing.

Results

Only correct responses were used for the calculation of mean reaction times. Responses incurring reaction times slower than 2,200 ms were recorded as incorrect.. Three items fell into this category. This is about 0.35% of the total responses of the 24 participants. Before the analysis was performed, reaction times more than 2.5 standard deviations above or below a participant's mean reaction time were replaced by the boundaries set by the individual mean plus and minus 2.5 standard deviations. Mean reaction times and error rates for the lexical decision task are presented in Table 2. They were calculated for correct 'Yes' responses to the 27 real words from which nonwords were created (not included the 9 filler words). Analyses of variance (ANOVAs) were conducted using both participant (F_1) and item (F_2) means. It should be noted that since all participants perceived the semantically similar nonword 遠離 as an existing real word, this wrongly identified item was excluded from item analysis of reaction times.

Insert Table 2 about here

A one-way ANOVA showed a significant difference in reaction times in both participant and item means [$F_1(1,23)=10.68$, $MSE=52656.9$, $p<.005$, and $F_2(1,51)=4.27$, $MSE=14163.9$, $p<.05$]. Participants responded to semantically similar nonwords more slowly than to dissimilar nonwords. A one-way ANOVA showed a significant difference in error rates in both participant and item means [$F_1(1,23)=14.37$, $MSE=1875.0$, $p<.001$, and $F_2(1,52)=6.18$, $MSE=2.02$, $p<.05$]. Participants incorrectly judged semantically similar nonwords more than dissimilar nonwords.

Discussion

Experiment 1 indicated that semantic similarity of kanji had an influence on 'No' responses in the lexical decision task. Participants responded slower and made more errors with semantically similar nonwords than with semantically dissimilar nonwords. Participants seemed to hesitate in rejecting semantically similar nonwords. This may be due to the fact that semantically similar nonwords had a combination of kanji that seemed possible, although in reality, nonexistent. Thus, participants seemed to use semantic information of single kanji to reject semantically similar nonwords. This finding leads to Experiment 2 where effects of semantic similarity at the sentence level were examined.

EXPERIMENT 2

Proofreading Task at the Sentence Level

Experiment 1 showed effects of semantic similarity in the lexical decision task. In order to investigate the effects of semantic similarity at the sentence level, Experiment 2 was conducted where the same nonwords used in Experiment 1 were embedded into sentences. For example, from a sentence like 景気が悪くなり，就職できない学生が激増している meaning 'Because of the economic decline, students who cannot get jobs are increasing markedly', an incorrect sentence was created by changing one of the two kanji (indicated by the underlined word) to form 烈増, a semantically similar nonword. Both the original kanji 激 and the replaced kanji 烈 share the same meaning of 'intensity'. Sentences with semantically dissimilar nonwords were created by replacing correct kanji with a semantically dissimilar one. For example, the nonword 麦増 was produced using the unrelated kanji 麦 meaning 'oats'. If semantic similarity affects the processing of two-kanji compound words individually, it was assumed that sentences with semantically similar nonwords would take longer to process and cause greater errors than those with semantically dissimilar nonwords.

Method

Participants. Twenty-four graduate and undergraduate students at Hiroshima University, who had not participated in Experiment 1, participated in Experiment 2. The average age of participants was 23 years and 5 months. All participants were native Japanese speakers.

Stimuli. The stimuli were the same as those used in Experiment 1, but were presented in sentences (see Appendix). There were 27 sentences with real words, 27 sentences with semantically similar nonwords, and 27 sentences with semantically dissimilar nonwords. The same 9 filler real words from Experiment 1 were embedded in sentences for correct 'Yes' responses and included on all three lists given to participants. The cross-counter design technique from Experiment 1 was used in this experiment so each participant saw only one list with 18 sentences with real words and 18 sentences containing nonwords.

Procedure. The 36 sentences were randomly presented to participants in the center of a computer screen (Toshiba, J-3100 Plasma display) 600 ms after the appearance of an eye fixation point marked by a series of asterisks '*********'. The participants were instructed to respond as quickly and as accurately as possible in deciding if the words in the sentence were correct. Twenty-four practice trials were given to participants prior to commencement of the actual testing.

Results

Only correct responses were used for the calculation of mean reaction times. Responses incurring reaction times slower than 10,000 ms were recorded as incorrect. One item fell into this category. This is about 0.12% of the total responses of the 24 participants. Before the analysis was performed, reaction times more than 2.5 standard deviation above or below a participant's mean reaction time were replaced by the boundaries of the mean plus and minus 2.5 standard deviation. Mean reaction times and error rates for the proofreading task are presented in Table 3. They were calculated for correct 'Yes' and 'No' responses to sentences containing all the words and nonwords (not including sentences with fillers). ANOVAs were conducted using both participant (F_1) and item (F_2) means. As the semantically similar nonword 余額 was wrongly identified by all participants, it was excluded from item analysis of reaction times.

Insert Table 3 about here

A one-way ANOVA showed a significant difference in reaction times in participant means [$F_1(1,23)=4.96$, $MSE=244544.1$, $p<.05$]. In item means, however, there was no significant difference. Participants noticed semantically similar nonwords faster than semantically dissimilar nonwords. A one-way ANOVA showed a significant difference in error rates in both participant and item means [$F_1(1,23)=66.09$, $MSE=9570.5$, $p<.001$, and $F_2(1,52)=24.27$, $MSE=2.84$, $p<.0001$]. Participants missed more semantically similar nonwords than dissimilar nonwords.

Discussion

Experiment 2 showed that semantic similarity also had an effect in proofreading at the sentence level. Unlike the results of Experiment 1, the results of Experiment 2 showed a reversal trend with regards to reaction time. Semantically similar nonwords in sentences were more quickly detected as incorrect Japanese words than semantically dissimilar nonwords in sentences. Error rates showed similar trends in Experiments 1 and 2, except that in Experiment 2 many more errors were made. The difference between the proofreading task and the lexical decision task was simply that the target nonwords were embedded in sentences for the proofreading task. In this task, participants had to locate an incorrect word within a string of real words in a sentence. When a semantically similar nonword looked like a real word in the sentence, the participants judged it as ‘correct’ although they were detected faster than semantically dissimilar ones. In other words, participants were likely to mistake semantically similar nonwords for real words, because semantically similar kanji seemed to fit in the semantic context in which it was found. Thus, the context of sentences seemed to affect one’s judgment of incorrect words. The results of Experiment 2 indicate that single kanji semantics interfere in the detecting of incorrect words embedded in sentences. However, as it is possible that the participants may not have comprehended the context of the sentences in the proofreading task, a further experiment was conducted employing a semantic decision task which required participants to decide whether or not the sentence was correct.

EXPERIMENT 3

Semantic Decision Task at the Sentence Level

Dummy sentences composed of only real words were constructed using the sentences from Experiment 2, where real words had meanings that were inappropriate for the semantic context of the sentence. This was done in order to force participants to pay attention to the sentence context. For example, a dummy sentence like 向こうにみえる大きな建物は，私の知人が設備したものだ, meaning 'the building over there is facilitated by my friend', was an example of where a real two-kanji compound word 設備（'facilitate'） was used incorrectly according to context. The correct word is '設計' meaning 'design'. Participants were asked to judge whether each sentence made sense (i.e., semantic decision). This provided an actual reading situation where comprehension of semantic context would be essential for responding correctly. Under this situation, the semantic processing of single kanji was examined.

Method

Participants. Twenty-four graduate and undergraduate students at Hiroshima University participated in the experiment. Average age of participants was 23 years and 4 months. All participants were native Japanese speakers.

Stimuli. The sentences used in Experiment 2 were also used in Experiment 3. However, in order to make participants read sentences according to comprehension, nine dummy sentences were added. Although the dummy sentences did not contain a nonword, they contained a two-kanji compound word that did not suit context of the sentence. Nine new filler sentences were also added. Thus, each participant saw 27 correct sentences and 27 incorrect sentences (nine had semantically similar nonwords, nine had dissimilar nonwords, and nine had real dummy words which were contextually incorrect).

Procedure. The 54 sentences were randomly presented to participants in the center of a computer screen (Toshiba, J-3100 Plasma display) 600 ms after the appearance of an eye fixation point marked by a series of asterisks '*********'. Participants were instructed to read the sentences to understand their meaning and to respond as quickly and as accurately as possible in deciding whether the words in the sentence were correct. Twenty-four practice trials were given to participants prior to commencement of the actual testing.

Results

Only correct responses were used for the calculation of mean reaction times. Responses incurring reaction times slower than 10,000 ms were recorded as incorrect. One item fell into this category. This is about 0.12% of the total responses of the 24 participants. Before performing the analysis, reaction times more than 2.5 standard deviation above or below a participant's mean reaction time were replaced by the boundaries of the individual mean plus and minus 2.5 standard deviations. Mean reaction times and error rates for the semantic decision task are presented in Table 4. They were calculated for correct 'Yes' and 'No' responses. ANOVAs were conducted using both participant (F_1) and item (F_2) means.

Insert Table 4 about here

A one-way ANOVA showed a significant difference in reaction times in both participant and item means [$F_1(1,23)=14.53$, $MSE=1117462.8$, $p<.001$, $F_2(1,52)=10.66$, $MSE=154674.2$, $p<.005$]. The mean reaction time for semantically similar nonwords was longer than that for dissimilar nonwords. A one-way ANOVA showed a significant difference in error rates in both participant and item means [$F_1(1,23)=22.54$, $MSE=4032.9$, $p<.001$, and $F_2(1,52)=11.4$, $MSE=1.170$, $p<.005$]. Participants missed more semantically similar nonwords than dissimilar nonwords.

Discussion

Experiment 3 indicated that semantic similarity had an influence on kanji word recognition during sentence comprehension. Participants judged sentences with semantically similar nonwords slower and made more errors than with those with semantically dissimilar nonwords. These results were similar to those of Experiment 1. Reaction times were longer, but there were not as many errors made as in Experiment 2. Because participants were asked to comprehend sentence meaning in Experiment 3, they had to pay attention to the meaning of the target words. Although semantically similar nonwords looked like real words, participants were able to reject them when they paid attention to the meaning of the two-kanji combinations. Thus, the processing of contextual information seems to act as an effective mechanism for detecting nonwords which contain kanji that are semantically similar to those in real two-kanji compound words.

GENERAL DISCUSSION

The purpose of this study was to examine effects of semantically similar kanji on the processing of two-kanji compound words. The present study tested this at the lexical level in Experiment 1 using a lexical decision task and also at the sentence level using a proofreading task in Experiment 2 and a semantic decision task in Experiment 3. The mean reaction times and error rates of participants in Experiments 1–3 are shown in Figure 1.

Insert Figure 1 about here

In the lexical decision task, when participants saw semantically similar nonwords, the semantic representations of single kanji were activated. Although phonological and orthographic information activated by the stimulus word made it look incorrect, semantic information of single kanji seemed to indicate that the stimulus word was correct. Thus, participants were forced to sort though these three conflicting types of information and therefore their judgments became slower. When they saw semantically dissimilar nonwords, however, there was no such conflict.

In the proofreading task, participants had to locate a nonword in a sentence. When they encountered a semantically similar two-kanji compound nonword, they were likely to take it for an existing word because semantic information from the replaced kanji within the two-kanji combination seemed to suit the context of the word required in the sentence. Unlike in the lexical decision task, when the same stimuli were embedded in sentences, their context within a sentence seemed to help in the detection of semantically similar nonwords in proofreading which made reaction times for semantically similar nonwords shorter than for semantically dissimilar nonwords. However, because semantically similar nonwords often fit nicely into sentence context, greater errors were produced for semantically similar nonwords than for semantically dissimilar nonwords. This tendency seemed to display a speed and accuracy trade-off.

In the semantic decision task, participants were asked to read stimulus sentences while paying attention to context. As well as in Experiment 2, information from semantically similar nonwords needed to suit the context of the sentences in Experiment 3. Different from when proofreading in Experiment 2, participants had to pay attention to the exact meaning of the two-kanji compounds. In this situation, since participants had to carefully process information from semantically similar nonwords according to sentential context, they were much more cautious about making a decision on whether or not the sentence was correct. Thus, they rejected sentences with semantically similar nonwords more accurately than those with semantically dissimilar nonwords. However, this careful processing caused participants to take longer to reject sentences with semantically similar nonwords than those with dissimilar nonwords.

In sum, there were similar effects of semantic similarity in the lexical decision task and the semantic decision task trend between semantic similarity effect in lexical decision task and that in semantic decision task, though not in the proofreading task. Error rates for semantically similar nonwords in the proofreading task were higher than those in the lexical decision task and in the semantic decision task. In addition, participants responded to semantically similar nonwords earlier than to semantically dissimilar nonwords in the proofreading task, whereas participants took longer to judge semantically similar nonwords in the other two tasks. In the proofreading task, target nonwords were embedded in sentences where participants did not have to pay much attention to exact meaning. Thus, attention of participants may have been spread out and not specifically focused on the target word. In this situation, sentence context seemed to play an important role in the detection of nonwords. Because semantically similar nonwords looked like existing words with a combination of incorrect kanji where the meaning suited the context, participants judged them as 'correct' in the proofreading task. However, when the same nonwords were embedded in sentences where participants were required to comprehend the context of the sentence, as in Experiment 3, they did not make as many errors. Consequently, when participants were required to search for nonwords in sentences, they paid little attention to exact word meaning, and more to sentence context. This indicates that semantic involvement in the processing of Japanese kanji produces different effects, depending upon whether this processing is done at the lexical or sentence level which in turn is related to where the reader's attention lies.

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TABLE 1

Possible Influential Factors in the Processing of Two-kanji Compound Words

Influential factors	Semantically similar	Semantically dissimilar
School grades	5.81	5.15
Number of strokes	11.40	11.44
Kanji frequency (1976)	0.40	0.37
Kanji frequency (1998)	7706.00	6553.00
CD-ROM kanji frequency (1998)	10864.00	9892.00
Accumulative left-hand neighborhood size	37.92	41.03
Accumulative right-hand neighborhood size	68.52	33.96
Total accumulative neighborhood size	105.81	75.00
Radical frequency	21.26	27.07
Number of constituents	2.22	2.15
Number of kanji homophones	7.30	7.30
On-reading frequency	281.70	207.60
On- and Kun-reading frequency	322.00	318.10

TABLE 2

Mean Reaction Times and Error Rates in Experiment 1

	RT (ms)	Error (%)
Correct 'Yes' responses	710 (121)	4.2 (5.5)
Correct 'No' responses		
Semantically similar nonwords	859 (178)	18.5 (18.1)
Semantically dissimilar nonwords	792 (133)	6.0 (9.3)

TABLE 3

Mean Reaction Times and Error Rates in Experiment 2

	RT (ms)	Error (%)
Correct 'Yes' responses	2385 (989)	1.4 (3.8)
Correct 'No' responses		
Semantically similar nonwords	2292 (646)	38.0 (21.7)
Semantically dissimilar nonwords	2402 (1371)	9.8 (17.4)

TABLE 4

Mean Reaction Times and Error Rates in Experiment 3

	RT (ms)	Error (%)
Correct 'Yes' responses	2443 (708)	6.9 (8.6)
Correct 'No' responses		
Semantically similar nonwords	2500 (660)	14.8 (13.4)
Semantically dissimilar nonwords	2195 (607)	1.9 (4.2)

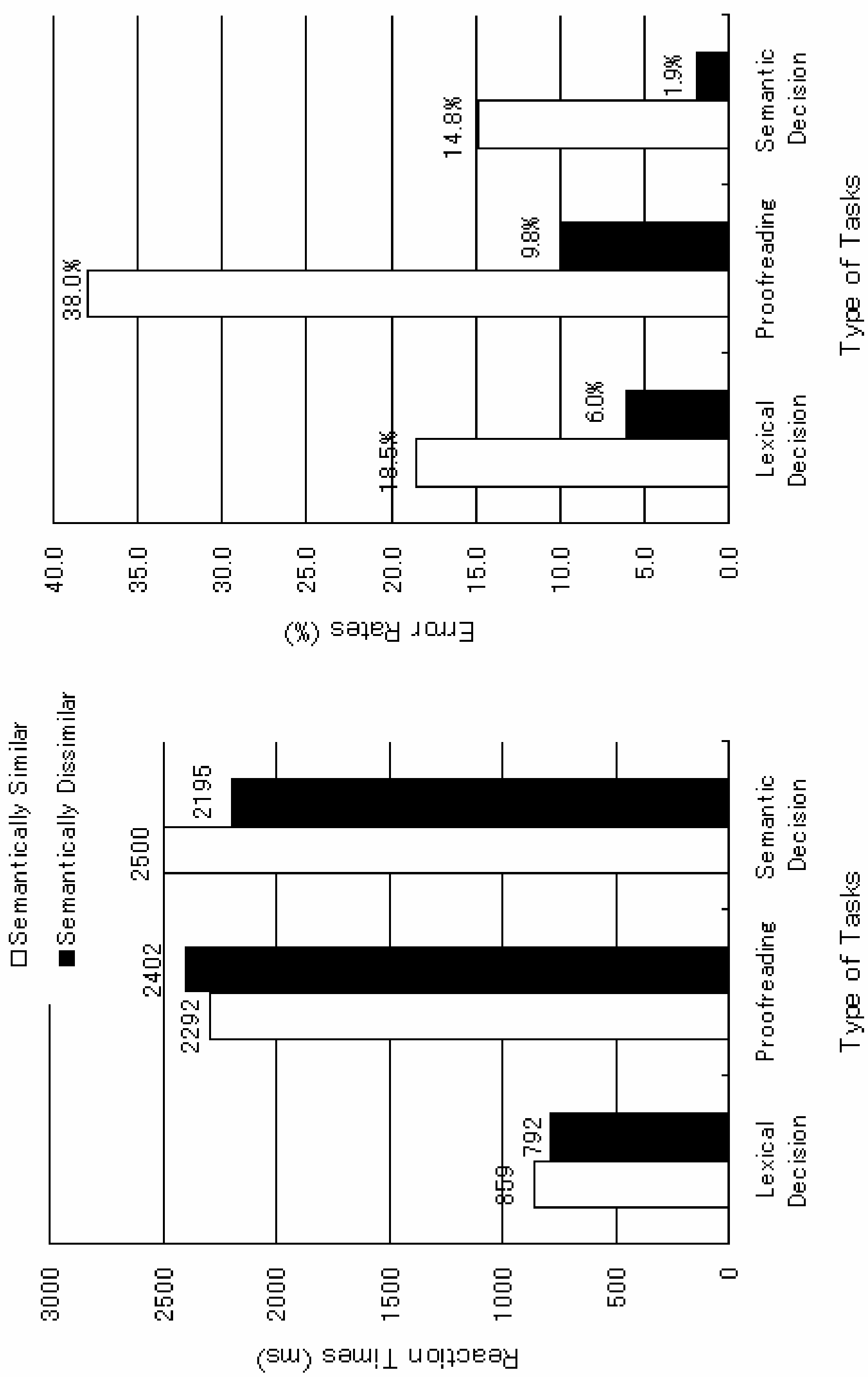

FIG. 1. Reaction times and error rates depending upon type of tasks

APPENDIX

Lexical Materials and Sentences Used in Experiments 1-3

Sentences	Correct 'Yes'	Correct 'No'	
	Real words	Semantically similar nonwords	Semantically dissimilar nonwords
日本が独自の文化を築いたのは、□□をしていたからだ。	鎖 国	封国	脚国
大型の台風が上陸するらしいので、□□するかもしれない。	停 電	断電	福電
国政の実権を握るため、首相を□□するという噂まである。	暗 殺	密殺	雑殺
この都市の人口は、いずれ百万を割ると□□されている。	推 定	憶定	廣定
沈没した船の荷物が、この下の□□に眠っているらしい。	深 海	奥海	賛海
社会での地位はある程度、□□によって決まっている。	所 得	所益	所秒
この説に関しては、様々な□□に分かれての論争が続いた。	学 派	学系	学洗
生徒たちは校庭にきちんと□□し、先生の話を聞いている。	整 列	整並	整渋
その事件では、少年が顔面を□□されてひどい怪我をした。	殴 打	殴撃	殴難
景気が悪くなり、就職できない学生が□□している。	激 増	烈増	麦増
今月は出費がかさんだので、預金の□□が少ししかない。	残 額	余額	乱額
銃声らしい音で皆が驚いたが、風船が□□した音だった。	破 裂	壊裂	賦裂
伝統を受け継ごうという風潮から、古い習慣が□□した。	復 活	戻活	端活
その旅行には多くの人が妻子を□□するので、人数が多い。	同 伴	同随	同握
彼は長い年月をかけて、やっとその作品を□□させた。	完 成	完達	完陸
教師や警察の人はその職業の性質から、□□が問われる。	品 行	品挙	品速
社員の士気を高めるためか、毎日のように□□を行っている。	朝 礼	朝式	朝多
二次の試験に合格すれば、最後は□□で採用が決定される。	面 接	面遇	面俊
ずっと銀行に勤務していたので、□□を扱い慣れている。	貨 幣	銭幣	繊幣
彼女はもう大人だが、少女のように□□な面を持っている。	潔 癖	純癖	兵癖
仕事の経験が違うのだから、先輩には□□を表すべきだ。	敬 意	尊意	微意
働いていても給料が安いので、生活は両親に□□している。	依 存	頼存	郡存
この一文は前と同じ意味なので、□□した方がいいだろう。	削 除	却除	軟除
家庭で使ういろいろな製品も、□□からの操作が可能だ。	遠 隔	遠離	遠幅
私の田舎では野菜を栽培しており、広い□□を所有している。	農 地	農野	農話
権力を持つことよりも、その状態を□□する方が難しい。	維 持	維保	維受
この近辺の土地は□□しているので、迷うことはない。	熟 知	熟識	熟歴