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Feature-focusing constraints on implicit learning of function word and meaning associations

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Abstract
Recent research has begun to investigate implicit learning at the level of meaning. The general consensus is that implicitly linking a word with a meaning is constrained by existing linguistic knowledge. However, another factor to consider is the extent to which attention is drawn to the relevant meanings in implicit learning paradigms. We manipulated the presence of cue saliency during implicit rule learning for a grammatical form (i.e., articles) linked to meaning (i.e., animacy vs. varying notions of size). In a series of experiments, participants learned four novel words but did not know that article usage also depended on a hidden rule, creating an opportunity for implicit rule learning. We found implicit learning through the use of a highly salient meaning (Experiment 1) or if image size was made salient by being explicitly cued (Experiment 3), but not in a low salient paradigm for intrinsic object size (Experiment 2). The findings suggest that implicit learning of semantic information might not be as constrained as previously argued. Instead, implicit learning might be additionally influenced by feature-focusing cues that make the meaning contrasts more salient and thereby more readily available to learning.

Keywords: attentional cues; cue saliency; form–meaning connections; implicit learning; semantic association

Humans have a remarkable ability to acquire regularities in language implicitly, that is, without intent and without awareness to learn. The implicit learning of content words such as nouns and verbs has been the focus of considerable research attention yielding insight into the mechanisms supporting the learning of both phonological and semantic aspects of such words. An important finding arising from this work is that implicit content word learning is facilitated in the co-presence of attention-focusing constraints such as pointing and looking at an object (Akhtar & Gernsbacher, 2007; Tomasello, 2000). Arguably, such constraints are necessary given the cognitive overload that would be imposed if learners had to process all aspects of their complex, multisensory environment.

The challenge in understanding how form–meaning associations are established may be even greater for another word class, namely, function words such as the English articles *the* and *a*, and the preposition *of*. Function words carry little lexical or concrete meaning, which makes it impossible to use strategies such as pointing to the "the." Bloom (2000) has suggested that the learning of such words occurs through implicit rule abstraction over multiple cross-situational learning opportunities. Findings have been mixed, however, with some studies reporting evidence of implicit learning for function words (e.g., Leung & Williams, 2012, Experiment 1; Williams, 2005), while others did not find learning (e.g., Faretta-Stutenberg & Morgan-Short, 2011; Hama & Leow, 2010; Leung & Williams, 2012, Experiment 2). It has been suggested that these contradictory findings could be accounted for by the learner's existing language knowledge and, in particular, the extent to which the to-be-learned concepts are grammaticalized in that language. Beyond the influence of extant knowledge, however, implicit learning of functor–meaning associations may be expected to be influenced by constraints similar to those found for content word–meaning associations. Based on this prediction, the present study examined how implicit learning in less salient conceptual distinctions, especially ones that require additional computation, would especially benefit from additional cues to highlight their meaning compared to concepts that are more readily available to implicit learning.

Background

It is important to first understand how meanings of words are typically learned. Children, and humans in general, have a remarkable ability to successfully learn the meanings of words quite rapidly and accurately. Word learning is particularly impressive given that it is typically accomplished in ambiguous contexts. Consider Quine's (1960) classic example: If a native speaker utters the foreign word "gavagai" and points to a rabbit, what is the reference of this word? Does the word mean "rabbit," "undetached rabbit parts," "white," or "grass"? Herein lies the referential ambiguity problem language learners encounter when learning the meanings of words.

Language learners have effective strategies for resolving this referential uncertainty during word learning. Learners can map a word to its referent in as little as a single exposure, a process known as *fast mapping*. Fast mapping is supported by various social constraints that facilitate referent selection (e.g., Tomasello, 2000). For instance, pointing and looking at an object being labeled helps children learn that the meaning is associated with that specific object (e.g., joint attention; for a review, see Akhtar & Gernsbacher, 2007). Similarly, children can use mental states, such as goals, intentions, and knowledge, to learn that the new word referred to the object intentionally labeled or that a novel verb referred to the goal-orientated action, and not an accidental one (Baldwin, 1991; Tomasello & Barton, 1994). Other proposed constraints on word learning include linguistic constraints (Gleitman, 1990), the shape bias (Landau, Smith, & Jones, 1988), the principle of contrast (Clark, 1993), and the whole object bias and mutual exclusivity assumption (Markman, 1990).

In contrast to fast mapping, some words may be learned through *cross-situational learning*, that is, the learning of a word through repetition across contexts (Yu & Smith, 2007). Although an individual instance of word–referent pairing would be

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ambiguous, learners could form a probabilistic association between words and potential referents across trials. This type of learning relies on tracking statistical information, an ability demonstrated for several aspects of language and most notably for word segmentation in infants (Saffran, Aslin, & Newport, 1996) and adults (Saffran, Newport, & Aslin, 1996). In a single trial, for example, a learner might hear a novel word "modi" in the ambiguous context of seeing objects X and Y and as a result would not know to which object the word refers. If the learner then hears "modi" again while seeing objects X and Z, the learner would start to learn a probabilistic meaning. With more experience, the learner would eventually infer that the word "modi" maps to object X. In a series of experiments, Yu and colleagues provided empirical evidence showing that cross-situational learning supports word learning (Smith & Yu, 2008; Yu & Smith, 2007). Despite the learning context being ambiguous in a single trial, leaners were able to calculate statistics across trials to map words with their referent.

Of importance here, the cross-situational learning paradigm provides a framework for considering not only how content words but also how function words might be learned. In the absence of a clear referent, it has been suggested that functors such as articles are learned through rule abstraction over multiple instances (Bloom, 2000). Take, for example, the learning of novel articles with an unknown animacy distinction such that *ul* is used with inanimate objects, while *gi* is associated with animate objects. Initial individual trials would be ambiguous (e.g., *ul* car, *ul* house, *gi* fish, and *gi* girl). Over multiple trials, however, the probabilities of co-occurrence could support rule abstraction in learning the specific relationship between articles and respective animacy values.

Williams (2005) employed such a paradigm to examine grammatical form–meaning learning in healthy adults. Participants were asked to learn four novel words: *gi*, *ro*, *ul*, and *ne*. They were told that these articles functioned like the English article word "the" and were explicitly instructed (explicit rule) that these words encoded relative distance (*gi* and *ul* referred to nearby objects and *ro* and *ne* referred to objects far away). However, article usage also correlated with a hidden semantic feature not revealed to participants but available for implicit learning. This implicit rule was governed by animacy information, with *gi* and *ro* used with animate objects and *ul* and *ne* used with inanimate objects. Participants were trained on sentences such as "The little boy patted gi tiger in the zoo" over multiple trials. At test, participants were presented with new sentences that were incomplete (e.g., "The lady spent many hours sewing . . . ") and two noun phrases that were either items trained during the training phase or untrained (new) items. Through a two-alternative forced-choice task, they selected the noun phrase that best completed the sentence (e.g., *gi dress* vs. *ul dress*; correct answer: *ul dress*, because *ul* refers to a near, inanimate object). Results revealed significantly above-chance performance indicating learning of the implicit rule. In addition, participants claimed to be unaware of any hidden meanings. This study provided the first demonstration that article–meaning connections can be learned across trials without awareness of the hidden regularities, and has since been replicated (e.g., Leung & Williams, 2011; Rebuschat, Hamrick, Riestenberg, Sachs, & Ziegler, 2015).

To consolidate and extend Williams's (2005) novel findings, Leung and Williams (2012) employed a different methodology. Participants were to learn the same miniature artificial language, except that the article–noun phrases were presented on their own without a sentence (e.g., *gi tiger*) with two images. Isolating the noun phrase could also serve to avoid a potential confound with using familiar sentence frames to support learning. As before, participants were told explicitly about one rule governing the presented determiner phrase (explicit rule) but not a second rule, making it available for implicit learning (implicit rule). In Experiment 1, the explicit rule was the near/far distinction and the implicit rule was the inanimate/animate distinction, whereas in Experiment 2, the explicit rule was animacy while the implicit rule was relative size. Important to the current study is how the authors operationalized relative size. Relative size in Leung and Williams (2012) was based on a comparison between two objects that differed in their intrinsic size but appeared as the same size on the screen. For instance, a frog would be judged as large compared to a pen on one trial but small compared to a house on another trial, even though the two images were the same size on the screen.

The experiment proceeded as follows. During the training phase, participants were presented with a set of two pictures, heard a phrase about one of the items (e.g., *ro bull*), were asked to make a judgment based on the implicit rule (i.e., Experiment 1 involved an animacy judgment and Experiment 2, a relative size judgment), and then repeated and translated the phrase out loud (e.g., *ro bull*, *the far bull*). If they made an incorrect judgment, corrective feedback was provided, and the trial was repeated. The paradigm finished with grammatical items in the control block and grammatically incorrect items violating the implicit rule in the violation block. Slower responses in the violation block were considered indications of learning. Findings revealed significantly slower reaction times in the violation block in Experiment 1 but not 2 reflecting implicit learning of animacy but not of relative size information. The results were unchanged when analyses were confined to those who reported no awareness of the respective implicit rules. Similar patterns of implicit learning have also been replicated using tasks in which sentence context was unavailable to provide additional support (Batterink, Oudiette, Reber, & Paller, 2014; Chen et al., 2011; Leung & Williams, 2014)

As preliminary findings, Leung and Williams's (2012) observations of implicit learning for the concept of animacy but not relative size is interesting. The results appear to suggest that some concepts may be more readily available for implicit learning. However, it is important to remain cautious regarding the interpretation of implicit learning given the available cues inherent to Leung and Williams's (2012) picture choice paradigm. First, participants were asked to make an explicit judgment about the semantic concept that was supposed to be learned implicitly, and second, participants received corrective feedback if there was an error in their explicit judgment. Even the use of a picture size distinction to represent near/far—"near" was depicted by a large and centered image, while "far" was depicted by a smaller and left-justified image—makes it difficult to understand how this cue supported learning. In contrast, when there was no distinction in size or justification of the pictures to depict the relative size rule (i.e., images were the same size on the screen), implicit learning was not found. Hypothesizing that these explicit cues could have influenced learning by inadvertently drawing attention to or raising the awareness of the implicit rule in previous studies, we conducted the present study to systematically control for explicit cues in the paradigm. We removed the need for judgments and feedback as well as varied feature saliency (e.g., size information) in the current task to carefully assess implicit learning.

Further examination of implicit learning of form–meaning associations is also warranted given contradictory findings using paradigms similar to that of Williams and colleagues (Leung & Williams, 2012; Williams, 2005). Faretta-Stutenberg and Morgan-Short (2011) closely followed the paradigm used by Williams (2005), and yet did not observe implicit learning. Of note, their participant criteria were restricted to native English speakers and those who were not studying a language-related discipline. Hama and Leow's (2010) extension of the Williams (2005) study also failed to find evidence of implicit learning. However, significant methodological differences included using a four-alternative (compared to two-alternative) forced-choice test and a think-aloud protocol (compared to a postexperiment questionnaire) to assess awareness. The think-aloud task may have been a more sensitive measure of awareness but could also have impaired learning by imposing a cognitive load (Rebuschat et al., 2015). In using a similar paradigm, Rebuschat et al. (2015) reported evidence of implicit learning only for participants who were encouraged to think aloud during the training phase. Chen et al. (2011) also conceptually replicated implicit learning of linguistically relevant features while showing that such knowledge was unconscious using trial by trial subjective measures to assess awareness. A more recent large-scale study by Kerz, Wichmann, and Riedel (2017) was the first to demonstrate implicit learning of phonological cues in the form of suffixes as well as showing that such learning could occur outside laboratory settings by using crowdsourcing experiments. At minimum, these divergent findings suggest that further investigation of the factors influencing implicit learning of article–meaning associations is warranted.

One constraint on implicit learning of abstract article–meaning associations suggested by Leung and Williams (2012) is existing linguistic knowledge. Leung and Williams argued that article–meaning associations may be obtained if they interact in some way with the grammatical processes and representations present in a learner's existing linguistic knowledge. It would follow from this notion that language learners should have an easier time learning or noticing noun classification systems that are similar to their own language. For instance, across many languages, information about animacy interacts with grammatical processes, and hence is available for forming associations with grammatical morphemes. By contrast, it might be harder to learn relative size information because it is usually not encoded in a language (though note lexical distinctions such as *balle/ballon* for small and large ball in French, and *tea cup/mug* for small and large cup in English, respectively). Williams (2005) found a relationship between knowledge of gendered languages and implicit learning and Leung and Williams (2014) further advanced this conclusion by finding that English speakers were unable to learn a Chinese classifier signaling a contrast not marked in English. However, the relevance of experience with gendered languages was not evident in Faretta-Stutenberg and Morgan-Short (2011). Thus, careful consideration about linguistic factors that impact implicit learning is needed. The current work, however, explores an alternative explanation to address these mixed findings. We considered whether salient cues can serve as strong indicators of noun class membership for meaning contrasts that may not be encoded in the learner's language.

Drawing on lessons learned regarding object word–meaning associations (Akhtar & Gernsbacher, 2007; Tomasello, 2000), it seems likely that implicit learning of functor–meaning associations may be influenced by similar constraints needed to focus attention to certain features of a word (henceforth referred to as feature-focusing cues). Cues may be especially important for forming word representations given that language processing may be incomplete. In their "good enough" approach to language comprehension, Ferreira, Ferraro, and Bailey (2002) argued that the language processing system creates semantic representations that are not fully complete but are just sufficient to understand the task at hand. It would follow from this line of thinking that concepts requiring some inferencing such as determining relative size may not be computed unless inherent to the task or otherwise highlighted. In situations when a fine-detailed representation is not needed for comprehension, creating such a representation would impose an unnecessary cognitive load.

We postulate that some meanings may be more available to implicit learning because the concept is readily available in the "good enough" representation. Specifically, the concept of animacy may be more likely to be represented even in the general semantic representation than other semantic cues for the following two reasons. First, because animacy is recognized with little or no focal attention (Kirchner & Thorpe, 2006; Li, VanRullen, Koch, & Perona, 2002), it may not require the same type of (relative) computation as relative size, making animacy more readily available for learning. Second, animacy has been shown to be a highly salient and reliable semantic cue. Culbertson, Gagliardi, and Smith (2017) recently found that animacy-based semantic cues have the largest effect on implicit learning of word class membership. Taken together, animacy may be unique in that it is readily processed and is highly salient, which would facilitate implicit learning. However, semantic cues associated with a linguistic distinction but requiring computation, such as relative size, would rely on additional feature-focusing cues to necessitate its computation. Only then would these more arbitrary linguistic distinctions be made available for implicit learning, otherwise its semantic representation would not have been encoded. Hence, we expect the impact of adding a salient cue to be especially beneficial for learning size information. Cues would serve to prompt relative size computations, making them readily available for implicit learning as the additional cue would highlight an otherwise low salient implicit rule.

The main focus of the present study was to examine implicit learning across rules that have been shown to be more or less amenable to implicit learning in a modified version of the Leung and Williams (2012) implicit learning paradigm. The learning of rules related to animacy or size distinctions were investigated across three studies in the absence of explicit judgments and implicit feedback, in addition to participants being unaware about the occurrence of such learning. Critically, at test, when participants were making noun phrase–picture judgements, we expected that learning would manifest itself in faster responses when processing predictable targets (e.g., Misyak, Christiansen, & Tomblin, 2010; Turke-Browne, Junge, & Scholl, 2005). We predicted longer response times when there was a violation to the implicit rule as these items would be unpredictable compared to grammatically correct phrases, similar to previous findings (Batterink et al., 2014; Leung & Williams, 2012, 2014).

We evaluated the implicit learning of an animacy rule in Experiment 1 and the implicit learning of a relative size rule in Experiment 2. In our study, relative size referred to the intrinsic object size of a single item on the screen relative to other items in the experiment. This contrasts with the notion of relative size used in Leung and Williams (2012), in which relative size was derived on each trial by comparing two images. Experiments 1 and 2 provided a comparison of potential differences in the availability of concepts for implicit learning in a low salience paradigm. In particular, we were interested in whether a concept requiring computation such as intrinsic object size might be less readily learned than animacy. Evidence of implicit learning of the animacy but not the intrinsic object size across otherwise matched Experiments 1 and 2 would suggest that size information may be less available for learning in a low salience paradigm.

Finally, in Experiment 3, implicit learning of the size rule was reexamined, but this time, size corresponded to image size. This manipulation allowed us to use the size of the image presented as the feature-focusing cue to make size information more salient. A comparison between Experiments 2 and 3 would allow us to explore whether the influence of a salient cue would extend semantic representations to include information about a concept with lower availability. Higher levels of learning in Experiment 3 than 2 would indicate that implicit learning of size information can be supported by a cue prompting this computation.

Experiment 1

In the first experiment, we tested whether learning of a mapping between a function word, a novel article in this case, and an animacy value could proceed implicitly. The study was also intended to replicate previous work using a modified version of Leung and Williams's (2012) paradigm in which cues that could have overtly drawn attention to the implicit rule were removed. The paradigm was revised by (a) removing the judgment about whether the object was animate or inanimate, (b) removing explicit feedback about that response, and (c) presenting only one image at a time during the training phase.

Method

Participants

We recruited 34 participants (23 females) who were proficient or native speakers of English and ranged in age from 17 to 28 years ($M_{age} = 18.56$ years; $SD_{age} = 2.077$). One participant stated that her primary language was French. A range of ethnicities resembling the diversity of the population was represented. Participants were recruited from the undergraduate psychology research pool and received a course credit for their participation. The study was approved by the institutional research ethics board for human subjects at the University of Western Ontario (Protocol # 107410: Learning Grammatical Form-Meaning Connections).

Material

The experiment was conducted on a 14-inch laptop screen, using E-prime 2.08 software (Schneider, Eschman, & Zuccolotto, 2002). The semiartificial grammar system employed in the present study was based on stimuli used by Leung and

Table 1. The grammatical agreement between articles and meanings used in Experiment 1, with animacy as the implicit rule

	Explicit rule (told to participants)	
Implicit rule (not told to participants)	Big	Small
Animate	Gi	Ro
Inanimate	Ul	Ne

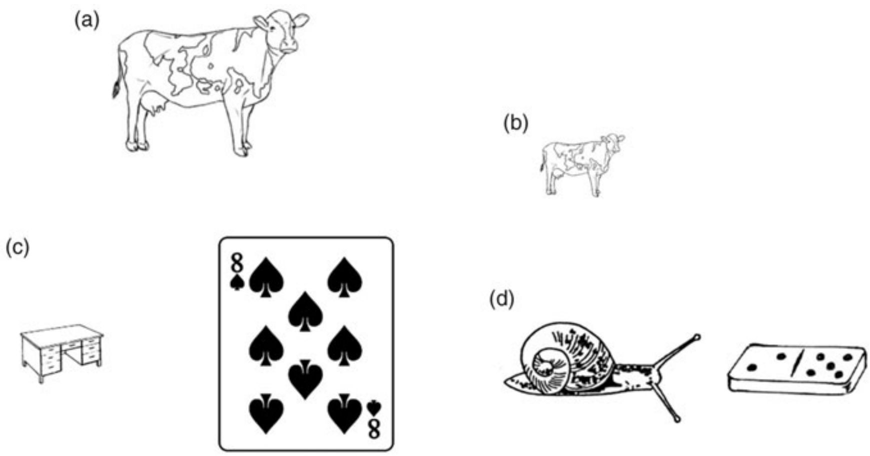

Figure 1. Example of slides from Experiment 1. a) A training slide: A big (animate) cow with the audio, "gi cow". b) A training slide: A small (animate) cow with the audio, "ro cow". c) A testing slide from the explicit block: Both objects are "inanimate" (implicit rule) but differ in size (explicit rule). "Ul card" (*ul/big* pairing) would be grammatical and occur during a control trial, while "ne card" (*ne/small* pairing) would be ungrammatical and occur during a violation trial. d) A testing slide from the implicit block: Both objects are "big" (explicit rule) but have different animacy value (implicit rule). "Gi snail" (*gi/animate* pairing) would be grammatical and occur during a control trial, while "ul snail" (*ul/inanimate* pairing) would be ungrammatical and occur during a violation trial.

Williams (2012). Note that the terms "big" and "small" are used here to draw parallel with Experiments 2 and 3, but the terms "near" for big objects and "far" for small objects were used during instructions to participants. The four novel articles *gi*, *ro*, *ul*, and *ne* varied according to two semantic features, animate/inanimate and big/small image size distinctions (Table 1). Participants were explicitly instructed (explicit rule) that these novel articles encoded size: *gi* and *ul* meant "near" (or big) objects and *ro* and *ne* meant "far" (or small) objects. As depicted in Figure 1, the images appeared as big ($M = 250 \times 250$ pixels) or small ($M = 75 \times 75$ pixels) corresponding to the novel articles that marked big and small objects. However, unbeknownst to participants, *gi* and *ro* also encoded "animate" objects and *ul* and *ne* encoded "inanimate" objects, making this rule available for implicit learning (implicit rule). All of the objects chosen were clear depictions of animate or

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inanimate things. Only humans and animals were used as living objects; plants and food items were not included to prevent confusion.

Audio descriptions of the noun phrase were recorded by the third author, a native speaker of English. A new recording was made for each article and noun, and Audacity software was used to insert a 1-s pause between the end of the article and the onset of the noun. The 1-s pause was added based on the findings in our pilot study of no learning when the pause was absent.[1] The auditory stimuli were presented at a comfortable listening level via headphones connected to the computer in a quiet room.

Training phase. In the training phase, participants saw 60 unique single-item images (30 animate and 30 inanimate) appearing as both big and small for a total of 120 trials and heard each item's corresponding spoken phrase (e.g., *gi cow*). The images were displayed in the center of the screen, one at a time. The slides were presented in a random order.

Testing phase. The testing phase was presented in a blocked design. There were four testing blocks; each composed of 16 trials. The four testing blocks were the explicit rule control and violation blocks (Figure 1c), and the implicit rule control and violation blocks (Figure 1d). The blocks were paired together to form the explicit blocks and the implicit blocks; the respective control block always appeared before the violation block. The pair presented first was counterbalanced across participants. Moving between blocks was imperceptible to the participant as all trials in the test phase proceeded without pauses.

All objects in the testing phase were new and unique images that did not appear in the training phase (16 images randomized across the control blocks, 16 new images for each of the violation blocks). On each trial, the screen was divided into two frames, with one image displayed on the left side and another object displayed on the right side. In the explicit blocks, images were of the same animacy type, but one object appeared as big and the other object appeared as small (Figure 1c; the side in which they occurred was counterbalanced). Trials in the implicit blocks involved pairs of images of the same size, but one object was animate and the other was inanimate (Figure 1d). In the implicit trials, only the animacy (implicit rule) and not the size feature (explicit rule) could be used to predict the noun based on the meaning encoded by the article. The trials within blocks were presented in random order.

In both phases, the training and control trials only consisted of items that were grammatically correct, that is, they followed both the explicit (big/small) and the implicit (animate/inanimate) rules. For example, in Figure 1a, "gi cow" would be considered correct as *gi* refers to a big and animate object, while in Figure 1b, "ro cow" would also be considered correct as *ro* refers to a small and animate object. However, the violation blocks consisted of items that were ungrammatical (and incorrect) such that articles previously used with big objects were paired with small objects, and vice versa. For instance, in Figure 1c, using "ne card" to refer to a big and inanimate card would violate the explicit rule because *ne* referred to small objects during the training phase. Similarly, in the implicit rule violation block, the implicit rule would be used incorrectly as articles previously used with animate objects were now used with inanimate objects, and vice versa. In Figure 1d, using "ul snail" would be incorrect because *ul* was used with inanimate objects during training. Of note, animacy associations were consistent with training for all trials in the explicit violation block and size associations were consistent with training for all trials in the implicit violation block.

Procedure

Each participant was tested in a quiet room, one participant at a time.

Training phase. The experimenter introduced the four determiner-like words and instructed participants that these articles functioned like the English article word "the." Then participants were explicitly told that *gi* and *ul* meant big objects and *ro* and *ne* meant small objects (explicit rule). Participants were not told that article usage was also governed by an implicit rule.

Participants completed 6 practice trials before the experiment, to ensure that they understood the instructions. During the training, participants saw only one object on the screen (e.g., a cow; Figure 1a), heard an audio description corresponding to that picture (e.g., *gi cow*), and then had to repeat and translate the phrase out loud (e.g., "gi cow, big cow"). Once they were finished, participants proceeded to the next trial via button press. Participants were reminded of the explicit rule after Trials 40 and 80, which also served as a brief break. They were not informed about a subsequent test following the training phase.

Testing phase. Instructions for the testing phase followed the training phase. Unlike Leung and Williams (2012), there was a division between the training and testing phases due to the nature of the task. Participants were instructed on the testing phase and received eight practice trials. During the testing phase, two images were presented with an audio description involving the correct or incorrect article (depending on the block) and one noun. Participants were asked to choose the picture (by same-side button press) that matched the presented phrase as quickly and accurately as possible. They did not have to repeat and translate the phrase. Reaction time was recorded from the onset of the article.

Postexperiment questionnaire. After the test, participants were asked about their awareness of the relationship between articles and animacy in the study in a post-experiment questionnaire (Appendix A) based on the one administered by Leung and Williams (2012). Participants were asked what they thought the experiment was about, if they noticed any differences within the testing phase of the experiment, and to make a guess regarding the different conditions for *gi* and *ul* (both meant big) and *ro* and *ne* (both meant small). Responses indicating any knowledge of these relationships were considered indicators of awareness.

Results and discussion of Experiment 1

Reaction times 2.5 *SD* above and below the mean were replaced with the participant's cutoff value, and only correct trials were included in reaction time analyses. Two participants were removed from the reaction time data set only due to insufficient data for analysis (i.e., less than two trials correct for the explicit violation block), but their data was included for the error rate analyses. Error rates were compared across testing blocks.

Table 2. Summary of results from the three experiments

Experiment	Awareness	Control			Violation		
		Mean RT (ms)	*SE* of mean	Error (%)	Mean RT (ms)	*SE* of mean	Error (%)
1: Explicit blocks	All (unaware)	1877	61	6.62	2543	107	13.79
1: Implicit blocks	All (unaware)	2048	25	3.68	2090	26	3.49
2	All	2236	29	2.18	2345	28	1.25
	Unaware	2313	31	2.71	2351	35	1.25
3	All	2250	24	1.40	2163	24	3.75
	Unaware	2166	28	1.67	2234	26	1.67

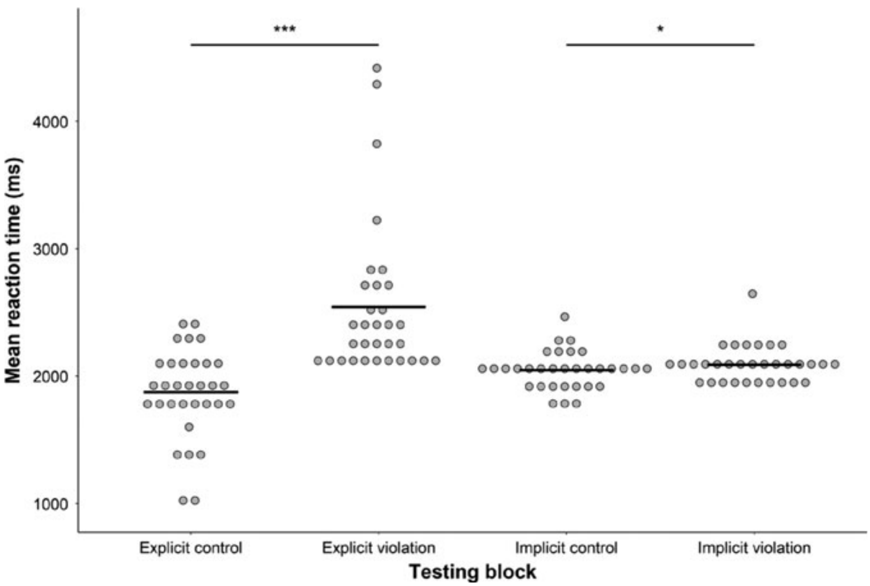

Figure 2. Dots represent the individual reaction time in milliseconds across testing blocks in Experiment 1. Horizontal line represents mean reaction time for each block. Slower reaction time in the Violation block compared to the Control block is evidence for learning both explicit and implicit rules. *** indicates $p < .001$; * indicates $p < .05$.

Table 2 includes descriptive statistics for response time performance across all three experiments. Response time performance across the four testing blocks in Experiment 1 is plotted in Figure 2. Mean response time was slowest for the explicit violation block, and fastest for the control blocks. Relative to respective control blocks, the explicit violation block was 666 ms slower, and the implicit violation block was 43 s slower. A one-factor analysis of variance (ANOVA) revealed a significant effect of test block on participants' response time, $F\ (3,\ 93) = 22.24$, $n_p^2 = .42$, p two-tailed $< .001$. Planned t tests confirmed significantly longer responses

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Table 3. Number of trials in which participants made correct or incorrect responses across the three experiments

	Control		Violation	
Experiment	Correct	Incorrect	Correct	Incorrect
1: Explicit blocks	508	36	469	75
1: Implicit blocks	624	20	525	19
2	626	14	316	4
3	631	9	308	12

for the explicit violation than corresponding control trials with a large effect size, $t\,(31) = –5.08$, $d = 0.90$, $p < .001$, and for the implicit violation than corresponding control trials with a medium effect size, $t\,(31) = –2.4$, $d = 0.42$, $p = .023$.

Table 3 presents the number of correct and incorrect responses across the three experiments, including the four testing blocks in Experiment 1. Mean error rates were highest for the explicit violation trials (75/544; 13.79%), and similar for the remaining blocks. A 2 × 2 χ^2 analysis on the error count was significant for the explicit data, χ^2 (1, $N = 34$) = 14.49, $V = 0.16$, $p < .001$, but not the implicit data, χ^2 (1, $N = 34$) = 0.044, $V = 0$, $p = .83$. In order to interpret the significant χ^2 result, standardized residuals were evaluated. A significantly higher than expected count was observed for the explicit violation error count only ($z = 2.62$; $z < 0.88$, all remaining cells). These results provide evidence of a sensitivity to grammatical violations for the explicit but not the implicit rule.

The postexperiment questionnaire revealed that almost all participants realized that the explicit rule was violated during the testing phase. Participants were able to correctly report the violation ("[articles] previously meaning 'big' now meant 'small'"). As a result of the explicit rule violation, some participants decided to base their decisions on the noun alone ("I had to wait for the actual object to be said before I could make my selection"), which resulted in an error in the ungrammatical, violation trials based on the full phrase (i.e., including the noun), as reflected by the increased error count. It is interesting to note that no participants reported awareness of the implicit rule, indicating that our paradigm did not draw attention to the hidden regularity.

Our findings in Experiment 1 provide additional evidence of implicit learning for animacy-based grammatical agreement even when judgment or feedback cues were not provided. Unlike Leung and Williams (2012), who showed an effect for both reaction time and accuracy, an effect was observed only for reaction time in Experiment 1. Participants were slower to respond to the trials including an implicit rule violation despite making judgments that did not differ in accuracy relative to trials without a violation. The more limited evidence in the present experiment could reflect the removal of the judgment and feedback elements from Leung and Williams's (2012) paradigm. Nonetheless, the results suggest that asking participants to explicitly focus on the concept manipulated in the implicit rule might have enhanced learning. Even the effect observed in Experiment 1 was dependent on the presence of a 1-s pause between the novel article and the familiar noun based on our pilot study. It may be too that the effect was only observed because the animacy value of an object is available preattentively and requires little or no focal attention (Kirchner & Thorpe, 2006; Li et al., 2002) and is a highly salient semantic cue (Culbertson et al., 2017). If this is the case, we should expect no learning using a similar paradigm for a concept requiring computation such as intrinsic object size (Experiment 2), but evidence of learning if cues to compute the image size are provided (Experiment 3).

Experiment 2

In Experiment 2, we tested whether learning of relative size could proceed implicitly in a low salience paradigm wherein computation was not prompted by the task. Relative size in our experiment referred to the intrinsic size of each object, as opposed to forming a comparison between two objects per trial as in Leung and Williams (2012). To this end, all images presented were similarly sized although real-world referents for chosen objects were highly familiar as big or small. The notion of size here can be characterized as bigger or smaller than a prototypical dog (e.g., a cow is big, and a pen is small; Appendix B). Implicit learning would then require participants to compute relative size based on real-world knowledge and compare the objects across trials, and no cues were provided to indicate the necessity of this computation. Given that Experiment 1 confirmed explicit rule learning, Experiments 2 and 3 were further revised by removing the explicit blocks in order to focus on learning of the implicit rule.

Method

Participants

We recruited 22 new participants (19 females) for Experiment 2. The data of two participants were excluded as their mean response time exceeded ±2.5 *SD* from the group mean. The remaining 20 participants (18 females) ranged in age from 17 to 35 years ($M_{age} = 19.82$ years; $SD_{age} = 3.96$). There were four participants who reported that their primary language was Farsi (1), Bengali (1), Punjabi (1), or Mandarin (1), but all reported being proficient speakers of English.

Material

The experiment was conducted on a 14-inch laptop screen, using PsychoPy 1.83.04 software (Peirce et al., 2019), an open-source alternative to E-prime. The semiartificial grammar system employed in the present study was based on Experiment 1, except that the explicit rule encoded animacy and the implicit rule referred to the intrinsic object size (Table 4). For the explicit rules, the articles *gi* and *ro* now referred to "animate" objects and *ul* and *ne* to "inanimate" objects, while for the implicit rules, *gi* and *ul* referred to "intrinsically big" objects (e.g., gi cow) and *ro* and *ne* referred to "intrinsically small" objects (e.g., ne pen).

Training phase. A subset of the objects was adopted from Experiment 1, and new objects were added so that there were 120 slides in the training phase (see Appendix B). This involved the repetition of 60 unique images presented at the same screen size (e.g., the picture of the cow and pen were the same size on each trial; $M = 250 \times 250$ pixels). The repetition of images was necessary given the need to have unambiguous

Table 4. The grammatical agreement between articles and meanings used in Experiments 2 and 3, with the notion of size as the implicit rule

	Implicit rule (not told to participants)	
Explicit rule (told to participants)	Big	Small
Animate	Gi	Ro
Inanimate	Ul	Ne

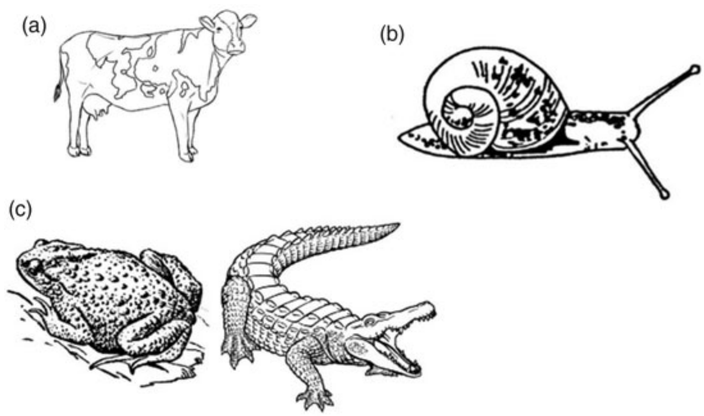

Figure 3. Example of slides from Experiment 2. a) A training slide: An animate (intrinsically big) cow with the audio, "gi cow". b) A training slide: An animate (intrinsically small) snail with the audio, "ro snail". c) A testing slide: Both objects are "animate" (explicit rule) but differ in their intrinsic size (implicit rule). Hearing "ro frog" (*ro/intrinsically small* pairing) would be grammatical, while "gi frog" (*gi/intrinsically big* pairing) would be ungrammatical.

items that fit the respective categories. Overall, there were 15 animate/small, 15 animate/big, 15 inanimate/small, and 15 inanimate/big objects. The slides were presented in a random order.

Testing phase. There were three testing blocks presented in a blocked design, the first control phase (Control 1), the violation block, and the second control phase (Control 2). The control and violation blocks are analogous to the implicit control and violation blocks in Experiment 1, respectively. The order of presentation of the two control blocks was counterbalanced across participants. The additional control block after the violation block was included to show that any difference between the first control and violation block was not due to general practice effects or fatigue.

All objects in the test phases were new and unique images that did not appear in the training phase (48 new images). In all testing slides, unambiguously big and small objects of the same animacy type were presented side by side in similarly sized images (Figure 3). Thus, the implicit rule could be used to anticipate whether the noun accompanying the article would be a big or a small object. Participants were asked to choose the image named by the audio recording by using the same-side button key.

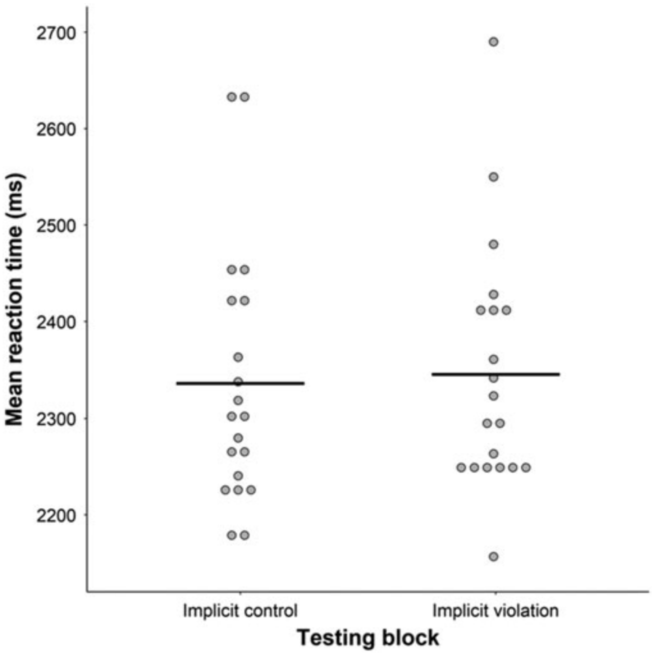

Figure 4. Dots represent the individual mean response times in milliseconds, with the lines indicating the overall group mean. Response time did not differ across testing blocks in Experiment 2.

In both the training phase and the control blocks, items were grammatical, that is, they followed both explicit and implicit rules. For example, a cow is an animate/big object, and was labeled *gi cow* (Figure 3a). However, the violation block consisted of items that were ungrammatical according to the implicit rule, for example, *gi frog* conflicts with training because *gi* corresponded to animate/big objects during training and a frog is intrinsically small (Figure 3c).

Procedure

The procedure was exactly the same as Experiment 1 except that the participants were explicitly instructed to learn the animacy rule and not told about the intrinsic size rule.

Results and discussion of Experiment 2

In a preliminary analysis, response times (Control 1: $M = 2351$ ms, $SE = 39$; Control 2: $M = 2320$ ms, $SE = 27$) and error rates (Control 1: 2.22%, $SE = .82$; Control 2: 2.22%, $SE = .82$) were compared across the two control blocks only, and revealed no significant differences ($t < 0.96$ or $\chi^2 < 0.87$, $p > .05$, all cases). As a result, the data from the control trials were collapsed by averaging each participant's mean across the two blocks, and these composites were used in all remaining analyses.[2]

Figure 4 compares response times of the control ($M = 2336$ ms, $SE = 29$) and the violation blocks ($M = 2345$ ms, $SE = 28$). The 9-ms slowdown in the violation block

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was negligible and insignificant, $t\ (19) = 0.33$, $d = 0.073$, $p = .75$. See Table 3 for the number of correct and incorrect responses made in Experiment 2. The proportion of error rates was similar across testing blocks (Control: 2.19%, $SE = .60$; Violation: 1.25%, $SE = .57$), and the difference was not significant, $\chi^2\ (1,\ N = 20) = 0.14$, $V = 0.012$, $p = .71$.

Based on the postexperiment questionnaire, 15 participants (75%) were unaware of the implicit rule. The unaware participants were unable to make any guesses regarding the implicit rule; anecdotal evidence matched their verbal reports. For example, comments suggested that they were completely unaware of any hidden regularities ("I didn't realize that"), some were only relying on the noun ("… the [article words] weren't that important. The photos were based on the last word which was in English"). By contrast, all of the aware participants were able to, at least partially, identify which article went with which size concept. In a post hoc analysis, we removed the 5 aware participants and only analyzed data from unaware learners. Response time (Control: $M = 2313$ ms, $SE = 31$; Violation: $M = 2351$ ms, $SE = 35$) and error rate (Control: 2.71%, $SE = .74$; Violation: 1.25%, $SE = .63$) were submitted to separate analyses. The results did not change for response time, $t\ (14) = -1.45$, or error rate, $\chi^2\ (1,\ N = 15) = 0.31$, $p > .5$ for both cases.

We did not find evidence of implicit learning when the concept was of low salience and required computation across items. However, the finding of a null effect could be an effect of a relatively small sample size. Bayes factor (BF)[3] analysis was performed on reaction time data to compare the likelihood ratio of the alternative hypothesis (effect of interest: implicit learning) to the null model (Jeffreys, 1998; Wagenmakers, Wetzels, Borsboom, & van der Maas, 2011). BF analysis on the entire data set provided moderate evidence for no implicit learning, BF = 4.10. When the analysis was done on unaware learners only, the result also demonstrated no evidence for implicit learning nor for no implicit learning, BF = 1.60. While we cannot completely rule out the possibility of no implicit learning, we suspect that the experimental paradigm might not have activated real-world knowledge related to size, and consequently, intrinsic object size was not computed or available for forming associations with its corresponding word form. When learning concepts with lower availability, it is important to consider differences in computational demands and cue saliency. Implicit learning of animacy (Experiment 1) but not intrinsic object size (Experiment 2) provides suggestive evidence that intrinsic size was less readily available for learning than the more readily recognized concept of animacy. Experiment 3 was designed to examine whether implicit learning would be enhanced when a cue was used to signify size information, and thus, engage computation. In Experiment 3 we examined implicit learning of size information in the co-presence of feature-focusing constraints (visual cues). That is, size information depended on computing the size of the image on the screen in Experiment 3.

Experiment 3

Given the lack of evidence for implicit learning of intrinsic object size in a low salience paradigm (Experiment 2), we reexamined learning of the notion of size when feature-focusing cues were available. The final experiment was designed so that the predictability of size was inherent and highlighted in the task. In this case,

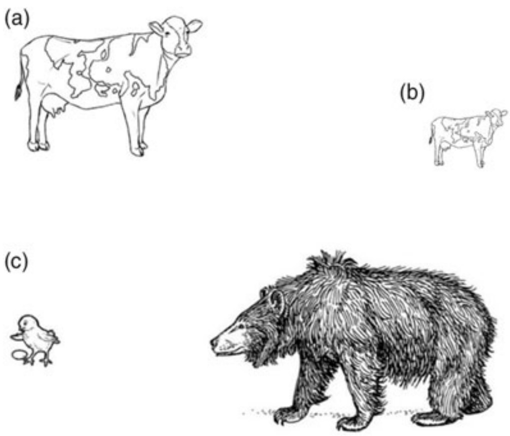

Figure 5. Example of slides from Experiment 3. a) A training slide: An animate (visually big) cow with the audio, “gi cow”. b) A training slide: An animate (visually small) cow with the audio, “ro cow”. c) A testing slide: Both objects are “animate” (explicit rule) but differ in their image size (implicit rule). Hearing “ro chick” (*ro/small image* pairing) would be grammatical, while “gi chick” (*gi/big image* pairing) would be ungrammatical.

the concept of big and small was cued through image size on the screen (Figure 5). In order to ensure that it was presentation of the image size rather than any other knowledge (e.g., real-word knowledge) that impacted learning, all items were presented as either big or small in the paradigm. Therefore, size information was dependent on computing the size of the image on the screen, not the object concept as in Experiment 2. Further, real-world knowledge was not consistent with presented size in many instances.

Method

Participants

Twenty-one participants were recruited. None had participated in Experiments 1 or 2. One participant was excluded because they did not complete the experiment. The remaining 20 participants (18 females) ranged in age from 17 to 23 years ($M_{age} = 18.55$ years; $SD_{age} = 1.32$). One participant said that their primary language was Korean with proficiency in English and the remaining participants were native English speakers.

Material

The stimuli for this experiment were the exact same as Experiment 1. We used the same grammatical agreement between articles and nouns from Experiment 2 (Table 4). A big image was shown as larger on the screen ($M = 250 \times 250$ pixels) and a small object as smaller on the screen ($M = 75 \times 75$ pixels; Figure 5). At test, participants compared two objects of the same animacy type but with varying size:

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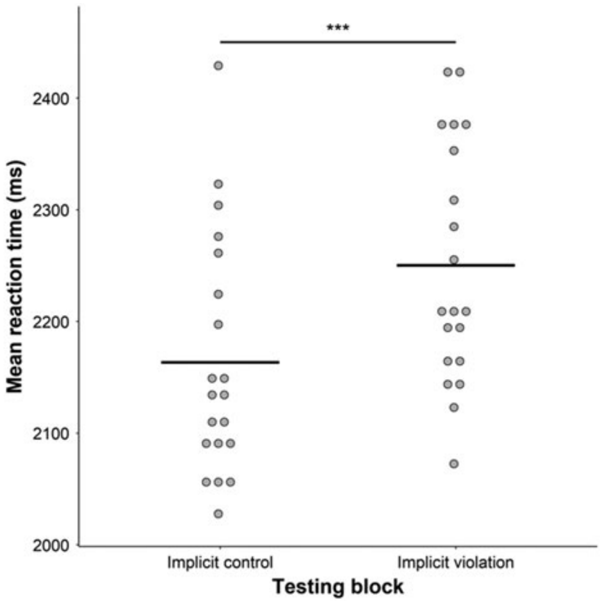

Figure 6. Dots represent the individual mean response times in milliseconds, with the lines indicating the overall group mean. Slower reaction time in the Violation block compared to the Control block is evidence for implicit learning in Experiment 3. *** indicates $p < .001$.

one object was big and the other was small (Figure 5c). Again, participants could use the hidden meanings of the articles predictively had they learned the image size rule.

Procedure

Save for the visual presentation of objects on the screen, the procedure was exactly the same as Experiments 1 and 2. The rules were the same as those of Experiment 2 (see Table 4) such that participants were told that the articles *gi* and *ro* marked "animate" objects and *ul* and *ne* marked "inanimate" objects (explicit rule), but they were not told that the articles *gi* and *ul* were "bigger" objects and *ro* and *ne* referred to "smaller" objects (implicit rule).

Results and discussion of Experiment 3

There was no significant differences between the control blocks for response time (Control 1: $M = 2141$ ms, $SE = 25$; Control 2: $M = 2186$ ms, $SE = 30$), $t\,(19) < 0.37$, $p > .05$, or error rate (Control 1: 1.56%, $SE = .62$; Control 2: 1.25%, $SE = .57$), $\chi^2 < .01$, $p = 1$. Control blocks were thus analyzed in the same way as in Experiment 2.

Figure 6 shows that participants responded differently across the testing blocks. As predicted, response times were slower in the violation block ($M = 2250$ ms, $SE = 24$) than the control block ($M = 2163$ ms, $SE = 24$). Planned two-sample t tests for repeated measures demonstrated that this 87-ms difference between the

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violation and control blocks was significant, with a large effect, t (19) = –4.18, $d = 0.94$, $p < .001$, indicating that participants were learning the implicit rule. There were numerically more errors in the violation block (3.75%, $SE = 1.66$) than the control block (1.40%, $SE = .42$), shown in Table 3. The error count across testing blocks was also significantly different, χ^2 (1, $N = 20$) = 4.44, $V = 0.068$, $p = .035$. Standardized residuals revealed that the expected count for the violation error count was the only cell approaching more than expected ($z = 1.90$; $z < 0.20$, all remaining cells). The association between the testing blocks and errors rates indicates that more errors were being made during the violation block in response to ungrammatical items.

According to questionnaire responses, 15 participants (75%) were unaware of the implicit rule, while 5 participants reported (some) awareness. The unaware participants were unable to make any guesses regarding the implicit rule. Comments such as "[I] just looked at the picture to see if I would normally associate the object as being animate or inanimate" confirmed their unawareness and suggested that they continued to be focused on the explicit rule. By contrast, participants who reported awareness were able to allude to a potential size difference ("something to do with the size of the image on the screen"), with only 1 participant able to make the correct associations. In a post hoc analysis, we constrained our data set to only unaware learners, removing the 5 aware participants. Data from response time (Control: $M = 2166$ ms, $SE = 28$; Violation: $M = 2234$ ms, $SE = 26$) and error rate (Control: 1.67%, $SE = .52$; Violation: 1.67%, $SE = .74$) were submitted to separate analyses. We found that the reaction time difference remained statistically significant, t (14) = –3.34, $d = 0.86$, $p = .0049$, but error count was not, χ^2 (1, $N = 15$) < 0.01, $V = 0$, $p = 1$.

Taken together, these results suggest that sensitivity to the image size rule occurred without awareness in many participants, which was confirmed by their verbal reports. Unlike Experiment 2, violation of the implicit rule resulted in both slower response times and increased error rates demonstrating that participants likely learned the image size rule implicitly, or at least could use the article to anticipate the correct size information. Implicit learning remained significant even when participants were unaware of the implicit rule. Moreover, there continued to be robust implicit learning for unaware learners as measured by the large effect size for reaction time analysis ($d = 0.86$). The fact that implicit learning was found in Experiment 3 but not Experiment 2 suggests that when learning about conceptual distinctions not typically contrasted in English, the implicit rule can be learnable if made salient by being explicitly cued in the task (in this case by image size). It is also worth noting that accuracy judgments were significant only with the additional feature-focusing cue in Experiment 3, a finding similar to that of prior studies using explicit cues such as judgments and feedback (e.g., Leung & Williams, 2012).

Comparison among experiments 1, 2, and 3

In order to compare learning across the three studies, the reaction time data from the unaware participants in Experiments 1, 2, and 3 were analyzed in a 3 × 2 ANOVA with group (Experiment 1—animacy rule, Experiment 2—intrinsic object size rule, and Experiment 3—image size rule) as a between-subjects variable and testing blocks (control vs. violation block for the implicit rule) as a within-subjects variable. There were significant main effects of group and testing blocks, $F > 15.07$, $p < .001$. The critical interaction between group and testing blocks was not significant, $F\ (2, 123) = 0.43$, $n_p{}^2 = .007$, $p = .65$, suggesting that learning was not greater in one experiment than another. In addition, we compared only Experiments 2 and 3 in a separate ANOVA as they would provide a more direct test of the effect of feature-focusing cues, and results were similar to the comparison across all three experiments. However, these results must be interpreted with caution given that the individual studies were fairly small in terms of items and participants.

It is interesting to note that inspection of effect sizes (Cohen's *d*) in the reaction time data for unaware learners reveals that the learning effect was more than two times greater in Experiment 3 ($d = 0.86$) than in Experiment 1 ($d = 0.42$). This trend provides suggestive evidence that the presence of feature-focusing cues in the paradigm had a powerful effect on supporting implicit learning even when participants were unaware of the hidden rule.

General discussion

This study provides the first empirical evidence showing that implicit learning of article–meaning associations might be linked to feature-focusing constraints. Using a modified paradigm that eliminated explicit judgments and implicit feedback about a hidden regularity, we found implicit learning of an article rule related to animacy in Experiment 1 (replicating the findings from previous work; e.g., Leung & Williams, 2012), but not intrinsic object size in Experiment 2. However, implicit learning of image size was observed when visual cues highlighting size distinction were incorporated into the paradigm in Experiment 3. Given that size information is often not contrasted nor computed in English, participants may not be attending to relative size across items in Experiment 2, and thereby, not forming a detailed semantic representation. In contrast, Experiment 3 utilized visual cues to make size differences more apparent. This would have engaged computation of image size and facilitated the creation of a more detailed semantic representation, which in turn promoted implicit learning.

Overall, the concept of animacy appears to be a conceptual distinction that is readily available to implicit learning, while semantic distinctions like relative size may not be as easily learned. Experiment 1 demonstrated implicit learning after brief training of a grammatical form–meaning association for function words that were playing the role of articles. The findings replicate and extend prior work demonstrating learning of animacy-based agreement in an implicit manner (Batterink et al., 2014; Chen et al., 2011; Kerz et al., 2017; Leung & Williams, 2012, 2014; Rebuschat et al., 2015; Williams, 2005). Specifically, participants were able to learn the hidden animacy rule without requiring explicit judgments or implicit feedback and, further, without relying on additional context from a sentence frame. Leung and Williams (2012) attributed this effect to linguistic experience. That is, the learner's extensive experiential knowledge classifying nouns as animate or inanimate facilitates the implicit learning of animacy. Further, previous research has shown that animacy features can be accessed in the near absence of attention

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(Li et al., 2002) and are considered salient and reliable semantic cues (Culbertson et al., 2017). Thus, computing object animacy may impose a negligible cognitive load resulting in its virtually automatic calculation and availability for learning. In contrast, other concepts with fewer links to existing linguistic contrasts and experience such as relative size would be expected to impose a higher cognitive load for computation, which may limit when such computations are completed. This line of thinking suggests that implicit learning requires at least some minimal attention focusing cue to highlight the relevant feature to be learned.

According to Ferreira et al.'s (2002) "good enough" approach to language comprehension, semantic representations are not fully complete but sufficient to understand the task at hand. Good enough representations would allow successful task completion without imposing unnecessarily large cognitive loads on the system, thereby preserving processing resources for other tasks. It would follow from this notion that features of the stimulus requiring additional computations or inferencing are not computed unless specifically required by the task. In Experiment 2, no cues were present to signify the importance of comparing and encoding intrinsic object size across items. Given that relative size is not routinely contrasted in English and would require additional computation through comparison and inferencing, relative size may not have been encoded in a "good enough" representation of stimuli in Experiment 2 making intrinsic object size unavailable for learning.

This finding was contrasted with a parallel learning opportunity with the inclusion of cues to signify the importance of size information in Experiment 3. In this experiment, the concept of size was made salient by being cued via image presentation. These cues would have triggered the allocation of resources toward forming more complete representations including the computation of image size. Thus, implicit learning of size information was observed despite being considered an arbitrary rule and not being encoded in language. It is also notable that the results remained significant even when only participants who reported being unaware of the implicit relative size rule were included in the analysis. Finally, an interesting fact to note about the implicit rule in Experiment 3 is that the meaning was derived from computing information that was a property of the image, as opposed to a semantic property of the noun. Animacy (Experiment 1) and intrinsic object size (Experiment 2) require access to the conceptual object representations, whereas image size (Experiment 3) depends on computing the size of the image used in the experiment.

Across a series of studies, we found that implicit learning of animacy could be attributed to its automatic recognition and saliency as a semantic cue, while relative size could be learnable if additional cues are available to highlight its saliency. The results of our cue salience manipulation support the idea that learning the meaning of functor words or knowing grammatical features of words could be acquired in an implicit way. Given that implicit learning proceeded in parallel paradigms dependent only on the presence or absence of a feature-focusing cue, it is likely that implicit learning is constrained by focusing attention in similar ways across word categories. Implicit learning opportunities may be limited to the concepts encoded in partial representations of stimuli. However, one way to potentially guide learning toward relevant information of otherwise arbitrary distinctions (e.g., relative size) would be by using explicit cues to make such concepts more salient. Meaning concepts of high salience, such as animacy, seem to be readily available for implicit learning. In contrast, when meaning contrasts are less salient, such as relative size, additional cues would be required to draw attention to the meaning-related information.

Future work and limitations

Building on the methodology used by Leung and Williams (2012, 2014), our results provide a new perspective on the role of attention in cue-based learning of functor–meaning associations. Limitations of the current work concern the methodological design and participant pool, however. We used the same rules based only on semantic cues (i.e., animacy value and the concept of size), and testing trials were blocked. However, other types of noun classification systems are found in many languages, involving both semantic cues (e.g., gender systems) and phonological cues (e.g., prefix and suffix). Previous work has also found learning effects with intermingled trials (Batterink et al., 2014). Our understanding of how learners acquire functor–meaning associations would be extended through implicit learning investigations of gender rules rather than just animacy, semantic, and/or phonological cues rather than semantic cues alone, and mixed design rather than blocked design.

Even determining what precisely makes the notion of size more or less learnable is a challenge for future studies. Differences in the characterization of relative size in the present studies should be noted. In previous work, Leung and Williams (2012) required a relative size comparison between the two objects presented on a single trial such that a frog would be judged as large compared to a pen but small compared to a house, for example. In contrast, participants in this study were asked to make judgments against knowledge of intrinsic size of objects in Experiment 2 (e.g., a frog is intrinsically small; a house is intrinsically large). Nonetheless, implicit learning of relative size was not found in either case. In contrast, in Experiment 3, implicit learning was observed for image size, which acted as an explicit cue to the feature. Future work might investigate how implicit learning for more arbitrary distinctions could be obtained using different types of cuing to engage the computation of semantic information.

Another difference between Experiments 2 and 3 concerns the variation between the exemplars presented. Due to constraints on stimuli selection, participants were exposed to 60 unique noun phrases (i.e., each noun with only one determiner) twice in Experiment 2 and 120 different noun phrases (i.e., each noun occurred with both determiners) in Experiment 3, creating an exposure rate difference across experiments that could have influenced learning. Note that Williams (2005) accounted for the distributional structure of the article–noun input and found that implicit learning occurred in a similar fashion whether each noun occurred with both determiners or each noun occurred with one determiner. However, it is possible that variability in the input could have impacted learning (e.g., Plante et al., 2014) and further investigation is warranted.

Divergent results across previous studies have been attributed, at least in part, to the different language backgrounds of learners. For instance, implicit learning was evident with a group of participants with diverse language backgrounds

(Williams, 2005), while implicit learning was absent when the participant pool was restricted to monolingual native English speakers (Faretta-Stutenberg & Morgan-Short, 2011). In the present work, we did not systematically collect information about language background and/or program of study, which inadvertently restricts our discussion about the link between language experience and implicit learning. Given that some meanings may not be as automatic in other languages, it is important for future work to study the role of language experience on implicit learning.

Finally, the pilot study led to an unexpected finding such that there was no evidence of implicit learning when the 1-s pause between the article and noun was removed. Thus, implicit learning in these types of task may depend on a minimal distinction between the article and the noun. However, we know from seminal work on statistical learning that humans have the remarkable ability to learn from a continuous stream of speech (Saffran, Aslin, et al., 1996; Saffran, Newport, et al., 1996). As well, there is typically not a pause between words in natural speech. One possible reason for the results of the pilot study is that articles are generally not phonologically salient and may not be easily perceived by adult participants when paired with a well-known English noun. When participants heard "gi cow," for instance, they might have just heard "cow." The 1-s pause then allowed them to more easily perceive and encode the article independently from the noun.

Despite finding that the use of feature-focusing cues facilitated learning, we should remain curious about how explicit processes such as attentional demands support implicit learning more generally. For instance, introducing an attention demanding secondary task should affect learning even for highly salient cues because attention is diverted. Moreover, mixed findings from the use of think-aloud protocols might be explained by the fact that attentional resources were consumed compared to when resources were available to learn the critical article/implicit rule pairing (Rebuschat et al., 2015). In addition, we used postexperiment verbal reports to reduce cognitive load during the training phase. Although the sensitivity of verbal reports poses as a potential limitation, previous work has shown that interviews measuring awareness were as adequate as think-aloud protocols without detrimental effects on implicit learning (Rebuschat et al., 2015).

Finally, learning in this experiment was based on the extremity of the rule violation (i.e., pictures were presented very small) with the reason only becoming apparent after the task. Although the depiction of size manipulated this way made it highly available in the visual presentation, it should be recognized that a more natural version of Experiment 3 would have combined depth cues to derive an estimate of relative size. For example, two animals on a farm, with the closer animal appearing as bigger and the farther animal appearing as smaller to justify the presentation of very big and very small pictures.

Conclusion

In conclusion, the ability to learn regularities between words and their meanings is a hallmark of human cognition as successful language comprehension requires more than just knowing the phonological form of new words. When it comes to learning

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the meanings of function words, it is impossible to point to a specific referent and say "*the*." It is therefore crucial to understand how the meanings of such words are acquired through the process of implicit rule abstraction. We found that feature-focusing constraints might facilitate this process; as the novel article–meaning association became easier to process and understand through cue salience or cue-based task, implicit learning was more likely to occur. The effect was observed for animacy, a concept computed with little or no focal attention, while size information, a concept imposing a higher cognitive load to compute, was only learned when feature-focusing cues were used to highlight information about the semantic feature. It is important that associative learning is facilitated by such constraints because language learners require cues to the linguistically meaningful aspects of their complex, ambiguous environment.

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Notes

1. A pilot study involving the exact same paradigm as Experiments 2 and 3 except without the insertion of the 1-s pause yielded no evidence of learning. Moreover, there was an unexpected slowdown during the control trials ($M = 1261$ ms, $SE = 19$) compared to the violation trials when there was a grammatical violation ($M = 1206$ ms, $SE = 17$) and this was significant, $t\ (19) = 4.31$, $d = 0.55$, $p < .001$.

2. Despite unequal sample sizes for the violation and combined control blocks in Experiments 2 and 3, the assumption of homogeneity of variance was met for all completed *t* tests. Nevertheless, alternative analyses comparing both reaction time data and error count from only the first control block against the violation block revealed no changes to the reported findings in both experiments.

3. We thank an anonymous reviewer for suggesting this analysis.

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Appendix A

Postexperiment questionnaire used in experiment 2

1. What do you think the experiment was about?

 ____

2. (a) Did you notice anything odd toward the end of the experiment?
 ☐ Yes
 ☐ No
 (b) If yes, what do you think the oddity was?

 ____

3. Did you have any feelings about the different condition in which *gi* vs. *ro* (both meant animate) and *ul* vs. *ne* (both meant inanimate) were used?

 ____

Appendix B

Full list of stimulus items used in experiment 2

Table B.1. Animate and inanimate objects used in the intrinsically big condition

Animate objects	Inanimate objects
Alligator, Archer, Bear, Camel, Cow, Doctor, Elephant, Firefighter, Giraffe, Gorilla, Grandmother, Horse, Kangaroo, King, Leopard, Lion, Magician, Model, Moose, Musician, Ostrich, Queen, Scientist, Shark, Soldier, Worker, Zebra	Airplane, Barn, Bathtub, Boat, Bus, Camper, Car, Church, Crib, Drawers, Fireplace, Gym, Helicopter, Hospital, House, Motorcycle, Mountain, Piano, Rocking chair, Sailboat, Shed, Stove, Tent, Tow truck, Train, Truck, Windmill

Table B.2. Animate and inanimate objects used in the intrinsically small condition

Animate objects	Inanimate objects
Ant, Bedbug, Bee, Beetle, Butterfly, Caterpillar, Centipede, Chick, Cockroach, Cricket, Dragonfly, Flea, Fly, Frog, Goldfish, Grasshopper, Koi, Ladybug, Lizard, Mosquito, Moth, Mouse, Shrimp, Slug, Snail, Spider, Worm	Bottle, Button, Candle, Cap, CD, Cigar, Cigarette, Clock, Clothespin, Fork, Key, Knife, Mask, Match, Nail, Needle, Nut, Pen, Pencil, Pool ball, Rings, Ruler, Scissors, Spoon, Stapler, Watch, Whistle

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