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L1 and L2 working memory: An investigation into the domain specificity and processing efficiency issues

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1. INTRODUCTION

This paper is a report of a study investigating the relationship between processing efficiency, working memory capacity, and second language (L2) reading comprehension.[1] This investigation is primarily motivated by the domain specificity issue and the processing efficiency issue of WM currently debated in cognitive psychology (e.g., Daneman & Tardif, 1987; Engle et al., 1992; Jurdan, 1995; Shah & Miyake, 1996).

1.1. Working memory

Working memory (henceforth, WM) is viewed as a "computational arena" for the simultaneous storage and processing of information in real-time, or a system in which information is temporarily held while being manipulated and transformed (e.g., Baddely, 1986; Gathercole & Baddely, 1993; Just & Carpenter, 1992; Miyake & Shah, 1999). Shah and Miyake (1996, p. 4) define WM "as consisting of flexibly deployable, limited cognitive resources, namely activation, that support both the executions and the maintenance of intermediate products generated by these computations." This conception of WM is in contrast with "short-term memory" as a fixed set of slots for maintaining information (e.g., Miller, 1956).

The most widely employed measure of WM is the reading span test (RST) that Daneman and Carpenter (1980) developed. In the prototype version of RST, subjects read aloud a series of increasingly longer sets of unrelated sentences (ranging from two to six sentences) and recall the last word in each sentence. WM capacity is operationally defined either as the reading span "size," i.e., the largest set size (2, 3, 4, 5, or 6) at which all of the words are recalled (in at least three out of a total of five trials) or the total number of sentence-final words recalled from all the trials.

This study addresses two closely related issues of WM in cognitive psychology research: the domain specificity issue and the processing efficiency issue.[2]

1.2. The domain specificity issue

The domain specificity issue is concerned with how many resource pools we should posit in constructing a functional model of WM. Shah and Miyake (1996, p. 4) explain this issue as follows: "Is working memory a unitary construct, in the sense that all higher level cognitive activities are supported by a single pool of general purpose resources? Or, is it the case that there are separate pools of resources dedicated to supporting different processes and representations? If so, how many pools of resources are there?"

In investigating the domain specificity issue, we first need to look at a conceptual model of the cognitive processes hierarchy, and one such model is presented in Figure 1. Studies to date have investigated the separability of WM resource pools for language and spatial thinking (e.g., Shah & Miyake, 1996) and also for language and numerical computation (e.g., Turner & Engle, 1989). This study is concerned with a more local level of domain specificity: the functional dissociation between L1 and L2 resource pools.

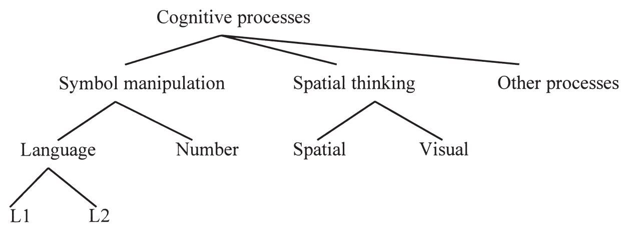

Figure 1. A hierarchy of cognitive processes

Regarding the functional separability between L1 and L2 resource pools, Carpenter et al. (1994) argue that "at least in highly skilled second language users, the processing of L2 may share the same pool of working memory resources as the processing of L1" (p.1112). This argument is in part based on the high correlations between L1 and L2 reading span tests that have been observed, for example, in Osaka and Osaka (1992), $r = .72$ ($p < .001$), $r = .84$ ($p < .001$), and Harrington and Sawyer (1991), $r = .54$ ($p < .05$).

1.3. The processing efficiency issue

The second issue motivating this study is the processing efficiency issue, that is, what produces individual differences in WM capacity, and what drives the significant relationship between WM measures and cognitive task measures (most typically reading comprehension tests) that has been observed in relevant studies to date? Two competing explanations have been proposed regarding this point: the processing efficiency explanation and the total capacity explanation.

The processing efficiency explanation is summarized by Tuner and Engle (1989) in the following way: "Good and poor readers have equivalent overall working memory capacities. Good readers are assumed to have efficient reading skills which demand relatively little from the gross WM resources leaving more of the WM capacity for the storage of products of the reading task" (p. 128). Daneman and Green (1986) also argue that "the capacity of working memory will vary as a function of how efficient the individual is at the specific processes demanded by the task to which working memory is being applied" (p. 17). In this explanation, it is linguistic processing efficiency (i.e., task- specific processing efficiency) that drives the significant relationship between WM measures and comprehension measures.

The total capacity explanation, on the other hand, provides a different perspective. Swanson (1993) claims that "poor readers have weaker working memories than skilled readers, not as a consequence of poor reading skills but because they have less working memory capacity available for performing a reading *and* non-reading task" (p. 473). Support for this explanation is found, for example, in Turner and Engle (1989) in which they examined the relationship between reading comprehension and RST and other span tasks, such as an operational span task. In the operational span task, subjects read and verified an operation (e.g., (4/2) - 1 = 1? SNOW, (3 x 1) + 4 = 7? TABLE) and recalled the words (i.e., SNOW, TABLE) after the operation. The results showed that this operation task performance correlated with comprehension as highly as RST scores did. In other words, the results indicate that "the memory-span test could be embedded in any secondary processing tasks and still predict success in higher level tasks [such as reading comprehension]" (Engle et al., 1992, p. 974). In the total capacity explanation, it is the total capacity of WM, independent of the efficiency of the specific task being performed, that drives the significant relationship between WM measures and comprehension measures.

1.4. The target-language processing efficiency hypothesis

Thus, extensive debate has been conducted on the domain-general versus domain-specific nature of WM and also on the relationship between WM capacity (as reflected in RST scores) and the efficiency of information processing. By examining L2 WM capacity in relation to

L1 WM capacity and also to L2 processing efficiency, we can make an original contribution to the ongoing debate on the domain specificity and processing efficiency issues discussed in cognitive psychology. In particular, the processing efficiency issues is probably more effectively investigated in the second language, in that the variance in linguistic processing skills is generally greater in L2 than in L1.

In this study, I propose a target-language processing efficiency hypothesis (henceforth, the TLPE hypothesis): L2 WM capacity, rather than general language-based WM capacity, relates to L2 reading comprehension, and this relationship is mediated by L2 processing efficiency. In terms of the domain specificity issue, this hypothesis assumes that there exists a unique pool of WM resources for L2 processing. From the viewpoint of the processing efficiency issue, this hypothesis predicts that L2 processing efficiency is the primary source of individual differences in L2 WM capacity and of their concomitant correlation with L2 reading comprehension.

In more operational terms, the TLPE hypothesis generates the following seven predictions.[3] This hypothesis is supported to the degree to which these predictions are confirmed.

Prediction 1. L2 RST as an index of L2 WM capacity is significantly correlated with L2 reading comprehension.

Prediction 2. L1 RST is not significantly correlated with L2 reading comprehension, or if it is, this correlation disappears when the effect of L2 RST is factored out statistically.

Prediction 3. L2 RST is still a significant predictor of L2 reading comprehension after the contribution of L1 RST is partialed out statistically.

Prediction 4. L2 processing efficiency measures are significantly correlated with L2 RST.

Prediction 5. L2 processing efficiency measures are significantly correlated with L2 reading comprehension.

Prediction 6. The correlation between L2 RST-L2 reading comprehension is eliminated when the effects due to L2 processing efficiency are partialed out statistically.

Prediction 7. A substantial amount of L2 RST variance is accounted for by L2 processing efficiency.

The rational behind Prediction 1 and Prediction 2 is that, if L2 WM measures, but not L1 WM measures, are correlated with L2 reading comprehension, this points to the functional separability of WM resources for L1 and L2 comprehension. This separability is further confirmed by the validation of Prediction 3. In terms of the processing efficiency issue, the TLPE hypothesis suggests that L2 processing efficiency has a significant relationship with L2 WM capacity and L2 comprehension, and this is the motivation of Prediction 4 and Prediction 5. The rational for Prediction 6 is that if L2 processing efficiency mediates the relationship between L2 WM and L2 reading comprehension, then such a relationship should disappear when the effects of L2 processing efficiency are removed. Finally, the strong from of the processing efficiency explanation indicates that the functional capacity of WM is determined by task-specific processing efficiency, and this is operationally stated in Prediction 7. In order to validate these predictions based on relevant data, the following study was designed and conducted.

2. METHOD

2.1. Participants

52 paid volunteers participated in this study.[4] They were Japanese university students (1st and 2nd year students) majoring in nursing, education, agriculture, and technology.

2.2. Materials

Ten types of tests were employed in the present study. The TOEFL test was group-administered, while the other tests were administered individually.

L2 reading comprehension. As a test of L2 reading comprehension, the reading section of the TOEFL exam was used. The test consisted of 39 multiple-choice items, and it achieved a reliability of .72 (Cronbach alpha).

Working memory capacity measures. In order to measure WM capacity, L2 (English) Reading Span Test and L1 (Japanese) Reading Span Test were employed. In these RSTs, subjects read aloud a series of increasingly longer sets of sentences (i.e., 2, 3, 4 and 5 sentences per set; with three trials of each set; for a total of 42 target sentences) and recalled the last word in each sentence. At the beginning of each set, they were reminded to fully comprehend the sentences presented and not to treat the task as one of rote memorization. The total number of words recalled from all the trials was used as data.

Processing efficiency measures. Seven measures were used to assess the efficiency with which the participants process information: number matching (Number), L2 word matching (L2 Word), L2 (English) lexical semantic judgment (L2 SEM), L2 (English) grammaticality judgment (L2 GJ), L2 (English) sentence verification (L2 SV), L1 (Japanese) lexical semantic judgment (L1 SEM), and L1 (Japanese) sentence verification (L1 SV). Various measures of professing efficiency were included, because multiple indicators would show a clear picture of what types of processing efficiency are actually related to WM capacity. (See Appendix for some examples of the materials used in this investigation.)

For the number matching measure, for example, the subjects were given sheets containing 200 pairs of numbers (e.g., 492 -- 492, 651 -- 657). They were instructed to mark the pairs that were identical by "○," and those that were different by "×." They were allowed 60 seconds, timed by stop watch, to complete as many items as possible. The number of the items completed was used as data. The same procedures were adopted for the other processing efficiency measures (60 seconds were allowed for L2 word matching, L1 lexical semantic judgment, and L1 sentence verification, and 120 seconds for the other measures). In the lexical semantic judgment tasks (L1, L2), the subjects were told to judge whether two words were synonyms or not (e.g., open – closed, fast – quick). The sentence verification tasks (L1, L2) required the subjects to determine whether a sentence was true based on their world knowledge, e.g., *Tokyo is the capital of China.* The seven types of processing efficiency measures were hypothesized to assess processing efficiency at different levels. The hypothesized constructs of each processing efficiency measure are summarized in Table 1 below:

Table 1. Various types/levels of processing efficiency

	Number identification	Letter identification	Retrieval of lexical information	Syntactic parsing	Encoding of propositional contents
Number	X				
L2 Word		X			
L2 SEM		X	X		
L1 SEM		X	X		
L2 GJ		X	X	X	X
L2 SV		X	X	X	X
L1 SV		X	X	X	X

Notes: Number = number matching; Word = word matching; SEM = lexical semantic judgment; GJ = grammaticality judgment; SV = sentence verification

For the purpose of this study, i.e., to examine processing efficiency and not linguistic knowledge, it was ensured that the linguistic items in these measures were familiar to the subjects. Also, because the focus of this study was to investigate individual differences rather than to compare the subjects' performance in various tests, these measures were presented in the same order (i.e., no counterbalancing).

3. RESULTS

Table 2 presents the descriptive statistics and correlations between L2 reading comprehension (TOEFL), WM capacity measures (L1 RST and L2 RST) and processing efficiency measures (number matching, L2 word matching, L2 lexical semantic judgment, L2 grammaticality judgment, L2 sentence verification, L1 lexical semantic judgment, and L1 sentence verification).

Although the magnitude of the correlations is generally weak, a rather clear pattern emerged. First, with regard to Prediction 1 of the TLPE hypothesis, i.e., the relationship between WM capacity and L2 reading comprehension, a reliable L2 RST-TOEFL correlation was observed, confirming this prediction. This result is also consistent with Harrington and Sawyer (1991) and most L1 studies.[5] The magnitude of L2 RST-TOEFL correlation in the present study ($r = .329$, $p < .05$) is lower than that observed in Harrington and Sawyer (1991) ($r = .54$, $p < .01$), and this may be because the proficiency level of the subjects of this study (Japanese undergraduate students majoring in nursing, education, and agriculture) is probably lower than those in Harrington and Sawyer (1991) (Japanese graduate students majoring in international studies). It is hypothesized that with the advancement of L2 lexical and syntactical acquisition, higher L2 RST-TOEFL correlations would be obtained, and this speculation merits further investigation. In contrast, the correlation between L1 RST and TOEFL was not significant, and this is in support of Prediction 2 of the TLPE hypothesis. Prediction 3 was also supported: The relationship between TOEFL and L2 RST remains significant even after the effect of L1 RST was factored out of the association ($r = .284$, $p = .043$), and this lends further support to the contention that L2 reading comprehension relies on an L2-specific WM resource pool, not on a general language-based WM resource pool. (Note, however, that this does not completely deny the existence of general purpose WM resources that can be used both in L1 and L2 comprehension.)

Regarding the relationship between processing efficiency and WM capacity (Prediction 4), it was found that two processing efficiency measures were significantly related to L2 RST: L2 semantic judgment and L2 sentence verification. The L2 word matching task, which also required the identification of L2 visual symbols, but did not require the activation of lexical meaning, did not have a significant relationship with L2 RST. Thus, these results indicate that processing efficiency at the levels of lexical semantic information retrieval, syntactic parsing, and propositional encoding is related to individual differences in L2 WM capacity. Thus, Prediction 4 of the TLPE hypothesis was also supported.

Table 2. Correlation matrix

Measures	Mean	*SD*	1	2	3	4	5	6	7	8	9	10
L2 reading comprehension												
1. **TOEFL**	20.10	4.67	---									
Working memory capacity												
2. **L2 RST**	24.02	3.40	.329*	---								
3. **L1 RST**	26.87	4.53	.174	.588**	---							
Processing efficiency												
4. **Number**	64.67	8.69	.064	.073	.176	---						
5. **L2 word**	45.81	5.35	-.010	.073	.055	.526**	---					
6. **L2 SEM**	31.33	5.35	.277*	.298*	.207	.185	.310*	---				
7. **L2 GJ**	20.87	6.10	.206	.151	-.089	-.069	.347*	.667**	---			
8. **L2 SV**	21.60	7.15	.340**	.288*	.069	.012	.184	.536**	.545**	---		
9. **L1 SEM**	47.27	7.15	.126	.047	.290*	.271	.206	.370**	.063	.144	---	
10. **L1 SV**	24.35	3.57	.039	.067	.117	.149	.099	.156	-.084	.183	.469**	---

Notes: SEM = lexical semantic judgment; GJ = grammaticality judgment; SV = sentence verification; * = $p < .05$; ** = $p < .01$

Turning now to the relationship between L2 processing efficiency and L2 reading comprehension (Prediction 5), the results show that L2 lexical semantic judgment and L2 sentence verification were reliably related to L2 reading comprehension as indexed by TOEFL reading test scores. Again, L2 word matching did not have any significant relationship with TOEFL, and this may indicate that the participants' word identification skills, at least for those frequently encountered words used as stimuli in this investigation, may be largely stabilized to the point where it is making a consistent contribution to comprehension, and that L2 reading performance is determined by higher levels of processing efficiency, e.g., lexical semantic access and propositional extraction.

The relationship between WM and L2 reading can be further investigated by statistically controlling the effects of processing efficiency, and this was the motivation behind Prediction 6 of the TLPE hypothesis. If the significant correlation between WM and L2 reading is due to good L2 readers having efficient L2 processing skills, then this significant relationship should disappear when the effects of L2 processing efficiency are factored out. Indeed, the significant TOEFL-L2 RST correlation did disappear when the effect of L2 semantic judgment or L2 sentence verification was partialed out, $r = .25$, $p = .08$. Note, however, that a nearly significant correlation remains, making an unambiguous interpretation of the results (and the (dis-)confirmation of Prediction 6) difficult.

Prediction 7 was concerned with whether L2 WM capacity is determined by L2 processing efficiency, and in order to test this prediction, a step-wise multiple regression analysis was conducted, with L2 lexical semantic judgment and L2 sentence verification as regressors of the dependent variable of L2 RST. The results showed that only L2 lexical semantic judgment met the statistical criteria for entry, and that the overall squared multiple regression correlation coefficient was $R^2 = .09$, $F(2, 49) = 4.88$, $p = .03$. This means that only about 10 % of the L2 RST variance was accounted for. Thus, Prediction 7 of the TLPE hypothesis was not supported.

4. DISCUSSION

As a way to resolve the domain specificity issue and the processing efficiency issue with regard to WM, this study examined the relationship between processing efficiency, working memory capacity, and L2 reading comprehension. The results generally lend support to the target-language processing efficiency hypothesis, in that the relationship between L2 WM and L2 reading comprehension is mediated by differences in the efficiency with which individuals process a second language.

In terms of the domain specificity issue, the findings of this study indicate that the resource pool for L1 processing and that for L2 processing are functionally dissociate, at least at the L2 proficiency level of the subjects examined. In fact, the results show that only L2 RST was significantly related to L2 reading, but not L1 RST. In addition, even after removing the effect of L1 RST, the L2 RST-TOEFL correlation remained significant. These results are not consistent with the unitary view of WM which states that L2 reading comprehension relies on a general language-based WM system.

The findings of the present study may have some important implications for the ongoing discussion of the domain specificity issue in cognitive psychology. The research to date has examined the separability of resource pools for language and for number processing, or the separability of language and spatial thinking resource pools, but this study shows that we need to examine the domain specificity in a lower level of a cognitive processes hierarchy (i.e., first language vs. second language). Thus, by investigating L2 WM in relation to L1 WM, we can advance our understanding of WM originally researched in the field of cognitive psychology.

In terms of the processing efficiency issue, however, the results do not allow a clear interpretation. The results did not support the strong form of the processing efficiency explanation, that is, processing efficiency of the target process(es) exclusively determines functional WM capacity. Hence, the strong version requires, at least theoretically, that all the variance of WM span tests is accounted for by relevant processing efficiency measures, but this was clearly not shown in the present study. The multiple regression analysis showed that only a small portion of variance in the L2 RST can be explained by L2 processing efficiency. However, the possibility still remains that L2 processing efficiency interacts with other factors (e.g., the total WM capacity or strategic allocation of WM resources) to determine L2 WM capacity as indexed by L2 RST scores.

In addition, the results are compatible with the weak version of processing efficiency explanation, that is, processing efficiency is significantly related to WM capacity and it mediates the relationship between WM span measures and cognitive ability measures. Indeed, this study revealed a significant relationship between two L2 processing efficiency measures (i.e., L2 lexical semantic judgment and L2 sentence verification) and L2 RST. Additionally, the significant L2 RST-TOEFL correlation disappeared when the effects of these two processing efficiency measures were statistically removed, indicating that L2 processing efficiency (possibly together with other factors) drives the relationship between L2 WM and L2 reading comprehension.

The total capacity explanation, which has been regarded as a rival hypothesis to the processing efficiency explanation, was clearly not supported by the findings of this study. For the total capacity explanation to be valid, at least the following two phenomena should be observed: (1) Any types of WM span tests show an equivalent degree of correlation with comprehension measures (or measures of other cognitive abilities), and (2) processing efficiency is not related to individual differences in WM capacity (i.e., RST scores). Contrary to these predictions of the total capacity explanation, the present study showed that only L2 RST, and not L1 RST, was related to L2 reading comprehension, and also that L2 processing efficiency measures did indeed have significant relationships with the L2 WM measure.

A caveat is in order here as to the relationship between the processing efficiency and the total capacity explanations. Although they have been so far regarded as mutually exclusive hypotheses, these two seemingly incompatible explanations can be modified so that they can complement each other. Given that people probably vary, as in many traits, in the total capacities of WM resources and also in professing efficiency, it is possible that their processing efficiency and sheer capacity (and other factors such as decay rate and the strategic allocation of activation resources) make independent contributions to individual differences in WM capacity. It is neither processing efficiency alone nor total capacity alone but the combination of them (and other factors) that determines the functional WM capacity as reflected in RST scores. Future research needs to examine this possibility.

5. CONCLUSION

This study attempted to examine the relationship between processing efficiency, WM capacity, and L2 reading comprehension. Although such an investigation is valuable, there are some limitations. First, the data presented here are basically correlational and are open to alternative interpretations. WM capacity, like many other individual-differences traits, cannot be manipulated easily, and as a result, we may be limited to showing an already existing relationship between WM and cognitive abilities (Daneman & Green, 1986, p. 17). Second, the processing efficiency measures used in this study might not have been sensitive enough to assess linguistic processing efficiency appropriately, and this may be the reason why only low, though significant, correlations between processing efficiency measures and L2 RST were obtained. The results of this study should be supplemented by data from studies employing other measures, such as naming and lexical decision tasks. Ideally, it is desirable to examine the processing efficiency of *those words, phrases, and syntactic constructions included in the RST* so that we can directly examine the processing and storage aspects of the RST task.

In spite of these limitations, the present study tentatively suggests the following: (1) L2 WM capacity, rather than a general language-based WM capacity, is related to L2 reading, and this relationship is mediated by L2 processing efficiency. (2) L1 and L2 WM resource pools are functionally separable. (3) Professing efficiency at the levels of L2 lexical semantic information retrieval and propositional encoding is related to individual differences in L2 WM capacity. However, (4) a substantial proportion of L2 WM capacity variance cannot be accounted for by L2 processing efficiency. These results are not in line with the unitary, domain-general view of WM, and they indicate the functional separability of L1 and L2 WM resource pools. With regard to the processing efficiency issue, the findings of the present study do not provide an unambiguous answer. While the results are not compatible with the total capacity explanation, L2 processing efficiency alone cannot explain a large proportion of individual differences in L2 WM capacity.

NOTES

1. This study is based on the same data as presented in Ikeno (2004) along with additional data of an L1 lexical semantic judgment task and an L1 sentence verification task. In the present study, the data in Ikeno (2004) were examined and discussed from different theoretical perspectives.
2. The domain specificity and processing efficiency issues are closely related, but their relationship has rarely been discussed in the literature. With regard to this relationship, I propose a tentative hypothesis as follows: Separability (i.e., the existence of a WM resource pool unique to a certain cognitive process) is a necessary condition for the validity of the processing efficiency explanation (i.e., this WM pool, at least its substantial proportion, is determined by the processing efficiency of the cognitive process). On the other hand, the validation of the processing efficiency explanation is a sufficient condition for the proof of separability.
3. These predictions are modeled on the logic presented in preceding studies on the domain specificity issue of WM, especially Daneman and Tardif (1987), Engle et al. (1992), and Shah and Miyake (1996). Also, this study adopted a correlation-oriented approach, as did the majority of the other studies on the domain-specificity issue. The preceding studies based their discussions on a pattern of correlations among several types of WM span tasks (e.g., reading span test, operation span test) and various cognitive ability measures (most typically reading comprehension). With a much larger sample size, structural equation modeling may be used as a more powerful alternative, in that it can test whether a hypothesized model of WM is compatible with the patterns of covariance in the data.
4. Originally, 53 subjects participated in this study, but data for one of them, whose accuracy rate for some processing efficiency measures was below 80%, were excluded.
5. Daneman and Merikle's (1996) meta-analysis of 77 relevant studies shows that the average correlation between RST and reading comprehension is r = .41 (with a 95% confidence interval of .38 to .44).

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APPENDIX: Some examples of the processing efficiency measures

Number Matching

1 ___ 492 - - - 492
2 ___ 651 - - - 657
3 ___ 297 - - - 397
4 ___ 682 - - - 682
5 ___ 057 - - - 027

L2 Word Matching

1 ___ star - - - stay
2 ___ train - - - train
3 ___ song - - - sing
4 ___ yard - - - card
5 ___ show - - - show

L2 Lexical Semantic Judgment

1 ___ open - - - closed
2 ___ speak - - - hear
3 ___ fast - - - quick
4 ___ wide - - - narrow
5 ___ most - - - least

L2 Grammaticality Judgment

1 ___ It is important that think about we our environment.
2 ___ Money does not always bring happiness.
3 ___ It was at this restaurant that Jane and John met ten years ago.
4 ___ The boy playing the guitar my brother.
5 ___ He told me that he would go to China in June.

L2 Sentence Verification

1 ___ Cars, trains and planes are means of transportation.
2 ___ If someone is born in France, he or she will usually learn to speak Japanese.
3 ___ Toyota is one of the largest automobile companies in Japan.
4 ___ Many junior and senior high school students wear uniforms in Japan.
5 ___ One year consists of twelve months.