L1-L2 Integrated Mental Lexicon and Dual Access Model in L2 Orthographic Word Processing

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1 Introduction

It has been reported that late second language (L2) learners have difficulty in acquiring the L2 phonetic and/or phonological contrasts that do not exist in their first language (L1). One of the examples of such L2 phones is the English /l–r/ contrast for Japanese learners of English. While there are a number of studies on the L2 English /l–r/ production and perception or the training (e.g., Goto, 1971; Takagi, 2002), the L1 phonological interference during L2 silent reading – an implicit phonological processing – has been less investigated.

Psycholinguistic approaches have been taken to observe the implicit processing. For example, Ota et al. (2009) presented two written words to the Japanese learners of English and found that they were likely to wrongly interpret *rock* as *lock* just as they failed to tell *rock* and *lock* in production and perception. However, the observation of the real-time orthographic processing is lacking in the previous studies. In other words, an experimental method that presents the two written words at the same time and asks the participants if they are semantically similar is not enough to investigate how the phonological and semantic information of L2 orthographic words is accessed according to the time course. Regarding the field of the L2 phonetic or phonological education, the approaches in the literature also seem to lack the viewpoint of the real-time L2 processing. For example, the assessment of the acquisition of L2 English phonemes is mainly the comparison of the learners' pronunciation of the L2 phonemes before and after training (e.g., Chujo, 2020). Additionally, current English education appears to treat L2 phonology and L2 word or sentence processing as if they were completely irrelevant and separated, even though psycholinguistic studies have shown the interference from phonological similarity with sentence comprehension (e.g., McCutchen & Perfetti, 1982). For instance, while Clarke & Silberstein (1977) suggest application of psycholinguistic methods to ESL classroom education, it is limited to the teaching of reading or vocabulary. Although these methods can work for making students aware of morphological or syntactic aspects of words, the measure is not enough for them to foster their monitoring system of real-time processing. This study therefore aims to provide psycholinguistic aspects with the field of English education to bridge between the L2 phonological acquisition and acquisition of vocabulary or reading skills by offering the method of observation of real-time processing.

2 L1 and L2 Mental Lexicon Model

2.1 Verification model and dual-access model

According to the literature, phonological information is activated even during orthographic processing. Lesch & Pollatsek (1993) conducted a naming task using a masked priming paradigm in which native English speakers were asked to read aloud a presented English target word after being presented a prime word. The results showed that homophonic priming effects appeared when the presentation time was 50ms but not when it was 200ms (e.g., target *nut* for the prime *beach*, which is homophonic with *beech*). In contrast, the appropriate semantic prime (e.g., *beech* for *nut*) facilitated the naming in both the short and long presentations. These results support the verification model proposed by Van Orden (1987), which assumes that phonological information activates lexical entries and is then subjected to the verification process (spelling check). In this case, the phonological representation /bi:tʃ/ activates the lexical entries of both *beach* and *beech*, but *beech* is rejected as the verification process proceeds with time.

Similarly, the dual-access model (Kadota, 1998) considers access to the semantic representation via the phonological one (Figure 1). What is different from the verification model is that it presumes the route that directly accesses the semantic representation. According to this model, processing has two routes, a phonology-mediated route and a direct route, and the route taken depends on the contents of the task.

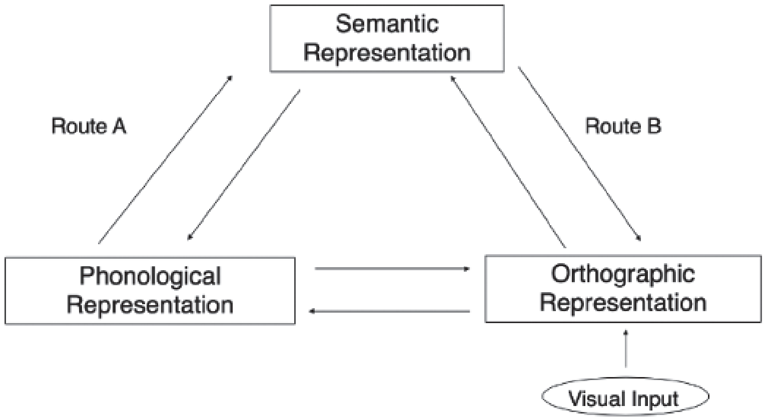

Figure 1: Dual access model by Kadota (1998)

Ishii (2009) suggests the psycholinguistic existence of the dual access model by a visual priming experiment using Japanese kanji words. In the experiment, the prime *kanko* "tourism" was shown as a prime. It facilitated the lexical judgement task on the target *syuppan* "publish", which is a synonym of *kanko* "publish". Crucially, however, a facilitative effect was observed only when the prime was presented for 120ms, and not when presented for 500ms[1]. Ishii (2009) interprets the results as follows: the parsers accessed the semantic representation of the prime when the prime was presented for 500ms while they accessed only the phonological representation of the prime when it was presented for 120ms. The accessed phonological representation /kanko:/ activated the lexical entry of the homophone /kanko:/ "publish" to facilitate the processing of the target *syuppan*, which also has the meanings of "publish" but the facilitation did not occur when the prime was presented for 500ms as the parsers had enough time to access the semantic representation of *kanko* "tourism." The results are similar to those obtained by Lesch & Pollatsek (1993), where the lexical entry of the homophone is activated only when the prime is presented for a short time (50ms). From the results, it is also hypothesized that, although the activation of the lexical entries of the homophones is more likely when there is a time limit in which the parsers can access only the phonological representation, direct access to the semantic representations is also possible. The hypothesis leads to the prediction that a parser can reach the correct semantic representation of, for example, *rock* without being interfered with the representation of *lock*, which is actually shown below to be rebutted by the experimental results in the current study.

2.2 L2 mental lexicon model

As the BIA+ model (Dijkstra & Van Heuven, 2002) shows, the L2 mental lexicon is considered united between L1 and L2 rather than separated, and the orthographic and phonological lexicons are interactive (Figure 2). The existence of an L1–L2 integrated mental lexicon is experimentally shown. For example, bilinguals whose L1 is French and L2 is English responded faster to the interlingual homophones between English and French such as

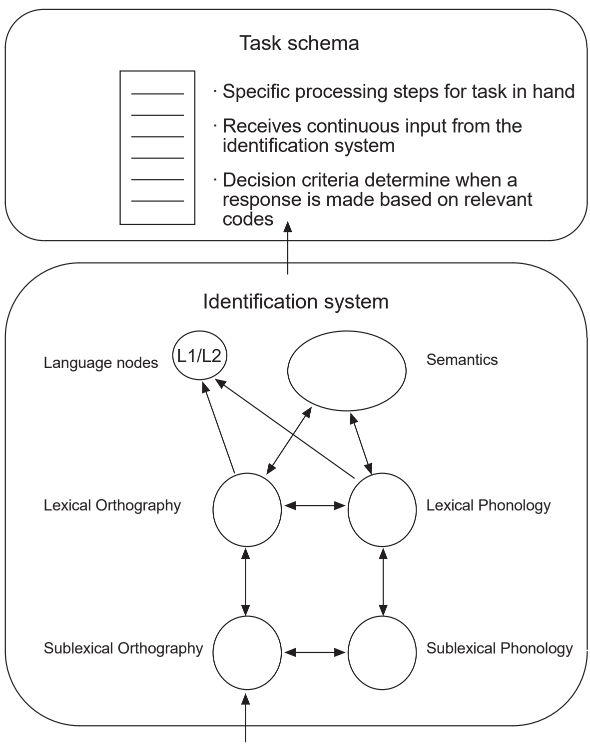

Figure 2: BIA+ model

sue /su:/ (French *sous* /su:/) in the lexical decision task (LDT) where they are asked to answer if the presented word is an existing word (Haigh & Jared, 2007). According to Kadota (Ed.) (2003), the time needed to judge whether a word is an actual word or not is the time required to access the lexical representations of the mental lexicon.

The integrated L1–L2 phonology in the L2 mental lexicon activates the lexical entries of L2 words that are not phonologically contrastive in L1. Pallier et al. (2001) conducted a medium-term auditory repetition priming task on Catalan-Spanish bilinguals which was comprised of a Spanish-dominant group and a Catalan-dominant group. They found a facilitation effect of words only with Catalan-specific phonological contrasts (e.g, /ɛ/–/e/ contrast: /netə/ "granddaughter" – /nɛtə/ "clean") in the Spanish-dominant group. They concluded that the Spanish-dominant bilinguals lose the phonological contrasts unique to Catalan in their mental lexicon, treating them as homophones. Confusion of the L2 phones has been reported even in L2 orthographic processing. For example, Ota et al. (2009) conducted a semantic decision task on Japanese learners of English, in which the learners were required to answer if a pair of English words (e.g., ROCK – KEY) were semantically related by Yes or No. The results revealed that they were more likely to incorrectly answer the question (i.e., these words are semantically related) and take significantly longer reaction times to answer. Their conclusion is that L1 phonology affects the L2 lexical representations even during L2 orthographic processing. Remarkably, while Pallier et al. (2001) observed a facilitative effect, an interfering effect was observed by Ota et al. (2009). One of the reasons of this difference might be the task difference: Pallier et al. (2001) performed a lexical decision task, which needs access to lexical representation (see Kadota (Ed.), 2003), while Ota et al. (2009) performed a semantic judgement task, which requires comparison of semantic representations. Therefore, it remains unclear how the L2 phonological confusion caused by L1 phonology affects lexical processing according to the time course where the parser processes words.

These results indicate that the input of a phonologically non-contrastive and frequent L2 word triggers activation of the lexical information of the L2 minimal pair as a homonym, which in turn activates the semantically related words. However, as shown by Lesch & Pollatsek (1993) and Ishii (2009), access to phonological information and the lexical activation of its homonyms occurs only at a very early stage, followed immediately by access to semantic information. Crucially, in the studies on L2 orthographic processing, the observation of the phonological processing at each stage including verification is lacking.

In order to determine how L1 phonology interferes with the L2 orthographic word processing in parallel with the verification process that is done as time proceeds (Figure 3), the current study uses a combination of the dual-access verification model and the idea of the L1–L2 non-selective mental lexicon as a mechanism. For instance, when the written input is *rock*, it is first transformed into the orthographic representation of *rock*. The phonological representation of the orthographic representation is accessed through the phonology-mediated route. As the phonological representation of the English /l–r/ words is merged into a single liquid category, the retrieval of the semantic information of the minimal pair can be retrieved during the initial stage of processing. However, after reaching the merged phonological representation, L2 learners apply the verification process and discard the lexical entry of the /l–r/ minimal pair (*lock* in this case), successfully accessing the semantic representation of *rock*. Therefore, it is predicted that the L2 learners are likely to retrieve the lexical entry of the minimal pair when they do not have enough time to process the input but are less likely to select the

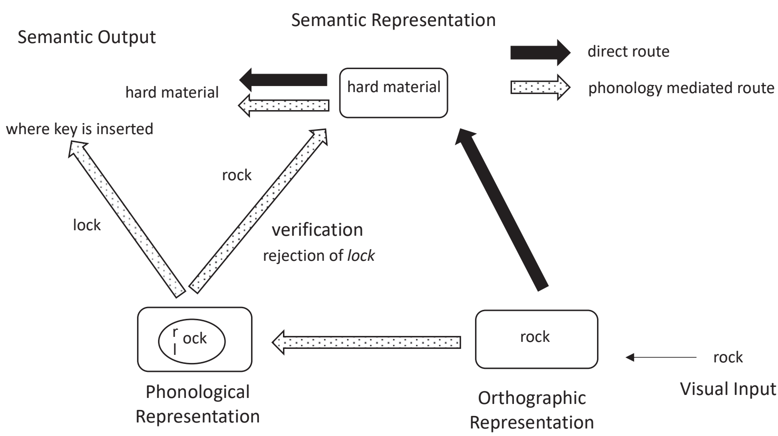

Figure 3: An L2 mental lexicon model that the study is testing

wrong semantic representation when they have enough time to proceed with verification. Moreover, L2 learners can also directly access the semantic representation of the input in a short time despite the confused L2 phonology.

An asymmetry between the L2 phonological representations is observed for an auditory input. Cutler et al. (2006) reported that, in an eye-tracking experiment, Japanese learners of English were likely to look at the competitor *locker* when instructed to click on *rocket* but were not inclined to look at the competitor *rocket* when instructed to click on *locker*. They attributed this asymmetry to the phonetic similarity between the English /l/ and Japanese /r/. Japanese learners are, therefore, thought to have /l/ as a default for the mental representations of the English /l–r/ words. If the asymmetry stemming from the phonetic similarity in the mental lexicon is also reflected in the orthographic word processing, the /l/ word is expected to be less likely to activate the lexical information of the /r/ counterpart (Figure 4, Figure 5).

For instance, when the written input word is *rock*, the phonological representation of *lock* will be primarily selected before verification as /l/ is a dominant category in the L2 mental lexicon for Japanese learners. In contrast, when the orthographic input is *lock*, it is more likely that the phonological representation of *lock* is activated and consequently the correct semantic representation is accessed.

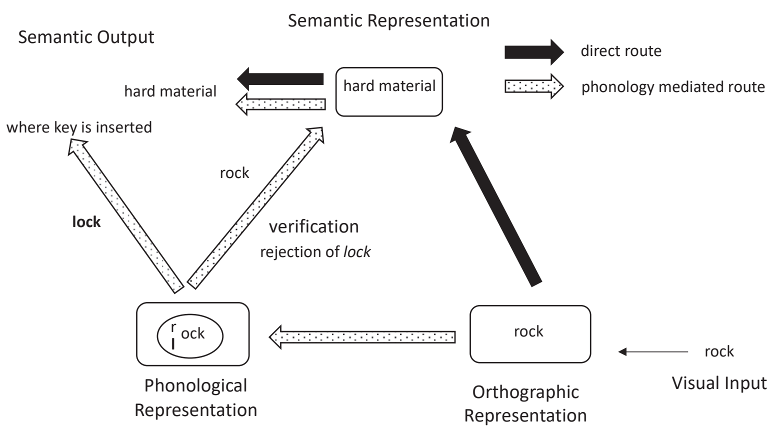

Figure 4: An expected asymmetric pattern (input is /r/)

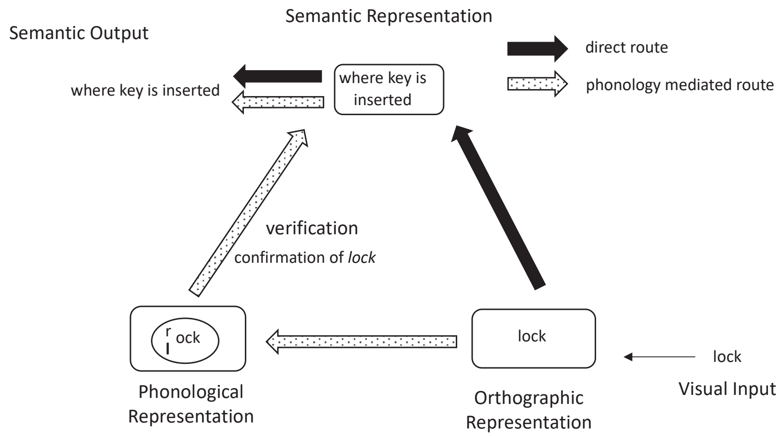

Figure 5: An expected asymmetric pattern (input is /l/)

Daidone & Darcy (2014) conducted an L2 LDT task with auditory stimuli and an ABX task that asks the listeners which of A or B they heard that is close to the third after hearing three sounds in a sequence. They reported that although the L2 learners were successful in the ABX task, they scored lower in the LDT task. They concluded that the lexical confusion of L2 words that include phones that are non-contrastive in L1 lies not at the phonetic level but at the lexical level. If this is also true for the L2 orthographic word processing, it is expected that the activation of the lexical entry of the phonological minimal pair can occur regardless of the difference in the ability to perceptually contrast the L2 phones.

The current study conducts a lexical decision task to test if and how the L1 phonology affects L2 orthographic processing. An ABX task is also conducted to measure the learners' ability to perceptually contrast English /l–r/ and to investigate if the L2 orthographic processing also supports the finding that the L2 phoneme confusion is not at the phonetic level but at the lexical level, by comparing the accuracy rate of the ABX task with the reaction times (RTs) of the LDT task.

3 Method

3.1 Participants

A total of 131 Japanese participants were mainly recruited from the University of Tokyo. After removing the data of those who recorded lower scores on the word test or those who encountered technical troubles and were unable to continue the experiments, 101 Japanese learners of English remained for analysis (mean age: 23.9 years, *SD* = 6.0). Fifty-five out of the 101 were assigned to the short-presentation (120ms) group and 46 were assigned to the long-presentation (500ms) group. A total of 116 English participants took part in the experiments and 72 out of 116 were analyzed as native English participants (mean age = 42.7 years, *SD* = 11.9); 33 were assigned to the short-presentation group and 39 were to the long-presentation group. They were recruited through Prolific, an online recruitment service, and reported themselves as English monolinguals (Answer to the questionnaire by Prolific: I only know English).

3.2 Materials

3.2.1 LDT task & word test

The items for the LDT task were as follows (for all of the examples, see Appendix).

Table 1: An example of the items of the LDT task

	Prime	Target
Semantically Related	rock	
Minimal Pair	lock	STONE
Visual Control	rich	

The total number of items was 18. In the prime in the Semantically Related condition, the prime is similar to the target in meaning. In the prime in the Minimal Pair condition, the prime is a minimal /l–r/ pair of the prime in the Semantically Related condition and is expected to work as a semantically related prime for Japanese learners who do not have the /l–r/ contrast in their L1. The prime in the Visual Control condition is visually similar to that in the Semantically Related condition.

Most of the prime words were selected from the database "The University of South Florida Free Association Norms" which lists the relatedness of two words rated by native speakers of English. Other prime words were selected from the words that underwent the norming by 39 native Japanese speakers (mean age: 36.31 years (SD = 7.83), CEFR: A1–C2). To ensure the validity of the semantic relation and the familiarity of the words for the learners, 28 native Japanese speakers (mean age: 21.2 years (*SD* = 10.6), CEFR: B1 – C1) different from the participants of the experiments were asked to rate the semantic relatedness of the candidate words on a 7-point Likert scale. The items whose relatedness rate was lower in the Semantically Related condition than that in the Minimal Pair condition or the Visual Control condition were omitted from the analysis. The first half of items were as /r–l/ (prime-target order) and the second half of items as /l–r/, in order to prevent the influence of the presentation order of /l/ or /r/ between prime and target, in addition to which the first half of the items are reversed (/l–r/ for the first 9 items, /r–l/ for the second 9 items). Thus, there were a total of 6 lists (3 lists x 2).

To ensure that the learners did not have the wrong lexical representations of the /l–r/ words, a word test that required them to write each experimental word which included /l/ or /r/ was conducted. The total number of tested words was 38. The breakdown is as follows: 36 words (prime words in the Semantically Related and Minimal Pair conditions) and 2 words, *race* and *lace*, in the Visual Control condition. The two words were tested because they have minimal pairs (*lace* for *race*, and *race* for *lace*). By testing the two words, the possibility that the learners had incorrectly activated the lexical entry of the minimal pair can be excluded.

To approximate the early stage of the processing where only the phonological representation is accessed and the medial stage where the input is verified, the participants were divided into two groups with respect to presentation time of the prime: 120ms (short-presentation group) and 500ms (long-presentation group). The 120ms and 500ms were interpreted as the time needed to access the phonological representation and the semantic representation respectively, based on the results in Ishii (2009).

3.2.2 ABX task

The experimental stimuli for the ABX task were CVC (e.g, *roog* /ru:g/) or CCVC (e.g., *crees* /kri:s/) nonwords that included the /l–r/ contrast. The /p–b/, /k–g/, and /t–d/ pairs were selected as controls. The control stimuli included a CVCC form (e.g., *buft* /bʌft/). The stimuli were human speech by two native speakers of American English (1 male, 1 female) and a native speaker of New Zealand English (female). Each utterance of the three speakers was assigned to A, B, and X respectively. To avoid contrasting the two sounds by the difference in vocalic quality that is caused by dialect variations, the vowels for the stimuli were limited to /i:/, /u:/, and /ʌ/, which are thought to be commonly pronounced among American English speakers and New Zealand English speakers. The total number of /l–r/ stimuli was 36.

3.3 Procedure

The three experiments were conducted online through PCIbex (Zehr & Schwartz, 2018). The participants accessed a link to the experiments, which were conducted in the following order: 1. the LDT task, 2. the ABX task, and 3. the word test (Japanese participants only). The participants could move on to the next experiment from a link at the end of the first (two) experiment(s).

In the LDT task, the fixation cross "+" was first presented for 1000ms. Then, the prime was presented for either 120ms (short-presentation group) or 500ms (long-presentation group), and the target was shown until the participants pressed the F key or J key, to determine if the target was an existing English word (F) or not (J) (lexical decision). The participants were trained for the task in a practice session, which was not included in the analysis. The 18 items were presented by a Latin Square with 54 non-experimental distractors. The order of presentation of the items was randomized. The maximum time allotted to the participants to answer each trial was 10000ms.

The ABX task followed the LDT task and required the participants to answer which third sound was similar to the first sound (A) or the second sound (B) by pressing F for A and J for B.

After the LDT task and the ABX task, the Japanese learners underwent a word test. The 38 words, some of which were hidden by underbars, were presented sequentially with a corresponding Japanese translation. The words were embedded in a collocation or combined with different words (e.g., _ock and stone: 岩と石). The participants were required to answer by typing either the whole word or the part of the word that was hidden by the underbars. The time limit for each item to answer was 10000ms.

3.4 Data Trimming

To omit outliers, data trimming was performed as follows. First, the participants with lower accuracy (no more than 55%) on the word test were omitted from the Japanese group. Those who recorded an extremely lower score on the LDT task compared to other participants were also omitted. As for the native speakers of English, those who recorded no less than 60% accuracy on the ABX task were excluded.

After removing these participants' data, the data with extremely longer RTs, determined from the histogram, were omitted. The percentage of the remaining data is presented in the column "Rate of correct answers" in Table 2. The final data trimming was performed to omit data that exceeded SD = ±2.5. The amount of data remaining is shown in column "Data Remained 2."

Table 2: The data trimming and the percentage of remaining data.

	RTs (ms)	Data Remained 1	Rate of correct answers	Data Remained 2
JPN & short	2000	93.4%	93.1%	99.9%
JPN & long	2000	94.9%	95.8%	98.5%
ENG & short	1500	94.9%	99.0%	98.2%
ENG & long	1500	96.1%	97.8%	99.5%

3.5 Analysis

For analyzing the effects of the prime, the prime presentation time, and/or the language group (Japanese learners/native speakers of English), the linear mixed effect (LME) model was used, with the formula below.

1. RTs~ Prime*Group + (1 + Prime | participant) + (1 + Prime + Group + Prime: Group | item)

2. RTs~ Prime*SL + (1 + Prime + SL + Prime:SL | participant) + (1 + Prime + SL + Prime:SL | item)

3. RTs~ Prime*LR + (1 + Prime + LR + Prime:LR | participant) + (1 + Prime + LR + Prime:LR | item)

4. RTs~ Prime*ABX + (1 + Prime + ABX + Prime:ABX | participant) + (1 + Prime + ABX + Prime:ABX | item)

5. RTs~ Prime + (1 + Prime | participant) + (1 +Prime | item)

The number 1 in the formula refers to the random intercept per participant and per item. The RTs were set as response variables. The individual differences among the participants and items were set as random factors (participant and item in the formula).

In the analysis of how the behavior toward the processing of /l–r/ differs between the learners and the native speakers, Group (Japanese/English) and Prime (Semantically Related/Minimal Pair/Visual Control) were set as fixed factors. The main effect of Prime was selected as a random slope for individual differences in the participants, and the main effects of Prime, Group, and the Prime x the Group interaction were set as random slopes for individual differences in the items. [1].

To examine if the different presentation times affect the processing, SL (Short & Long: 120ms or 500ms) and the Prime were set as fixed factors. The main effects of Prime, SL, and the Prime x SL interaction were set as random slopes for individual differences in the participants and items. [2].

In the analysis of whether the /l–r/ asymmetry of the mental representation affects the processing by learners, Prime and LR (the prime in the Minimal Pair condition starts with or includes /l/ or /r/) were set as fixed factors. The main effects of Prime, LR, and the Prime x LR interaction were set as random slopes for individual differences in the participants and items. [3].

For the analysis of whether and how the behavior toward the minimal pair primes differs depending on the ability to perceptually contrast /l–r/, Prime and ABX (the accuracy rate of the /l–r/ trial of the ABX task per participant) were set as fixed factors. The main effects of Prime, ABX, and the Prime x ABX interaction were set as random slopes for individual differences in the participants and items. [4].

For the analysis of each group (Japanese/English), the Prime was set as a fixed factor, and the main effect of Prime was set as a random slope. [5].

The best-fit model was selected by eliminating statistically non-significant random elements, which is called backward selection (Bates et al., 2015). To avoid confounding between the learners' unstable L2 lexical entries and the activation of wrong lexical entries by the phonological confusion, the data that contain wrong answers in the word test were excluded from the LDT analysis. To analyze the accuracy rate of the ABX task between the Japanese and English groups, the generalized linear mixed effect model (GLMM) was used. The answer to the ABX task (correct = 1/wrong = 0) ("answer" in the formula) was set as a response variable. The Group (Japanese/English) and the contrast type (lr/control) were set as fixed factors. The formula is as below.

6. answer Group + contrast type + Group: contrast type + (1 + contrast type |participant) + (1 + Group + contrast type + Group: contrast type |item))

The best-fit model was selected by backward selection (Bates et al., 2015) as well.

4 Results

4.1 LDT task

As the /l–r/ minimal pair is thought to affect Japanese learners of English but not native speakers of English, the prediction is that the main effect of the Prime would be observed only in the Japanese group, resulting in the Prime x Group interaction. A significant interaction effect was found between the Group and the Prime in the long-presentation group, with the significantly shorter RTs in the Minimal Pair condition in the Japanese group (Figure 6, 7; Table 4).

From the dual-access model and the verification model, it is predicted that the Prime x SL interaction effect would be observed in the Japanese group, with the RTs shorter in the Minimal Pair than in the Visual Control only in the short-presentation group. The significant effect between the Prime and the SL was not observed but the significant main effect of the Prime was seen only in the long-presentation group (Table 5, 6).

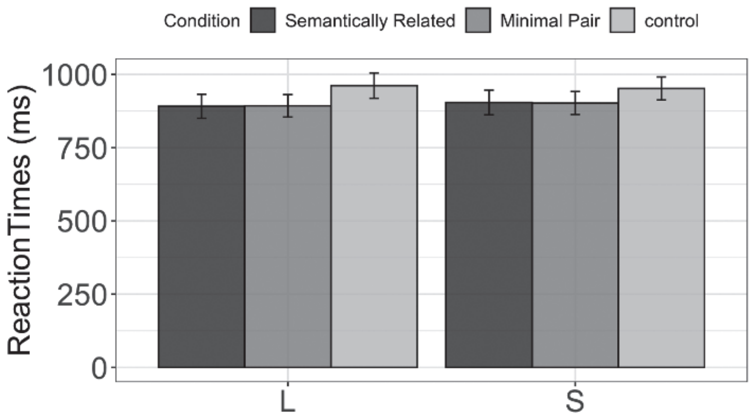

Figure 6: A graph of the differences in the Reaction Times between conditions in the Japanese learners. L represents Long (500ms) and S represents Short (120ms).

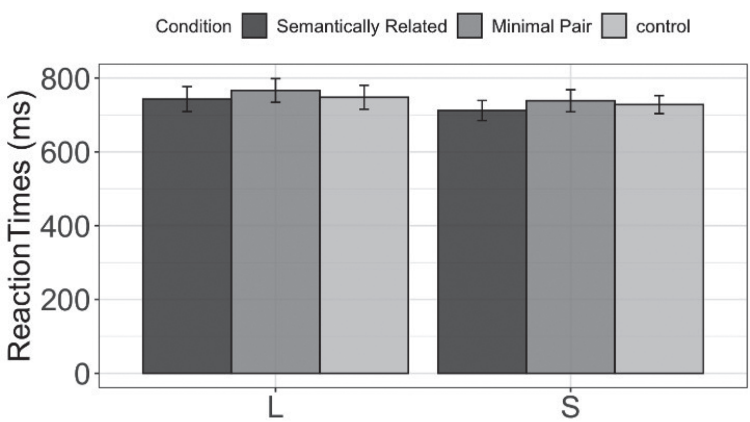

Figure 7: A graph of the differences in the Reaction Times between conditions in the native speakers of English. L represents Long (500ms) and S represents Short (120ms).

Table 3: The statistical results of the comparison of the RTs between the Japanese group and the English group (short-presentation group: 120ms).

	β	*SE*	*df*	*t*	*p*	
(Intercept)	752.4	34.69	140.94	21.692	< 2e−16	***
Prime (Semantically Related)	−37.75	23.54	1086.07	−1.603	0.109	
Prime (Minimal Pair)	−15.69	23.75	1085.91	−0.661	0.509	
Group (Japanese)	213.34	40.63	122.82	5.251	6.43E−07	***
Prime (Semantically Related) x Group (Japanese)	12.21	30.23	1080.32	0.404	0.686	
Prime (Minimal Pair) x Group (Japanese)	−24.24	30.62	1084.45	−0.792	0.429	

Table 4: The statistical results of the comparison of the RTs between the Japanese group and the English group (long-presentation group: 500ms).

	β	*SE*	*df*	*t*	*p*	
(Intercept)	765.674	32.06	148.538	23.882	< 2e−16	***
Prime (Semantically Related)	−14.661	22.814	1118.586	−0.643	0.5206	
Prime (Minimal Pair)	−3.586	22.771	1122.179	−0.158	0.8749	
Group (Japanese)	202.813	39.903	126.982	5.083	1.30E−06	***
Prime (Semantically Related) x Group (Japanese)	−40.156	31.187	1120.041	−1.288	0.1982	
Prime (Minimal Pair) x Group (Japanese)	−69.213	31.218	1122.19	−2.217	0.0268	*

Table 5: The statistical results of the comparison of the RTs between conditions in the Japanese group (short-presentation group).

	β	*SE*	*df*	*t*	*p*	
(Intercept)	973.08	36.61	85.11	26.581	< 2e−16	***
Prime (Semantically Related)	−24.99	21.33	613.97	−1.171	0.2419	
Prime (Minimal Pair)	−35.57	21.47	612.51	−1.657	0.0981	.

Table 6: The statistical results of the comparison of the RTs between conditions in the Japanese group (long-presentation group).

	β	*SE*	*df*	*t*	*p*	
(Intercept)	971.39	34.32	84.37	28.3	< 2e-16	***
Prime (Semantically Related)	−53.58	23.81	571.58	−2.25	0.02483	*
Prime (Minimal Pair)	−69.61	23.92	572.15	−2.911	0.00375	**

Table 7: The statistical results of the comparison of the RTs between conditions in the English group (short-presentation group).

	β	*SE*	*df*	*t*	*p*	
(Intercept)	739.272	21.783	51.111	33.939	< 2e−16	***
Prime (Semantically Related)	−23.344	16.384	393.162	−1.425	0.155	
Prime (Minimal Pair)	8.302	16.499	393.485	0.503	0.615	

Table 8: The statistical results of the comparison of the RTs between conditions in the English group (long-presentation group).

	β	*SE*	*df*	*t*	*p*	
(Intercept)	762.001	28.404	52.09	26.827	< 2e−16	***
Prime (Semantically Related)	−12.298	17.756	541.396	−0.693	0.489	
Prime (Minimal Pair)	6.237	17.706	540.811	0.352	0.725	

Table 9: The statistical results of the SL x Prime interaction in the Japanese group.

	β	*SE*	*df*	*t*	*p*	
(Intercept)	972.546	36.223	137.429	26.849	< 2e−16	***
Prime (Semantically Related)	−53.176	22.802	1209.535	−2.332	0.0199	*
Prime (Minimal Pair)	−66.451	22.849	1207.742	−2.908	0.0037	**
SL(S)	2.417	40.411	144.888	0.06	0.9524	
Prime (Semantically Related) x SL(S)	27.499	31.606	1207.883	0.87	0.3844	
Prime (Minimal Pair) x SL(S)	26.51	31.774	1207.627	0.834	0.4043	

There was a significant interaction effect between the Prime and LR in the long-presentation group (the Semantically Related Group < the Visual Control in Minimal Pair L = Semantically Related R) in the Japanese group (Table 11). The familiarity rate of target and prime did not affect the results when they were put into the formula as a covariant in the analyses.

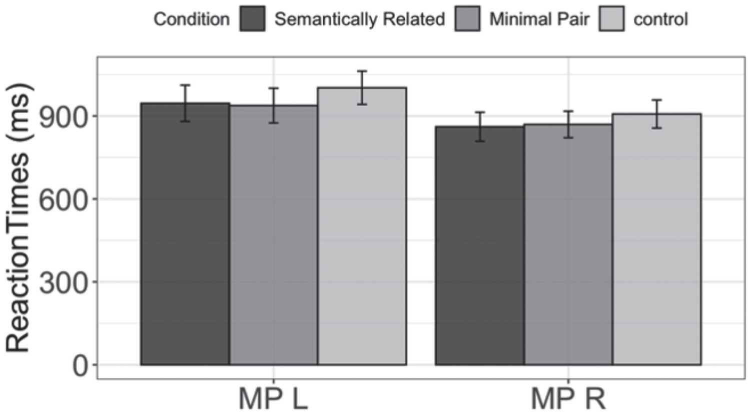

Figure 8: A graph of the differences in the Reaction Times between when the prime in the Minimal Pair condition starts with or includes /l/ (represented as MP L (= Minimal Pair L) in the graph) or /r/ represented as MP R (= Minimal Pair R) in the graph) in the short-presentation group. Minimal Pair L is equivalent to the Semantically Related R (the prime starts with or includes /r/) and Minimal Pair R is the Semantically Related L (the prime starts with or includes /l/).

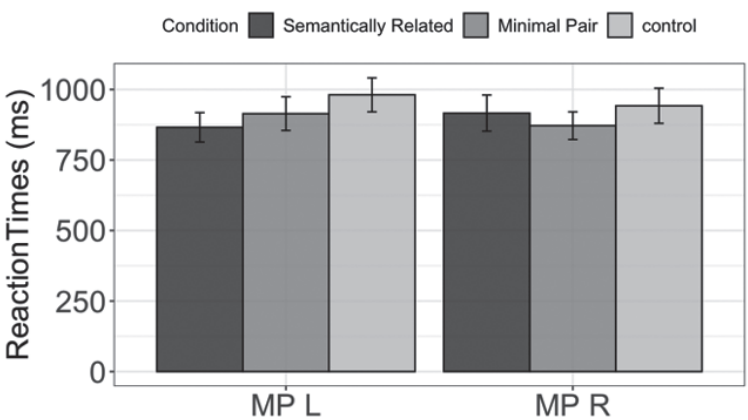

Figure 9: A graph of the differences in the Reaction Times between when the prime in the Minimal Pair condition starts with or includes /l/ (represented as MP L (= Minimal Pair L) in the graph) or /r/ represented as MP R (= Minimal Pair R) in the graph) in the long-presentation group. Minimal Pair L is equivalent to the Semantically Related R (the prime starts with or includes /r/) and Minimal Pair R is the Semantically Related L (the prime starts with or includes /l/).

Table 10: The statistical results of the Prime x Minimal Pair LR in the short-presentation group (Japanese)

	β	*SE*	*df*	*t*	*p*	
(Intercept)	924.6663	43.4408	78.0864	21.286	< 2e−16	***
Prime (Semantically Related)	−25.4976	29.9698	615.0471	-0.851	0.3952	
Prime (Minimal Pair)	−24.3953	29.5824	609.2304	−0.825	0.4099	
LR (Minimal Pair L)	97.0389	50.4112	45.8019	1.925	0.0605	.
Prime (Semantically Related) x LR (Minimal Pair L)	−0.2998	42.8215	615.4803	−0.007	0.9944	
Prime (Minimal Pair) x LR (Minimal Pair L)	−23.843	43.044	612.4484	−0.554	0.5798	

Table 11: The statistical results of the Prime x Minimal Pair LR in the long-presentation group (Japanese).

	β	*SE*	*df*	*t*	*p*	
(Intercept)	953.362	43.255	83.226	22.041	< 2e−16	***
Prime (Semantically Related)	4.009	33.58	574.592	0.119	0.905	
Prime (Minimal Pair)	−66.247	33.468	570.923	−1.979	0.0483	*
LR (Minimal Pair L)	35.692	52.372	55.682	0.682	0.4984	
Prime (Semantically Related) x Minimal Pair L	−114.114	47.255	570.759	−2.415	0.0161	*
Prime (Minimal Pair) x Minimal Pair L	−6.102	47.564	572.891	−0.128	0.898	

There was no significant interaction effect between the Prime and the ABX in the Japanese group either in the short-presentation group or in the long-presentation group (Table 12).

Table 12: The statistic results of the Prime x ABX in the Japanese group (short-presentation group).

	β	*SE*	*df*	*t*	*p*	
(Intercept)	1025.27	118.41	79.68	8.659	4.23E−13	***
Prime (Semantically Related)	18.46	82.99	609.25	0.222	0.824	
Prime (Minimal Pair)	65.38	86.63	611.76	0.755	0.451	
ABX	−86.39	186.21	74.64	−0.464	0.644	
Prime (Semantically Related) x ABX	−71.91	131.13	608.07	−0.548	0.584	
Prime (Minimal Pair) x ABX	−166.37	138.36	610.6	−1.202	0.23	

Table 13: The statistic results of the Prime x ABX in the Japanese group (long-presentation group).

	β	*SE*	*df*	*t*	*p*	
(Intercept)	1129.47	109.35	79	10.329	2.55E−16	***
Prime (Semantically Related)	−154.2	93.13	579.12	−1.656	0.0983	.
Prime (Minimal Pair)	−113.99	93.33	576.79	−1.221	0.2225	
ABX	−274.88	181.02	72.19	−1.519	0.1332	
Prime (Semantically Related) x ABX	171.84	153.58	576.27	1.119	0.2636	
Prime (Minimal Pair) x ABX	76.42	154.88	574	0.493	0.6219	

4.2 ABX task

The mean accuracy per participant was 59.2% (*SD* = 0.15) in the Japanese group and 89.2% (*SD* = 0.08) in the English group. The GLMM found a significant interaction between the groups (Japanese/English) and the contrast type (/l–r/ contrast/plosive contrast), with a stronger effect observed for the contrast type in the Japanese group. The main effect of the contrast type was, however, significant in both the Japanese and English groups (lr < control) (Table 15, 16).

Table 14: The statistical results of the contrast type x the Group analysis in the ABX.

	β	*SE*	z value	Pr (>∣z∣)	
(Intercept)	3.0799	0.1531	20.114	< 2e−16	***
contrast type lr	−0.6158	0.1502	−4.1	4.13E−05	***
Group (Japanese)	−0.3304	0.1938	−1.705	0.0882	.
contrast type lr x Group (Japanese)	−1.6217	0.1459	−11.115	< 2e−16	***

Table 15: The statistical results of the effect of contrast type in the Japanese group.

	β	*SE*	z value	Pr (>∣z∣)	
(Intercept)	3.5144	0.3066	11.462	< 2e−16	***
contrast type lr	−2.9637	0.3384	−8.758	< 2e−16	***

Table 16: The statistical results of the effect of contrast type in the English group.

	β	*SE*	z value	Pr (>|z|)	
(Intercept)	3.2689	0.1889	17.308	< 2e−16	***
contrast type lr	−0.8878	0.181	−4.906	9.31E−07	***

5 Discussion

The significant interaction effect between the Group and the contrast type of the ABX results indicates that the Japanese learners were less successful in perceptually distinguishing the /l–r/ contrast. These results agree with those obtained by previous studies, such as Goto (1971) that revealed the difficulty that Japanese learners have in acquiring the /l–r/ perceptual contrast.

The significant Group x Prime interaction effect in the Minimal Pair condition (Table 11) suggests that the Japanese learners were likely to incorrectly activate the lexical information of the minimal pair of /l–r/ due to the lack of the /l–r/ contrast in their L1, as expected from previous studies (Goto, 1971; Ota et al., 2009). However, what is different from the predictions is that a significant interaction effect was observed only in the long-presentation group (500ms), not in the short-presentation group (120ms), although there was no significant interaction effect between the Prime and SL. The semantic facilitation by the minimal pair of /l–r/ among the Japanese learners, despite the longer presentation time of the word, did not support the hypothesis that Japanese learners verify the activated phonological representation of the input and can reject the initial wrong lexical interpretation caused by the phonological representation of homophones that are judged by the L1 phonology. In other words, they might have retrieved the lexical representation of the minimal pair word from the phonological representation even when they should have had enough time to check if the interpreted phonology of the orthographic input corresponded to the appropriate lexical representation. When 500ms is assumed to be enough for them to access the semantic representation of the input, the Japanese learners are thought to have first accessed the phonological representation of the /l–r/-including word that is merged into a single liquid category affected by the L1 Japanese phonology and have chosen the semantic representation of one of the two, facilitated by the presentation of the target in the LDT task. The multiple semantic representations are stored (Figure 10). All this can be interpreted as indicating that the learners failed to accomplish the verification process.

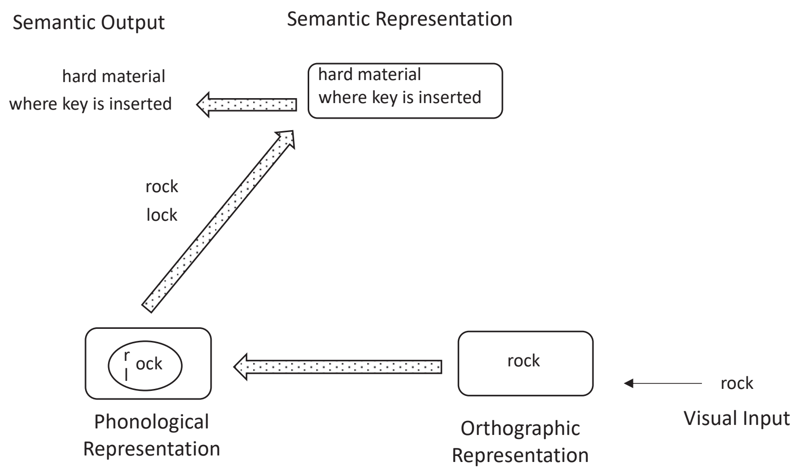

Figure 10: A possible processing pattern that can be led from the results of the experiments.

Given that the main effect of the Prime was only found in the long-presentation group of the Japanese group, the results can also be interpreted as indicating that 120ms was not enough for the learners to encode the input. If the Japanese learners need more than 500ms to access the semantic representation, the results indicate that the learner did not reach the verification process, accessing only the phonological representations and activating the semantic representation of the minimal pair word, as predicted by the dual-access model and the verification model.

Regarding the asymmetry in the /l–r/ phonological representation in the L2 English mental lexicon, the asymmetric pattern as in Cutler et al. (2006) was not observed in the experimental results. The non-significant interaction effect between the LR and the Prime in the Minimal Pair condition did not clarify whether /l/ or /r/ is the default representation in the L2 mental lexicon.

Nevertheless, there was a LR x Prime interaction effect in the Semantically Related condition in the long-presentation group, which implies that the semantic facilitative prime worked more strongly when the prime was a /r/-starting or /r/-including word. This indicates that it is easier for Japanese learners to access the correct phonolexical and semantic representations when the input starts with or includes /r/ than /l/.

The non-significant interaction effect between the ABX accuracy and the Prime did not provide any clear support for the idea that L2 learners with a higher ability to phonetically contrast the L2 phonologically non-contrastive phones are likely to have separated L2 mental lexicon for the L2 phonologically non-contrastive phones. To put it differently, the higher ability to phonetically contrast the L2 phones that are not distinct in the L1 cannot guarantee the correct phonolexical activation of the L2 words that include hard-to-differentiate phonetic/phonological contrast.

It can be concluded from the experimental results in this study that the L2 learners are subject to the L2 phonolexical ambiguity even if they have correct lexical entries for the /l-r/ words.

The results of the LDT task and the ABX task have an educational implication. What the results of the two experiments commonly showed is that the confusion in the L2 phonolexical representations during orthographic word processing can be triggered regardless of the ability to perceptually contrast the L2 phonologically non-contrastive phones and the correct lexical representations in the mental lexicon. From the results, it can be argued that the L2 learners are still likely to be affected by the L1 phonology during orthographic word L2 processing even after acquiring phonetic contrast of the L2 phones and separated L2 lexical entries of the words that are non-contrastive in their L1 phonology. The results can propose a new way of conducting L2 education that makes the L2 learners aware of the unconscious interference of L1 phonology, not just facilitating the L2 perceptual ability. A possible education strategy would be to encourage the L2 learners to monitor themselves during L2 orthographic processing including reading, in terms of not only their proficiency or reading speed but also their lexical confusion that stems from L1 phonological interference. For instance, it may be effective to assign to the learners a questionnaire that asks whether they failed to understand the correct meaning of the words after a vocabulary and reading training that includes the processing of English phonemic contrasts that are non-contrastive in their L1. This may foster the learners' ability to use a metacognitive strategy in L2 English learning, which can also be helpful in making them autonomous learners. Concretely, by making them conscious of the real-time processing, they will become capable of monitoring if they make mistakes in phonolexical interpretation whenever silently reading words or sentences and they can find what hinders their understandings of L2 English words or sentences without a teacher's help.

6 Conclusion

This study experimentally tested the psycholinguistic existence of L2 ambiguous phonolexical representations in the L2 mental lexicon. Although the results did not completely support the L2 mental lexicon model, which is based on the dual-access model and the verification model, the facilitative priming effect of the minimal /l–r/ pair on the Japanese learners suggested that the status of the L2 lexical representation of the phonologically non-contrastive words in their L1 was ambiguous. Applying the findings of this study to English education methods may help L2 learners become conscious of the mechanisms of L2 orthographic processing that is unconsciously working in themselves, which would improve their understanding of L2 English words or sentences.

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Notes

[1]120ms was selected as the short SOA where the participants cannot access the meanings of a two-character kanji word based on the results of Tan & Perfetti (1999).

Appendix 1

Items of the LDT task. The primes of Semantically Related condition in item 1 – 9 start with or include /r/ while those in item 10 – 18 start with or include /l/.

Item	Condition	Prime	Target
1	Semantically Related Minimal Pair Control	rock lock rich	STONE
2	Semantically Related Minimal Pair Control	prayer player painter	CHURCH
3	Semantically Related Minimal Pair Control	ray lay ran	BEAM
4	Semantically Related Minimal Pair Control	right light rigid	LEFT
5	Semantically Related Minimal Pair Control	fry fly shy	COOK
6	Semantically Related Minimal Pair Control	crown clown shown	KING
7	Semantically Related Minimal Pair Control	writer lighter waiter	AUTHOR
8	Semantically Related Minimal Pair Control	read lead feed	BOOK
9	Semantically Related Minimal Pair Control	road load roar	STREET
10	Semantically Related Minimal Pair Control	list wrist lift	CHECK

Item	Condition	Prime	Target
11	Semantically Related	late	EARLY
	Minimal Pair	rate	
	Control	land	
12	Semantically Related	cloud	SKY
	Minimal Pair	crowd	
	Control	chose	
13	Semantically Related	glass	WINDOW
	Minimal Pair	grass	
	Control	guess	
14	Semantically Related	lack	SHORTAGE
	Minimal Pair	rack	
	Control	lace	
15	Semantically Related	belly	STOMACH
	Minimal Pair	berry	
	Control	begin	
16	Semantically Related	lap	KNEE
	Minimal Pair	wrap	
	Control	map	
17	Semantically Related	collect	GATHER
	Minimal Pair	correct	
	Control	connect	
18	Semantically Related	alive	DEAD
	Minimal Pair	arrive	
	Control	aside	

Appendix 2

Items of the LDT task. The primes of Semantically Related condition in item 1 – 9 start with or include /l/ while those in item 10 – 18 start with or include /r/.

Item	Condition	Prime	Target
1	Semantically Related Minimal Pair Control	lock rock look	KEY
2	Semantically Related Minimal Pair Control	player prayer painter	SPORT
3	Semantically Related Minimal Pair Control	lay ray lag	SLEEP
4	Semantically Related Minimal Pair Control	light right limit	DARK
5	Semantically Related Minimal Pair Control	fly fry shy	BIRD
6	Semantically Related Minimal Pair Control	clown crown shown	CIRCUS
7	Semantically Related Minimal Pair Control	lighter writer letter	FIRE
8	Semantically Related Minimal Pair Control	lead read feed	FOLLOW
9	Semantically Related Minimal Pair Control	load road loud	HEAVY
10	Semantically Related Minimal Pair Control	wrist list whip	HAND

Item	Condition	Prime	Target
11	Semantically Related	rate	SPEED
	Minimal Pair	late	
	Control	rare	
12	Semantically Related	crowd	PEOPLE
	Minimal Pair	cloud	
	Control	chose	
13	Semantically Related	grass	TREE
	Minimal Pair	glass	
	Control	guess	
14	Semantically Related	rack	SHELF
	Minimal Pair	lack	
	Control	race	
15	Semantically Related	berry	FRUIT
	Minimal Pair	belly	
	Control	begin	
16	Semantically Related	wrap	COVER
	Minimal Pair	lap	
	Control	map	
17	Semantically Related	correct	ACCURATE
	Minimal Pair	collect	
	Control	connect	
18	Semantically Related	arrive	DEPART
	Minimal Pair	alive	
	Control	assign	

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