The influence of prior linguistic knowledge on second language semantic implicit learning: Evidence from Cantonese–English bilinguals

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Abstract

Previous studies have shown that prior linguistic knowledge affects semantic implicit learning when stimuli are presented in the first language. We report an experiment that investigated whether such crosslinguistic influence from the first language would still emerge in the second language for semantic implicit learning of novel articles and fire/water semantic category mappings, a semantic distinction that is explicitly marked by semantic radicals in Chinese but not in English and a type of form–meaning connections that has not been investigated. We found that 30 Cantonese–English bilinguals and 30 native English speakers learned the target form–meaning connections and that the knowledge that they developed may have been implicit, as shown through post-experiment verbal reports. Moreover, the bilingual group was significantly faster than the English group in distinguishing fire/water English nouns. These findings extend the range of semantic-based regularities that can be learned at the implicit level and suggest that the markings of fire/water distinctions in Chinese affect second language task performance.

A one-page Accessible Summary of this article in non-technical language is freely available in the Supporting Information online and at https://oasis-database.org.

Keywords: implicit learning; crosslinguistic effects; form–meaning connections; second language acquisition; semantic category

Introduction

Whether bilinguals can switch off their noncurrent language completely has been extensively researched, especially in the contexts where switching can occur during lexical processing (Mulder et al., 2018; Poort et al., 2016; Thierry & Wu, 2007; Wu & Thierry, 2010). For example, in a visual world paradigm where Russian–English bilinguals were asked to "click on the *marker*" in English, their eye gaze was likely to first fixate on the picture of a stamp because the first syllable of its Russian translation equivalent *marka* is similar to that of the English word marker (Marian et al., 2003). This suggested that words in the noncurrent language may be simultaneously activated, and the activation of the noncurrent language appears to take place at the unconscious level. A wide range of studies involving different linguistic phenomena, methods, and populations have revealed that simultaneous activation of bilinguals' languages results in crosslinguistic influence during comprehension and production (e.g., Marian & Spivey, 2003; Marian et al., 2003; Mulder et al., 2018; Weber & Cutler, 2004; Thierry & Wu, 2007; Wu & Thierry, 2010). However, these studies mainly investigated how the noncurrent language influences trial-by-trial real-time processing in the current language based on participants' existing linguistic knowledge. Whether the activation of bilinguals' noncurrent language affects the development of new implicit linguistic knowledge remains an empirical question. In this study, we aimed to examine how the covert activation of the noncurrent first language (L1) in bilinguals influences the implicit learning of form–meaning connections.

Background Literature

Implicit Language Learning

Implicit learning, a term first coined by Reber (1967), refers to the phenomenon of individuals' learning without awareness of what they are learning and typically results in nonverbalizable knowledge (DeKeyser, 2003; Williams, 2009). One prime example is child language acquisition, where the L1 is acquired with minimal need for explicit feedback. The field of second language (L2) acquisition has long been interested in the phenomenon of implicit learning, primarily because of Krashen's (1994) controversial distinction between language acquisition and language learning. He proposed that language acquisition is a subconscious, incidental process that results in implicit (acquired) linguistic knowledge. By contrast, language learning is a conscious process of knowing about a language, resulting in explicit (learned) linguistic knowledge. Crucially, Krashen claimed that there is no interface between the acquired and the learned knowledge. He postulated that L2 learners mainly rely on their acquired knowledge in L2 learning and production, while the learned knowledge only serves as a monitor for possible mistakes in learners' language output. For these reasons, Krashen suggested that L2 teaching should focus on fostering conditions that facilitate language acquisition instead of the explicit instruction of grammatical rules.

Krashen's controversial proposals were one of the reasons for the surge in implicit language learning research. The existing literature has provided a considerable amount of evidence that has supported the possibility of implicit learning of different novel linguistic features such as word order (Grey et al., 2014; Rebuschat & Williams, 2009, 2012), inflectional morphology (Rogers et al., 2016), derivational morphology (Ishikawa, 2019), novel stress patterns (Chan & Leung, 2014, 2018), and tonal phonotactics (Chan & Leung, 2020). Despite this surge, there have been aspects of implicit language learning that have received less attention.

First, a great deal of research done on implicit learning, particularly in and the pioneering studies (e.g., Reber, 1967; Reber & Allen, 1978), focused on form–form connections. However, at the core of a language system lies meaning, so it is imperative to determine if semantic-based regularities may be amenable to implicit learning (Leung &

Williams, 2011). It is only after Williams' (2005) study that semantic implicit learning, a term first used by Paciorek and Williams (2015c), began to receive more attention in the literature. It has been shown that verb meanings, particularly verb collocates, can be learned without awareness (Paciorek & Williams, 2015a, 2015b). In terms of form–meaning connections, studies have revealed that the mappings between novel articles and animacy (Batterink et al., 2014; Chen et al., 2011; Leung & Williams, 2012, 2014; Williams, 2005), thematic roles (Leung & Williams, 2011), and metaphorical meaning (Li et al., 2013) can all be learned at the implicit level. It has also been demonstrated that the mappings between novel suffixes and tense and plurality are amenable to implicit learning (Marsden et al., 2013). Our study aimed to extend the scope of the study of semantic implicit learning by looking at a type of form–meaning connections that has not been reported in the existing literature.

Second, relatively few studies have investigated constraints in implicit language learning, especially in bilinguals. It has been demonstrated that some semantic-based regularities are more amenable to implicit learning than are others, potentially attributable to learners' existing linguistic knowledge (Leung & Williams, 2012, 2014). For instance, Leung and Williams (2014) examined whether differences in the linguistic encoding of semantic distinctions in L1 would result in differential implicit learning outcomes. They looked at two kinds of form–meaning connections: novel articles and animacy (a semantically salient concept that interacts with grammatical processes) in Experiment 1 and novel articles and long/flat distinctions (a semantic concept derived from the Chinese classifier system) in Experiment 3. Native Chinese speakers and native English speakers were recruited in both experiments. In written Chinese, the classifier *張* is generally used with flat objects (e.g., photos, blankets), while the classifier *條* is commonly used with long, thin objects (e.g., ties, straws). Critically, this kind of explicit grammatical encoding of long/flat objects does not exist in English. Leung and Williams's experiments involved four artificial articles: *gi*, *ro*, *ul*, and *ne*. Both groups were informed that *gi* and *ro* were used with near objects and *ul* and *ne* with far objects. The experiments, including the instructions, the main task, and the verbal reports, were entirely in English for the native English group and were entirely in Chinese for the native Chinese group. In Experiment 1, the participants were not informed that *gi* and *ul* went only with animate nouns, whereas *ro* and *ne* with inanimate nouns (e.g., *gi fox*, *ul frog*, *ro book*, *ne pen*). In each trial, the participants had to decide as quickly and accurately as possible (a) whether the noun denoted a living or a non-living thing and (b) whether the object was near or far. Learning of the target form–meaning connections was measured by an increase in reaction time when the hidden rules were violated (violation trials) compared to when the hidden rules were followed (control trials). Experiment 1 revealed that both the Chinese and the native English groups learned the mappings between novel articles and animacy. Despite the explicit animacy judgement on the nouns, a great majority of the participants remained unaware of the connections between the novel articles and animacy as assessed by post-experiment verbal reports. However, in Experiment 3, where the learning targets were the mappings between novel articles and long/flat distinctions (e.g., *gi shoelace*, *ul belt*, *ro tissue*, *ne banknote*) and participants had to judge whether the stimulus meant long or flat, the Chinese group showed implicit learning effects while the native English group did not, potentially attributable to the difference in their prior linguistic knowledge. This study showed that implicit learning is not totally unconstrained but may be influenced by the extent to which a target linguistic feature is encoded in learners' L1. Crosslinguistic influences have also been observed in the incidental learning of tonal phonotactic patterns. Specifically, Chan and Leung (2020) found that prior tone language experience facilitated the incidental learning of novel tone–segment connections. These findings suggested that the implicit learning mechanisms, despite being believed to be domain-general, does not simply involve unconstrained associative learning but may interact with learners' prior linguistic knowledge. Given the key role of implicit learning in L1 and L2 acquisition, the scope and constraints in implicit language learning deserves more research attention.

The studies that we discussed above have demonstrated crosslinguistic effects in implicit language learning. However, because Leung and Williams (2014) and Chan and Leung (2020) conducted their experiments in their participants' L1, it is unclear whether the crosslinguistic effects observed in their studies would still emerge even if the L1 was not currently being used. Fukuta and Yamashita (2021) recently explored the feasibility of implicit learning mechanisms in L2 learning. They examined whether Japanese learners of English were capable of learning form–meaning connections in the L2 at the implicit level. They introduced novel determiners to Japanese speakers: *jika*, *joka*, *roka*, *jiga*, *riga*, *joga*, *rika*. In these determiners, the sounds *j*– and *r*– are inflectional morphology for ±animate, –*i*– and –*o*– for ±actor, and –*ka* and –*ga* for ±singular. The participants were taught that –*ka* was for plural and –*ga* was for singular. The inflections for ±animate and ±actor were hidden rules. In a training phase, the participants were presented with a sentence (e.g., "bite *jiga* dog sofa in the house") and a photo. They were asked to judge whether the first noun in the stimulus referred to a singular or plural object. In the immediate and delayed test phase, the participants were shown a picture with two sentences (e.g., "Help *jika* elephant traveler in the river" and "Help *joka* elephant traveler in the river") and were asked to choose the grammatically correct sentence that described the photo. Their findings revealed that unaware learners had higher than chance accuracy for all conditions except ±animate, suggesting that Japanese learners of English were able to learn thematic roles and plurality at the implicit level but not animacy, which is a type of noun property.

Our study further explored the possibility of semantic implicit learning in the L2 by conducting the experimental task in our participants' L2 and by looking at a noun property that is explicitly marked in Chinese, namely, fire/water semantic distinctions. We predicted that

Cantonese–English bilinguals would exhibit crosslinguistic effects during semantic implicit learning even when the L1 becomes the noncurrent language as we have ample evidence showing that L1 remains highly activated and influential in L2 processing (e.g., Marian & Spivey, 2003; Marian et al., 2003).

Bilingual Language Activation

It has been well-established that bilinguals are unable to completely switch off their noncurrent languages during real-time lexical processing. For example, Thierry and Wu (2007) and Wu and Thierry (2010) used an implicit priming paradigm with concurrent electroencephalography recording to investigate whether L1 Chinese speakers who had begun learning English as a L2 at age 12 would implicitly access their L1 when exclusively reading in English. In this paradigm, they asked participants to judge whether English word pairs were semantically related or not. Participants were not informed that half of the English word pairs involved repetition of the first character in their Chinese translation (e.g., *train–ham 火车–火腿* and *post–main 邮政–邮件*) and the other half did not. Thierry and Wu (2007) found a significantly reduced N400 effect, which is typically attributed to stimulus repetition, when Chinese–English bilinguals heard or read English word pairs whose Chinese translation had repetition in the first character, while no such effect was obtained for word pairs that did not repeat characters. In Wu and Thierry's (2010) study, it was further revealed that it was the sound repetition (e.g., *experience–surprise* "*Jing* Yan–*Jing* Ya") and not the writing repetition (e.g., *accountant–conference* "*會計–會議*") that reduced the N400 response. These studies suggested that English words were automatically and unconsciously translated into Chinese even though the relevance of Chinese was not apparent in the task.

The above studies primarily focused on facilitative effects between two types of stimuli (e.g., prime with hidden translation vs. without hidden translation) based on bilinguals' existing linguistic knowledge. One aspect that has not yet been explored is whether the well-attested parallel activation of L1 and L2 also influences the development of new implicit linguistic knowledge. With this line of inquiry, we aimed to bridge the gap between the bilingual lexical processing and the implicit learning literatures and extend understanding of crosslinguistic influence/transfer in L2 acquisition. Overall, in our study, we aimed to explore the following research questions:

1. To what extent can the mappings between novel articles and fire/water semantic categories be learned at the implicit level?

2. To what extent does the constant activation of a noncurrent language in bilinguals influence the implicit learning of form–meaning connections in a novel language?

Method

Participants

We recruited 77 participants for this experiment: 40 were L1 Cantonese–L2 English speakers (M_{age} = 21.3 years, range = 17–26) while 37 were L1 English speakers (M_{age} = 21.0 years, range = 19–30 years). The background questionnaire administered before the experiment asked the L2 English participants to report the English proficiency level that they had attained in the language examination that they had taken to enter the university; 33 participants reported advanced English proficiency while 5 participants reported upper intermediate English proficiency. The L1 English participants had mostly been exchange students from the United States and the United Kingdom. None of the native English speakers reported any knowledge of Cantonese or other Chinese languages (see Appendix S1 in the Supporting Information online for the complete language background of participants).

Learning Targets

We adapted the learning targets in our study from Leung and Williams's (2011, 2012, 2014) studies. We introduced a miniature artificial article system (*gi*, *ro*, *ul*, *ne*) that encoded how near or far objects or actions were relative to the speaker. Specifically, *gi* and *ro* went with near objects or actions and *ul* and *ne* with far objects or actions. For instance, *gi shower* can be read as "the near shower," *ro lantern* as "the near lantern," *ul rain* as "the far rain," and *ne candle* as "the far candle." The use of these articles also depended on the semantic category of the noun or verb being modified. Specifically, *gi* and *ul* went only with water-related words (e.g., *gi ocean*, *ul tears*) and *ro* and *ne* only went with fire-related words (e.g., *ro candle*, *ne bomb*).

We chose fire- and water-related words because of the difference in how these semantic categories are linguistically encoded in written Chinese and English. In written Chinese, the majority of Chinese characters are phonosemantic compounds that consist of two components: (a) a semantic radical that indicates the semantic category (e.g., fish, birds, wood) of the character and (b) a phonetic radical which provides a phonological clue for the pronunciation of the character (Hollmann, 2017). For instance, the character 河 "river" consists of the semantic radical 氵 which denotes "water," whereas a fire-related character such as 炸 "bomb" has the semantic radical 火 which denotes "fire." The fire and water semantic categories are typically explicitly encoded in the semantic radical of written Chinese characters. In contrast, fire and water semantic categories are rarely explicitly encoded in English words except in compound nouns such as *waterfall* and *fireball*. Given Leung and Williams's (2014) findings that linguistic encoding of long/flat objects in L1 Chinese facilitated the implicit learning of articles-to-long/flat mappings for Chinese speakers, we predicted that in our study only Cantonese–English bilinguals would show implicit learning effects when the learning targets involved associations between novel articles and fire/water semantic categories due to the linguistic encoding of fire/water semantic categories in written Chinese.

Materials and Procedure

The entire experiment was in English with 74 water-related words and 74 fire-related words chosen based on the following criteria:

1. The written Chinese translation of all the English words included in the experimental stimuli must have the semantic radical for fire or water.

2. The English words must not be compound nouns with morphemes that denote either of the semantic categories (e.g. *waterfall, fireball*) to ensure that the participants could not rely on morphological cues to decide whether a stimulus was fire- or water-related.

3. Ambiguous words between the two semantic categories (e.g., *lava, oil*, or *deep-fry*) would not be included.

We used the British National Corpus (BNC Consortium, 2007) and the Corpus of Contemporary American English (Davies, 2008) to check for frequency counts per million words. The control and violation trials had words with a respective mean frequency count of 21.29 and 19.82 per million words in the British National Corpus and 23.16 and 19.54 per million words in the Corpus of Contemporary American English; for half of the participants, we switched the items in control and violation trials to make two experimental lists. We further accounted for the potential variability due to item frequency by adding items as a random variable to the statistical model. Due to the limited number of fire/water-related words that fulfilled our three criteria, we included some relatively low-frequency English words (i.e., < 1.0) in the experiment but assigned them to the training blocks (Blocks 1 and 2), practice trials, or buffer phases (see Appendix S2 in the Supporting Information online for a complete list of English words and their frequency counts). We included 148 words in the experiment.

We presented the experiment on a computer using E-prime 2.0 (Schneider et al., 2002). We presented the entire experiment in English: the background questionnaires, instructions, the main experimental task, and the post-experiment verbal reports. We first introduced the four novel articles (*gi*, *ro*, *ul*, and *ne*) to the participants. We informed them that these novel articles encoded the distance between an object or an action and the speaker. Specifically, *gi* and *ro* went with near objects or actions and *ul* and *ne* with far objects or actions. However, we did not tell the participants that the use of these novel articles also depended on the semantic category of the words, that is, that *gi* and *ul* were used with water-related words and *ro* and *ne* with fire-related words.

We adapted the structure of this experiment from Leung and Williams's (2014) study. Each trial started with a fixation cross (+) for 500 ms. This was followed by a visually presented stimulus consisting of an article plus a noun or a verb (e.g., *gi drizzle*). The participants first had to decide whether the noun/verb was related to fire or water by pressing the appropriate button. The phrase then disappeared and was replaced by the prompt “N/F,” which designated “near” and “far,” respectively. The participants then had to indicate whether the object or action was near or far. Figure 1 summarizes the event sequence in each trial. We instructed the participants to respond as quickly and accurately as possible. We recorded the accuracy and reaction time (RT) of their responses. The near/far buttons were vertically arranged while the fire/water buttons were horizontally arranged (see Figure 2 for a visualization). This was to minimize interference between the two judgment decisions (Leung & Williams, 2014).

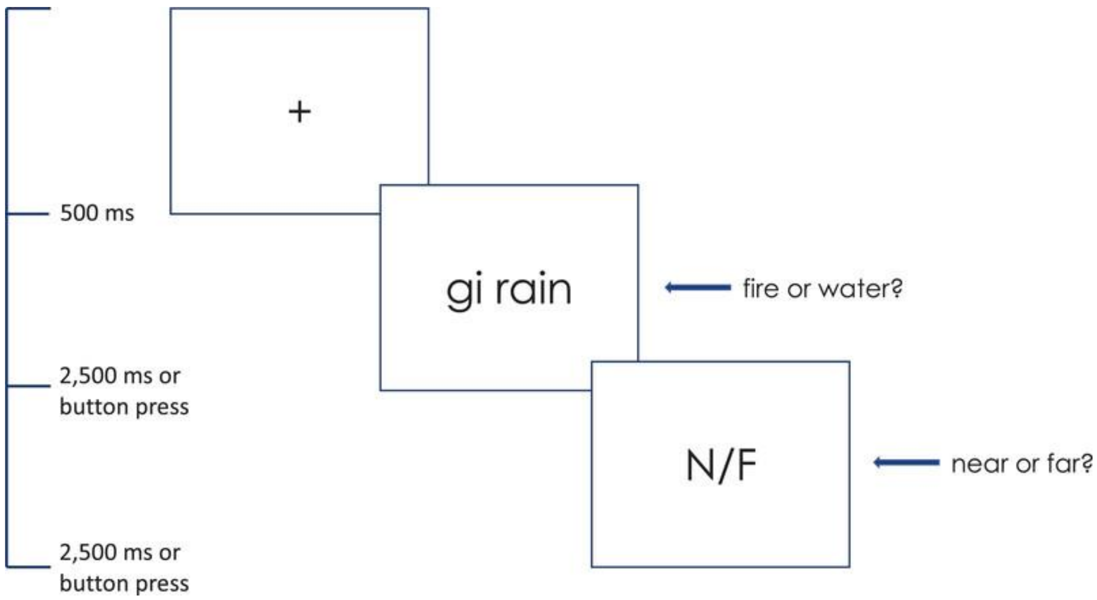

Figure 1: Sample trial showing the event sequence of the experiment.

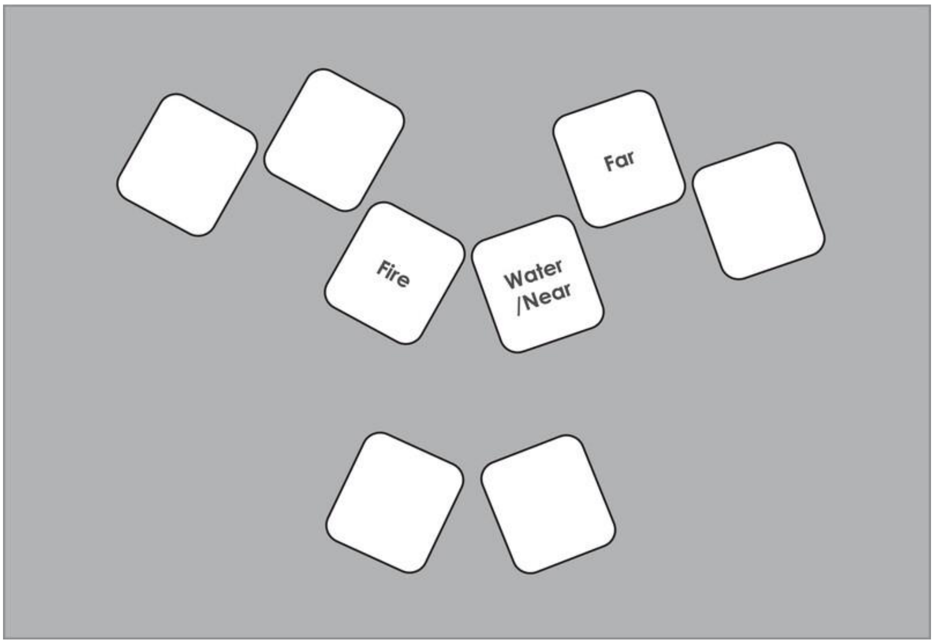

Figure 2: The configuration of response buttons on the millisecond-accurate response box (Cedrus RB-830).

The experiment consisted of four blocks comprising together 264 trials. Block 1 contained 84 trials that comprised 42 water- and 42 fire-related words paired with one of the two grammatically possible novel articles (e.g., *gi drizzle*, *ul flood*, *ro candle*, *ne lighter*). Block 2 also contained 84 trials with the same English words as in Block 1, but these English words were paired with a novel article of different grammatical distance. For example, if *gi ocean* appeared in Block 1, *ul ocean* appeared in Block 2. The first two blocks served as the training blocks for the participants. Block 3 involved 48 trials with new fire- and water-related words. There were two types of critical trials in this block: (a) 16 control trials with the correct mappings between the novel articles and fire/water semantic categories (e.g., *gi rain*, *ul shower*) and (b) 16 violation trials with the incorrect mappings between the novel articles and fire/water semantic categories (e.g., *gi stove*, *ul bomb*). We also added 16 filler trials with the correct mappings between the novel articles and fire/water semantic categories in this block. We did not include these filler trials in the statistical analyses as their only purpose was to make the distinction between control and violation trials less obvious to participants. Block 4 contained the same English words as in Block 3, but the words were paired with a novel article of different grammatical distance. For instance, if *ul sea* appeared in a control trial in Block 3, *gi sea* was used in a control trial in Block 4. Blocks 3 and 4 served as the testing blocks in the experiment. The addition of Block 4 was a departure from Leung and Williams's (2014) study, as we wished to expose the participants equally to all possible novel articles and fire/water mappings. Throughout Blocks 3 and 4, the differences among control, violation, and filler trials were not apparent to the participants. To control for potential item effects, we interchanged the English words in control and violation trials for half of the participants in each language group, for example, if *flood* and *ash* appeared in control trials for half of the participants, they appeared in violation trials for the other half. We pseudorandomized all trials. We provided a 30-second break between blocks. Since participants tend to slow down after a break, we provided eight buffer trials before Block 3 and before Block 4 as an adjustment period before the critical trials.

At the end of the experiment, we probed participants in English, asking them to report any knowledge of the connections between the semantic categories and the use of the articles. We then encouraged the participants who reported no awareness to make as many guesses as possible about what other variables might determine the use of the novel articles aside from grammatical distance. The questions used in the retrospective verbal reports are available in Appendix S3 in the Supporting Information online.

Data Analysis

Semantic Category Judgment

Because this experiment aimed to test the participants' ability to learn the mappings between the novel articles and fire/water semantic categories, data from their responses to the semantic category judgment were the focus of the analyses. We expected that, if the participants had learned the underlying mappings between the novel articles and the fire/water semantic categories, their RTs in the semantic judgment task should be significantly higher for violation trials than for control trials and their accuracy should be significantly lower for violation trials than for control trials. We used RT data as the primary measure of implicit learning effects in this study as time-pressured tasks using RTs with no direct focus on the target forms have been found to tap mostly implicit knowledge (Suzuki, 2017). We also analyzed accuracy data, and significantly lower accuracy in violation trials than control trials would indicate learning effects.

We conducted all analyses using the statistical application R (R Core Team, 2017). For the RT analysis, we excluded incorrect responses (4.50% of the data) as well as RTs faster than 200 ms (0% of the data) and slower than 2,000 ms (11.47% of the data; i.e., minimal trimming). We did further outlier trimming following Baayen and Millin's (2010) approach; we fit a simple mixed-effects model with only random effects and excluded all datapoints with residuals exceeding 2.5 standard deviations (9.73%). We then analyzed the model with accuracy rates and cleaned RTs using (generalized) linear mixed-effects modeling as implemented in the lme4 package (Bates et al., 2015). Models included trial (control trial vs. violation trial) and language group (bilingual vs. native English) and their interaction. We set control trial and bilingual group as baseline levels for the trial and language group independent variables, respectively. We included by-subject and by-item random slopes and intercepts as random effects. We have reported unstandardized beta estimates as estimated with the lme4 package (Bates et al., 2015), which is a measure of effect size (Lorah, 2018)[1].

To choose the best random effects structure, we progressively simplified the model following Barr et al.'s (2013) recommendations. We compared models using the anova() function (e.g., anova (model1, model2)). We further simplified the models if the less complex model had better goodness of fit. The final model had by-subject and by-item random intercepts and a by-subject random slope for trial. To test the significance of the Trial × Language Group interaction, we compared models with and without the interaction (Trial × Language Group vs. Trial + Language Group). We further dropped the fixed variable trial and compared it to the model with trial to test for a significant difference in RT and accuracy between control trials and violation trials. Finally, we compared models with and without the fixed variable language group to test for a significant difference in RT and accuracy between the two groups. We conducted all these comparisons using the anova() function. We used an alpha level of .05 to establish statistical significance. We also performed pairwise comparisons using the emmeans package in R to compute the Tukey HSD test to correct for multiple comparison[2]. This generated simple contrasts, comparing control and violation trials for each language group. The

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[1] The R code for conducting the initial maximal model for RT was: main_modelRT ← lmer(RT ~ Trial * LanguageGroup + (Trial*LanguageGroup|Subject) + (Trial*LanguageGroup Trial|Item), data = RTModel_Res, REML = F).

[2] The R code for conducting the pairwise comparisons was: (emmeans(main_modelRT, ~ Trial * LanguageGroup))

data and the scripts to reproduce the analyses and figures are available via IRIS (Cayado & Chan, 2022a) and through the Open Science Framework (https://osf.io/k7ry4)[3].

Classifying Aware and Unaware Participants

We classified the participants into "aware" and "unaware" groups before we conducted any analyses based on retrospective verbal reports. The majority of the participants from both language groups had no idea that there were hidden associations between the novel articles and fire/water semantic categories. Following the procedure reported in Leung and Williams's (2014) and Chan and Leung's (2018) studies, we classified the participants as unaware (a) when they reported no knowledge of the hidden rules even after being prompted to guess or (b) when they made guesses that did not overlap with the hidden rules (e.g., "the novel articles precede the nouns" and "the use of the articles depends on the parts of speech"). On the contrary, we classified those who reported complete or partial knowledge of the hidden rules as aware, and a total of 10 Cantonese–English bilinguals and seven native English speakers belonged to the aware category. Among the aware participants, six bilingual speakers and five native English speakers were able to fully verbalize the hidden rules. Three bilingual speakers and two native English speakers exhibited partial knowledge of the hidden rules (e.g., "*gi* was for water-related words, *ne* was for fire-related words," and "*ul* and *gi* were for water-related words"). One bilingual speaker mentioned the association between the articles and the semantic categories after being prompted to guess, but the rules stated by this participant were only partially accurate (e.g., "*gi* and *ro* were for water-related words"). We had also classified this participant as aware as this participant may have already developed partial low-confidence explicit knowledge of some aspect of the hidden rules. Although previous studies have shown that

[3] The raw E-prime files were accidentally wiped out during an institutional computer cleaning procedure. The datasets provided in Cayado and Chan (2022a) and through the OSF are the analysis-ready versions dating from before the data cleaning procedures described in the Data Analysis section of the manuscript.

possession of explicit knowledge might not necessarily have influenced the participants' judgement decisions during our experiment (Chan & Leung, 2018; Paciorek & Williams, 2015b), we removed from the subsequent statistical analyses the participants who had developed verbalizable knowledge of the hidden rules as we wanted to adopt strict criteria for unawareness. A summary is provided in Appendix S4 in the Supporting Information online for the classification of aware and unaware participants.

Results

Performance of the Unaware Participants

For the RT analysis for the fire/water judgement task, Table 1 shows that there was a substantial increase in RTs in the violation trials compared to the control trials for both language groups. A mixed-effects model revealed that there was no significant Trial × Language Group interaction, b = 19.76, SE = 24.10, 95% CI [−27.47, 66.99], t = 0.82, p = .414. We suspended judgement about the nonsignificant interaction effects in this and the other analyses in our study. The model revealed a significant main effect of trial, b = 62.95, SE = 18.80, 95% CI [26.10, 99.79], t = 3.35, $p < .001$, indicating that participants responded more slowly in violation trials than in control trials (see Figure 3). There was also a significant main effect of language group, b = 154.27, SE = 43.07, 95% CI [69.86, 238.68], t = 3.58, $p < .001$, with the native English group being generally slower than the bilingual group (see Figure 3). Post hoc comparisons of RT means for control trials and violation trials in each language group using the Tukey HSD test confirmed that means of the RTs in the violation trials were significantly higher than the means of the RTs in the control trials, thereby providing evidence that the unaware participants in both language groups had learned the mappings between novel articles and fire/water semantic categories, and the knowledge that they had developed might have been implicit (see Table 1).

Table 1: RT of the unaware bilingual group and the unaware native English group in the semantic category judgment task (=significant effect).*

RT							
	Control			Violation			
	Mean	SD	SE	Mean	SD	SE	Violation Effect
Native English (*N*=30)	1161	322.80	0.460	1251	338.38	0.523	90ms
Bilingual (*N*=30)	1035	322.98	0.398	1083	320.32	0.420	48ms
Accuracy							
	Control			Violation			
	Mean	SD	SE	Mean	SD	SE	Violation Effect
Native English (*N*=30)	97.80	0.146	0.000	95.30	0.211	0.000	-2.5
Bilingual (*N*=30)	96.45	0.184	0.000	92.39	0.265	0.000	-4.06

Table 2: Estimated β-coefficients and associated statistics for the mixed-effects models of the accuracy and RT data in the semantic category judgment task (=significant effect).*

	RT			
	β	*SE*	*t. ratio*	*p* value
(intercept)	1044.92	30.77	33.961	<.0000*
LanguageGroup * Trial	33.50	25.41	1.319	0.19296
LanguageGroup (Bilingual vs. English)	148.17	42.95	3.450	0.00104*
Trial (CT vs. VT)	58.65	19.41	3.021	0.00350*
	Post-hoc Comparisons for RT			
Bilingual Group: CT vs. VT	-58.6	19.7	-2.976	0.0198*
Native English Group: CT vs. VT	-92.2	21.0	-4.393	0.0002*
	Accuracy			
	β	*SE*	*z*	*p* value
(intercept)	4.4335	0.3979	11.144	<.00000*
LanguageGroup * Trial	-0.1684	0.4746	-0.355	0.72276
LanguageGroup (Bilingual vs. English)	0.7987	0.4929	1.620	0.10514
Trial (CT vs. VT)	-1.1713	0.3820	-3.066	0.00217*
	Post-hoc Comparisons for Accuracy			
Bilingual Group: CT vs. VT	1.171	0.382	3.066	0.0116*
Native English Group: CT vs. VT	1.340	0.482	2.781	0.0278*
Formula in R: ACC ~ Trial * LanguageGroup + (1+Trial|Subject) + (1|Item) RT ~ Trial * LanguageGroup + (1+Trial|Subject) + (1|Item)				

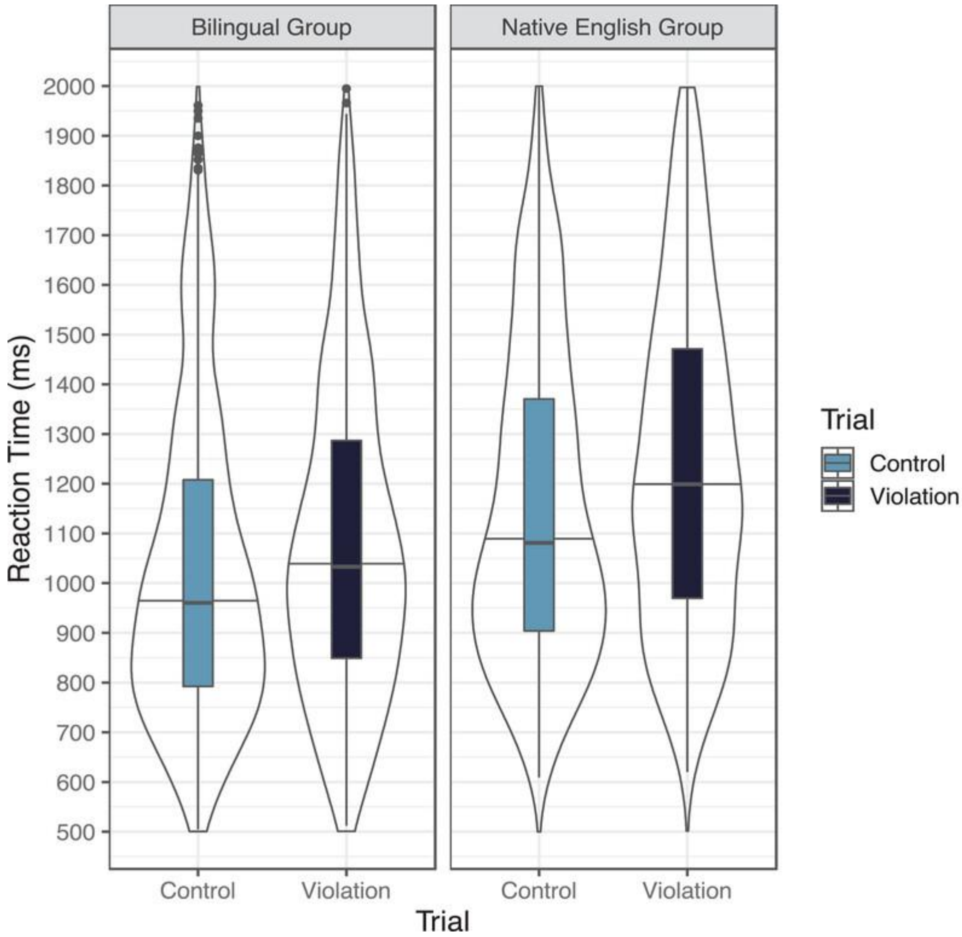

Figure 3: Reaction time of the unaware bilingual group and the unaware native English group in control and violation trials, with boxplots representing the 25–75% interquartile range. The horizontal line represents the median, the bottom and top whiskers represent the lowest and highest reaction time, respectively, and the violin plots show the data distribution.

For the near/far judgement task, there was no significant Language Group × Trial interaction, $b = -21.78$, $SE = 14.97$, 95% CI [−51.12, 7.56], $t = -1.46$, $p = .146$. There was also no significant effect of language group, $b = -14.18$, $SE = 32.22$, 95% CI [−77.33, 48.98], $t = -0.44$, $p = .427$, suggesting that the two groups did not differ in speed when responding to the distance rule. There was a significant effect of trial, $b = 37.41$, $SE = 11.53$, 95% CI [14.81, 60.01], $t = 3.24$, $p = .002$, with higher RTs in the violation trial condition than in the control trial condition. All the effect sizes (i.e., *b*) reported for fire/water semantic distinction RTs were very small (see Cohen, 1988, pp. 79−81, for effect size interpretation criteria). The total model's explanatory power was substantial: Conditional R^2 was .36, corresponding to a large effect. The part of the variance related to the fixed effects alone (marginal R^2) was .07, a medium effect.

For the accuracy analysis of the fire/water judgement task, Table 3 shows that there was a slight decrease in accuracy in violation trials compared to control trials in both language groups. A mixed-effects model revealed no significant Trial × Language Group interaction, $b = -0.17$, $SE = 0.50$, 95% CI [-1.09, 0.76], $z = -0.36$, $p = .720$. There was a significant main effect of language group, $b = 0.80$, $SE = 0.49$, 95% CI [-0.16, 1.76], $z = 1.62$, $p = .037$, with the native English group showing general higher accuracy. The model revealed a significant main effect of trial, $b = -1.17$, $SE = 0.38$, 95% CI [-1.91, -0.42], $z = -3.07$, $p < .001$, with lower accuracy found in violation trials than in control trials. Post hoc comparisons of accuracy means in control trials and violation trials in each language group using the Tukey HSD test (see Table 2) showed that accuracy in violation trials was significantly lower than in control trials in both language groups, suggesting that both language groups had learned the mappings between novel articles and fire/water semantic categories. All effect sizes reported for accuracy were very small (see Cohen, 1988, pp. 79−81, for effect size interpretation criteria). The total model's explanatory power was substantial: Conditional R^2 was .47, corresponding to a large effect. The part of the variance related to the fixed effects alone (marginal R^2) was .08, a medium effect.

Table 3: Accuracy of the unaware bilingual group and the unaware native English group in the semantic judgment task: Fire/water accuracy

	Control trials		Violation trials		
Group	*M*	*SD*	*M*	*SD*	Violation effect
Native English (*n* = 30)	97.80	14.65	95.30	21.16	−2.50
Bilingual (*n* = 30)	96.45	18.49	92.39	26.52	−4.06

Discussion

In our study, we asked two questions. To answer the first question, we investigated the extent to which the associations between novel articles and fire/water semantic categories can be learned through implicit learning; to answer the second question, we explored the extent to which the activation of bilinguals' noncurrent L1 influences learning of novel form–meaning connections at the implicit level. Our findings suggested that, under implicit learning conditions, both the bilingual and the native English groups learned the mappings between the novel articles and fire/water distinctions after only short and limited exposure. The unaware participants were unable to verbalize relevant knowledge of the target novel form–meaning connections, suggesting that the knowledge that they had developed was implicit. Since both language groups exhibited evidence of implicit learning of the target form–meaning connections, our findings were not totally conclusive as to whether or not the activation of bilinguals' noncurrent L1 had played a role in semantic implicit learning.

Semantic Implicit Learning in the L2

Our study advances understanding of the scope of semantic implicit learning. The implicit learning of form–meaning connections has been relatively less studied than have been form–

form connections such as the regularity of strings in artificial grammar learning (Reber, 1967; Reber & Allen, 1978). Since meaning is at the core of language, researchers' understanding of the scope of implicit language learning will not be complete without looking at different semantic-based regularities. Previous studies have provided evidence of implicit learning of semantic-based regularities such as the mappings between novel articles and animacy (Batterink et al., 2014; Chen et al., 2011; Leung & Williams, 2012, 2014; Williams, 2009), thematic roles like agent and patient (Leung & Williams, 2011), and metaphorical meanings (Li et al., 2013), as well as mappings between novel suffixes and tense and plurality (Marsden et al., 2013). Collocations of novel verbs (increase vs. decrease) and English nouns (abstract vs. concrete) have also been found to be amenable to implicit learning (Paciorek & Williams, 2015a, 2015b). However, previous studies have also demonstrated that implicit learning is not totally unconstrained. In fact, linguistic relevance and prior linguistic knowledge play a crucial role in facilitating and constraining implicit learning. Particularly, Leung and Williams (2012) and Chen et al. (2011) did not find implicit learning of novel article–relative size mappings as relative size is a linguistically arbitrary learning target, but they found evidence of implicit learning of novel article–animacy mappings, a linguistically relevant mapping. Moreover, Leung and Williams (2014) demonstrated that only Chinese speakers showed implicit learning effects of the mappings between novel articles and long/flat distinctions because they had explicit marking for long and flat in their L1, while native English speakers did not show such implicit learning because they do not mark such distinctions. Our findings provide evidence that the mappings between novel articles and fire/water semantic categories are also amenable to implicit learning, which is a type of form–meaning connection that has not been investigated in the previous literature, thereby extending the range of semantic-based regularities that can be learned implicitly. Most importantly, to the best of our knowledge, our study may be the first to show that semantic implicit learning of a noun property like the fire/water semantic distinction is feasible in the L2, despite L2 words typically having weaker semantic activation than do L1 words, for example, as shown by reduced semantic priming (Perea et al., 2008; Silverberg & Samuel, 2004; Zhang et al., 2020), which extends the implications of our findings to L2 acquisition. Our findings are in contrast with those of Fukuta and Yamashita (2021), who did not show evidence of semantic implicit learning of animacy in the L2, a type of noun property.

We originally predicted that Cantonese–English bilinguals would outperform native English speakers in learning the mappings between novel articles and fire/water semantic categories owing to the difference in linguistic marking of the fire/water semantic categories. Specifically, fire/water semantic categories are explicitly encoded in the semantic radical of phonosemantic compounds in written Chinese, while English only employs occasional explicit marking for fire and water semantic categories in the form of compound nouns (e.g., fireball, waterfalls). Contrary to the findings of Leung and Williams (2014), we found that both the native English and the bilingual groups showed evidence of implicit learning of the target form–meaning connections, suggesting that this mechanism may allow learning associations involving a distinction that may be unmarked in the speakers' L1. Our findings provide no conclusive evidence for our original prediction. Two possible variables might have been in play. First, English has compound nouns that mark fire and water semantic categories (e.g., waterfall, watershed, and fireball, firewood). Although we excluded compound nouns like these from our experiment, native English speakers' occasional exposure to these markings might have helped them detect novel articles that mark fire and water semantic categories. This raises the question of how the level of salience of semantic markings might affect implicit learning and of whether controlling for salience (i.e., making the fire/water judgement less explicit) might lead to differences between native English and Cantonese speakers. Second, we presented the entire experiment in English—the background questionnaire, instructions, main experimental task, and post-experiment verbal reports. This could have given the native English group an advantage as they were generally more proficient in English than was the bilingual group. The combination of occasional compound nouns that mark fire and water in English and the fact that the entire experiment was done in the English group's dominant language could have given them the advantage for learning the target form–meaning connections.

We could also argue that the lack of L1 effects in our experiment may be due to the fact that the semantic distinction for fire and water is a written language phenomenon. In other words, it could be the case that the possible L1 effects were hampered by the fact that the spoken noncurrent language, Cantonese, does not distinguish between fire and water. However, if this were the case, then Leung and Williams (2014), who also recruited Cantonese and Mandarin speakers, should not have obtained evidence of crosslinguistic influence in implicit learning, as long and flat distinctions are also purely written semantic markings in Chinese. Their findings suggested that these semantic markings in the written Chinese language could influence language learning, despite not being present in the spoken language.

Whether L1 semantic activation does or does not influence L2 semantic implicit learning needs further investigation; however, some aspects of our results may be used to address the question. The bilingual group responded generally faster than the native English speaker group during fire/water semantic judgement task, despite the task being in the bilingual group's L2. These findings are highly counterintuitive since L2 RTs are nearly always slower than L1 RTs. One possible explanation is the marking of fire/water semantic distinctions in Chinese and English. Specifically, it might have been easier for the bilingual group to identify whether a word was fire- or water-related since these were highly activated cognitive categories for them due to the existence of fire/water semantic radicals in written Chinese but not in English. Similar to Thierry and Wu's (2007) study, the English words in our experiment could be co-activating the forms of their L1 translations, and the semantic radical could have unconsciously facilitated the response of Cantonese–English bilinguals. An alternative explanation might be that there could just be a speed difference between the groups. However, in the near/far decision task that was not related to semantic markings, no such significant RT difference between the bilingual and the native English groups emerged, thereby supporting our hypothesis that the general RT difference between the two groups in fire/water semantic judgement task might have been due to fire/water semantic radicals in written Chinese. These findings suggest that some level of L1 transfer took place for the bilingual group in the experiment, which then raises an interesting question as to why this L1 transfer influenced the general speed of the bilingual group's reactions but not their implicit learning of the mappings between novel articles and fire/water semantic categories. One possibility could be that the effects of positive L1 transfer due to fire/water semantic markings in written Chinese might not have reached their full potential because semantic activation can be weaker in the L2, as previous studies have shown (Perea et al., 2008; Silverberg & Samuel, 2004; Zhang et al., 2020). In contrast, it is also possible that these findings are just a product of accuracy/RT trade off. The native English group was significantly more accurate than the Cantonese–English bilingual group. It seems that the native English group was more careful than was the bilingual group during the task, which then resulted in significantly slower response times for the native English group. We leave these questions and possibilities to future studies to explore.

Measure of (Un)awareness

Our study employed retrospective verbal reports to assess the participants' (un)awareness of the target form–meaning connections. However, this awareness measure is not without limitations. Specifically, there could have been a mismatch in the knowledge that the participants employed during the learning process and the knowledge that they reported after the experiment, and the participants may also have withheld potential explicit knowledge due to low confidence levels (Chan & Leung, 2018; Leow & Hama, 2013; Rebuschat, 2013). It should be noted that the participants were unaware of the distinction between control and violation trials in the experiment and that we had instructed them to respond as quickly and accurately as possible so as to minimize the involvement of explicit learning strategies (Paciorek & Williams, 2015c). Hence, it can be argued that learning effects based on RT differences between control and violation trials and speeded response might have tapped more into the participants' implicit knowledge. Moreover, the fact that we asked the participants not only to report any relevant knowledge but also encouraged them to make guesses about the hidden rules added a level of sensitivity to low-confidence knowledge that the participants may have developed (Leung & Williams, 2014). Previous studies have shown that possession of explicit knowledge does not necessarily influence participants' judgment decisions during an experiment (Chan & Leung, 2018; Paciorek & Williams, 2015b), but we removed from the analyses any of our participants who had already developed explicit knowledge of the hidden rules because we wanted to apply strict criteria for unawareness. Overall, we can argue that the combination of (a) control–violation trials, (b) RTs as the main measure of learning, (c) speeded responses, and (d) verbal reports with the participants' having the option to guess the hidden rules was still relatively sensitive enough to allow us to assess the implicitness of the knowledge that the participants had gained and was effective in promoting implicit learning (Leung & Williams, 2014).

Limitations and Future Directions

One of the limitations of our study that must be acknowledged is the post hoc exclusion of aware participants. Recent studies have shown that such a post hoc exclusion method of aware participants may lead to regression to the mean, which has become a prevalent problem in consciousness research (Shanks, 2017; Shanks et al., 2021). Skora et al. (2020) have also demonstrated that, if only a small number of aware participants are excluded, then the inflation of unconscious effects will also be small. We classified 22% of our participants as having conscious knowledge, while we classified 78% of them as having unconscious knowledge. Although a great majority of our participants were deemed unaware of the knowledge they had developed, it is possible that there was conscious knowledge contamination in what we classified as unconscious data. It is imperative for future studies to account for this conscious knowledge contamination as suggested by Skora et al. (2020). Moreover, a trial-by-trial design might also be used in future studies in order to have a more fine-grained assessment of conscious and unconscious knowledge. This would allow for a more sensitive exclusion of conscious trials and participants while avoiding regression to the mean. Another limitation of our study was the suspended judgement about the lack of significant Language Group × Trial interaction. Future studies will need to account for the Bayes factor so that they can fully reject the null hypothesis that one group did not perform better than the other in the implicit learning task.

Aside from the above-mentioned limitations that need to be addressed in future studies, there are numerous ways in which implicit learning studies can be extended. First, semantic implicit learning is relatively less studied than are other linguistic features in implicit learning. It is, therefore, of prime importance for future studies to explore other types of semantic-based regularities that may or may not be learned at the implicit level and to determine what variables may constrain or facilitate this learning mechanism. This endeavor will allow researchers to test the full extent of semantic implicit learning. Second, implicit learning in the L2 remains understudied. To the best of our knowledge, the only L2 semantic implicit learning studies so far have been our study and that of Fukuta and Yamashita (2021). Looking at L2 semantic implicit learning will inform how feasible this learning mechanism is for L2 learners and should, therefore, be given attention in future studies.

Conclusion

The objective of our study was twofold: First, we wanted to examine the extent to which the mappings between novel articles and fire/water distinctions might be learned implicitly; second, we aimed to explore the extent to which the activation of bilinguals' L1 Cantonese could influence semantic implicit learning. Although the second aim still remains an open question, our study provided evidence that the mapping between novel articles and fire/water semantic categories is amenable to implicit learning, thereby extending understanding of the range of semantic-based regularities that can be learned implicitly. Moreover, our findings also showed that semantic implicit learning is possible in the L2, albeit with relatively small effects compared to previously attested semantic implicit learning effects (e.g., Leung & Williams, 2011, 2014). We call for further research that examines the scope of semantic implicit learning as well as the constraints and biases that may hamper or facilitate this learning mechanism.

Open Research Badges

This article has earned Open Data and Open Materials badges. Data and materials are available at http://www.iris-database.org and https://osf.io/k7ry4/

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Appendix S1: Participants' Language Background

Cantonese-English Bilinguals		Native English Speakers	
French	Beginner	Assamese	Advanced
German	Beginner	Bengali	Advanced
Hakka	Beginner	Czech	Advanced
Italian	Beginner	French	Beginner-intermediate
Japanese	Beginner-intermediate	German	Beginner-intermediate
Mandarin	Beginner-advanced	Greek	Beginner
Spanish	Beginner	Hindi	Intermediate-advanced
Swedish	Beginner	Indonesian	Advanced
Tagalog	Beginner	Portuguese	Advanced
Urdu	Beginner	Russian	Intermediate-advanced
English	Advanced-upper intermediate	Spanish	Beginner-intermediate
		Tagalog	Advanced
		Urdu	Intermediate
		Yoruba	Advanced

Appendix S2: List of Stimuli

B1 = Block 1, B2 = Block 2, B3 = Block 3, B4 = Block 4, CT = Control Trial, VT = Violation Trial

Stimuli	Frequency per Million (BNC)	Frequency per Million (COCA)	Trial Type
moist	5.37	5.48	Practice
teardrop	0.47	0.42	Practice
tide	16.92	12.16	Practice
sprinkler	0.91	1.03	Practice
bazooka	0.12	0.35	Practice
blast	11.05	14.51	Practice
fiery	4.54	4.81	Practice
tobacco	14.53	19.17	Practice
dynamite	1.23	2.76	B1/B2
dye	4.29	3.86	B1/B2
creek	2.67	24.96	B1/B2
flow	51.36	40.61	B1/B2
droplet	0.37	0.47	B1/B2
moisturize	0.07	0.3	B1/B2
harbour	19.56	17.38	B1/B2
swirl	1.3	2.52	B1/B2
humidity	2.85	4.44	B1/B2
rinse	3.33	3.97	B1/B2
cove	2.57	3.26	B1/B2
overflow	3.95	1.93	B1/B2
pond	16.89	11.03	B1/B2
irrigate	0.25	0.47	B1/B2
reservoir	7.5	5.12	B1/B2

coast	45.5	52.36	B1/B2
gulf	31.87	34.59	B1/B2
paint	34.1	37.83	B1/B2
bathtub	0.26	3.7	B1/B2
perspire	0.08	0.16	B1/B2
rapids	1.15	3.68	B1/B2
seafarer	0.16	0.06	B1/B2
sewage	7.64	4.58	B1/B2
shore	17.37	21.25	B1/B2
bay	33.08	57.77	B1/B2
splatter	0.31	0.62	B1/B2
marine	20.97	28.2	B1/B2
submarine	4.99	4.08	B1/B2
beer	31.33	44.1	B1/B2
liquid	24.31	20.65	B1/B2
ripples	1.8	1.96	B1/B2
ditch	6.27	6.33	B1/B2
gargle	0.18	0.22	B1/B2
bubble	5.27	14.14	B1/B2
torrent	2.49	2.17	B1/B2
drench	0.14	0.15	B1/B2
shoal	2.16	0.47	B1/B2
ashtray	2.01	1.49	B1/B2
cannon	6.28	6.85	B1/B2
toaster	0.69	1.74	B1/B2
explode	3.49	6.45	B1/B2
cigarette	20.4	19.47	B1/B2
sizzle	0.39	1.04	B1/B2
flintstone	0.17	0.37	B1/B2
tinder	0.51	0.78	B1/B2

fumes	5.63	2.87	B1/B2
beacon	3.05	4.39	B1/B2
welding	1.96	1.5	B1/B2
smolder	0	0.21	B1/B2
rocket	5.97	14.78	B1/B2
scald	0.22	0.2	B1/B2
detonate	0.41	1.16	B1/B2
volcano	3.78	5.04	B1/B2
extinguisher	0.41	0.66	B1/B2
broil	0.02	0.93	B1/B2
combust	0.05	0.16	B1/B2
carbon	24.33	29.76	B1/B2
incinerate	0.12	0.24	B1/B2
stir-fry	0.1	1.08	B1/B2
simmer	2.44	5.67	B1/B2
sauté	0.2	3.27	B1/B2
stew	3.25	4.72	B1/B2
braise	0.01	0.16	B1/B2
scorch	0.54	0.46	B1/B2
sear	0.4	0.61	B1/B2
ignite	0.82	1.99	B1/B2
kindle	0.3	5.82	B1/B2
ablaze	1.6	1.03	B1/B2
artillery	7.2	5.86	B1/B2
flint	5.06	3.89	B1/B2
cinder	0.4	0.99	B1/B2
furnace	2.81	3.2	B1/B2
wick	1.82	1.1	B1/B2
soot	1.83	1.5	B1/B2
chargrill	0.01	0	B1/B2

brazier	0.95	0.24	B1/B2
fry	11.2	6.4	B1/B2
toast	10.71	11.37	B1/B2
grill	4.75	12.35	B1/B2
canal	20.66	9.93	B1/B2
vapor	4.78	3.85	B1/B2
juice	16	26.57	B1/B2
sea	124.8	80.69	B1/B2
swamp	2.99	5.96	B3/B4 (CT)
dive	6.23	9.51	B3/B4 (CT)
river	91.03	90.14	B3/B4 (CT)
tears	39.1	36.5	B3/B4 (CT)
barbecue	3.42	6.77	B3/B4 (CT)
lantern	2.48	3.22	B3/B4 (CT)
spark	5.58	8.64	B3/B4 (CT)
torch	8.35	4.96	B3/B4 (CT)
wash	23.97	24.57	B3/B4 (CT)
flood	14.59	18.05	B3/B4 (CT)
swim	13.74	15.33	B3/B4 (CT)
burn	16.76	28.75	B3/B4 (CT)
bomb	28.84	32.7	B3/B4 (CT)
explosive	7.91	9.86	B3/B4 (CT)
smoke	37.89	43.98	B3/B4 (CT)
wet	37.79	31.64	B3/B4 (CT)
sweat	12.33	19.63	B3/B4 (VT)
wave	33.88	38.13	B3/B4 (VT)
saliva	2.32	2.42	B3/B4 (VT)
downpour	1.2	0.93	B3/B4 (VT)
damp	18.73	7.87	B3/B4 (VT)
lighter	10.67	11.77	B3/B4 (VT)

bake	4.89	12.87	B3/B4 (VT)
ocean	19.81	41.67	B3/B4 (VT)
lake	38.52	63.23	B3/B4 (VT)
roast	5.1	7.6	B3/B4 (VT)
candle	7.64	7.01	B3/B4 (VT)
match	91.12	50.71	B3/B4 (VT)
lamp	12.42	9.17	B3/B4 (VT)
shower	15.02	22.08	B3/B4 (VT)
bath	37.29	14.68	B3/B4 (VT)
chimney	6.31	2.91	B3/B4 (VT)
erupt	1.21	1.67	Buffer
alcohol	29.72	36.94	Buffer
drip	2.81	3.49	Buffer
splash	5.19	5.62	Buffer
soup	12.71	19.45	Buffer
steam	28	14.59	Buffer
coal	50.28	21.11	Buffer
flare	2.98	3.28	Buffer
tsunami	0.87	4.83	Filler
whirlpool	1.12	1.24	Filler
lagoon	1.96	2.36	Filler
pool	44.29	42.79	Filler
flame	10.06	9.73	Filler
blaze	7.13	4.29	Filler
burner	1.35	3.11	Filler
cremate	1.37	0.75	Filler
soak	3.5	4.48	Filler
drown	3.55	4.62	Filler
thirsty	2.68	4.32	Filler
ash	12.25	9.79	Filler

stove	5.8	9.28	Filler
charcoal	4.93	4.11	Filler
oven	13.08	20.33	Filler
beach	36.83	65.02	Filler

Note. The stimuli in control and violation trials in Blocks 3 and 4 were rearranged to create four versions of the experiment to control for item effects.

Appendix S3: Questions in Retrospective Verbal Reports

Verbal Report Questions
1. What do you think the experiment is about?
2. Did you notice any patterns in the experiment?
3. At what point did you start noticing the patterns?
4. Did you actively look for patterns during the experiment?
5. There are hidden rules about the categorization of fire- and water-related words in the experiment. Do you have any guesses about what the hidden rules are? You may provide as many guesses as possible.

Appendix S4: Classification of Aware and Unaware Participants

Verbal Reports	***N***	**Example**
Classified as aware		
Verbalized all the hidden rules	11	*Gi* and *ul* are for water-related words, while *ro* and *ne* are for fire-related words;
Reported partial knowledge of the hidden rules	5	*Gi* was used with water-related words and *ne* was used for fire.
Associated the novel articles with semantic categories but the rules explained were not fully accurate	1	*Gi* and *ro* were for fire-related words while *ul* and *ne* were for water-related words.
Classified as unaware		
Made no guess or made guess but did not overlap with the hidden rules.	60	The novel articles always precede the nouns; The use of novel articles depends on the parts of speech; Fire should be far and water should be near.