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Short Communication

Unconscious structural knowledge of form–meaning connections

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ABSTRACT

We investigated the implicit learning of a linguistically relevant variable (animacy) in a natural language context (namely, the relation of forms of determiners to semantics). Trial by trial subjective measures indicated that exposure to a form–animacy regularity led to unconscious knowledge of that regularity. Under the same conditions, people did not learn about another form–meaning regularity when a linguistically arbitrary variable was used instead of animacy (size relative to a dog). Implicit learning is constrained to acquire unconscious knowledge about features with high prior probabilities of being relevant in that domain.

1. Introduction

Grammatical knowledge of our native language stands as a prototypical example of implicit knowledge (even if not all grammatical knowledge is implicit). Indeed, the case of language served as a motivation for the first implicit learning paradigm, artificial grammar learning (AGL) (Reber, 1967), in which an artificial grammar is used to specify which elements (e.g. letters) can follow other elements. Another key implicit learning paradigm, the Serial Reaction Time (SRT) task (Fu, Fu, & Dienes, 2008; Nissen & Bullemer, 1987), involves the perceptual-motor learning of similar regularities, namely, what elements can follow other elements, for example positions on a screen. Research using these paradigms has shown that people can acquire knowledge they are not aware of (e.g., Gaillard, Vandenberghe, Destrebecqz, & Cleeremans, 2006). Given the deliberate attempt by researchers to use arbitrary materials, the implicit learning literature to date can be construed as an attempt to show domain-general principles of implicit learning (e.g. Pothos & Bailey, 2000; Reber, 1989). The question arises however as to whether particular domains bring their own constraints; for example, does using distinctively linguistic material constrain the learnability of different features (cf., Williams, 2009)? We aim to investigate the properties of implicit learning as they apply to learning linguistically relevant information, rather than simply the learning of sequences of arbitrary elements.

It is plausible that implicit learning systems are sensitive to regularities with high prior probabilities for the domains in question (cf. Ziori & Dienes, 2008). Thus, implicit learning of linguistic structures may be especially sensitive to linguistic variables. Accordingly, Williams (2004, 2005; see also Leung & Williams, 2006) employed linguistically relevant variables in a laboratory implicit learning context. Specifically, they constructed a rule to create noun phrases in which determiners before nouns were categorized according to the linguistically relevant feature of animacy. (In English *determiners* include: ‘the’, ‘a’, ‘that’, ‘this’.) Living things used the determiners ig, i, ul, tei; and non-living things ga, ge, ula, tegge. The connection between the form of the determiner and the meaning of nouns was taken as the target rule. In Williams (2004), participants

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were asked to translate Italian phrases into English and decide the animacy of nouns, so that both relevant form and meaning were noticed. The results showed that participants responded correctly on a forced-choice test of form–meaning connections and were apparently unaware of having acquired knowledge. In Williams (2005), the tested connection was not focally attended. Participants were only required to notice that the form of the determiners specified how far the nouns were away from the subject of the sentence (like ''gi dog'' indicated a near dog), attending to the tested connection (i.e. that the determiners specified animacy of the nouns) was not part of task demands. Nonetheless, subjects performed significantly above chance. Williams assessed the question of whether the learning was implicit with oral report. In the 2004 experiment where form and meaning were demonstrably both consciously noticed, 30 of 37 participants claimed they were not aware of the relevance of animacy during training. In the 2005 experiment, it was 66% for the same question.

Oral reports have good face validity as measures of conscious knowledge but can be criticized on sensitivity issues (Berry & Dienes, 1993): When subjects report their subjective states at the end of an experiment, their glosses may not be accurate in detail. Indeed, Ziori and Dienes (2006) showed empirically that trial-by-trial subjective measures are more sensitive than post-task verbal reports. Dienes and Scott (2005) developed trial-by-trial subjective measures for the conscious status of the knowledge of the structure of a domain[1] (see also for further applications of these measures: Fu, Dienes, & Fu, 2010; Guo et al., 2011; Rebuschat, 2008; Scott & Dienes, 2008; Scott & Dienes, 2010a, 2010b; Wan, Dienes, & Fu, 2008). After a judgment, participants made one of four attributions about the basis of their judgement. ''Guess'' indicated that the judgment was based on nothing at all, it could just as well be based on a toss of a coin; ''Intuition'' indicated that the judgment was based on a hunch or feeling that could not be explicated further, i.e. there was confidence in the judgment but the person had no idea why the judgment was right; ''Memory'' indicated that the judgment was based on a recollection; ''Rules'' indicated that the judgment was based on a rule that could be stated if asked. Unconscious structural knowledge is indicated by guess and intuition attributions because in these cases the person claims no awareness of the basis of their judgments. Conscious structural knowledge is indicated by rule and memory attributions, because in these cases the person indicates conscious knowledge (of regularities or particular instances) of the structure of the domain used in their judgment.

The unconscious status of the knowledge acquired is one feature of implicit learning, perhaps the defining feature (Dienes, 2008; Reber, 1989); a more contingent feature is the relation of implicit learning to attention. Although implicit learning can occur incidentally, it is modulated by what features are selectively attended (Jiménez & Méndez, 1999), just as explicit learning is. Consistently, Schmidt (1990, 1994, 2001) proposed we only learn about features of a language which are consciously ''noticed''. More generally, while some studies found evidence that unattended features could hardly be learned implicitly (Eitam, Schul, & Hassin, 2009; Tanaka, Kiyokawa, Yamada, Dienes, & Shigemasu, 2008), other studies have found implicit learning of background features (Jiang & Chun, 2001). Williams (2005) concluded that as attention was not directed to animacy in his experiment, form–meaning connections were learned under conditions where only the relevant forms, and not the relevant semantic features, were noticed in the input (Williams, 2005). At least, Williams showed that learning can occur when noticing a relevant feature is not part of task requirements nor even useful for performing the task (cf. Perlman & Tzelgov, 2006; van den Bos & Poletiek, 2009).

The current research sought to determine if people can acquire unconscious structural knowledge of linguistically relevant relationships when attention is not directed to a key variable in the relationship. Specifically, we adopted Williams' experiment (2005, experiment one) by using Chinese noun phrases as relevant instantiations of the animacy rule. A paradigm, such as that offered by Williams, in which implicit learning effects are seen in a distinctively linguistic context is an important one to establish. Thus, the first aim of this research was to establish a conceptual replication of the form–meaning learning found by Williams (2005). The second aim was to increase the sensitivity by which the conscious status of the knowledge was measured by using the structural knowledge attributions of Dienes and Scott (2005) to assess awareness on a trial by trial basis rather than by free report (see also Guo et al. (2011) and Rebuschat (2008), for additional applications of these measures to second language learning). Finally, the third aim was to establish whether the linguistic relevance of a feature affects how easy it is to implicitly learn in a language context. Such an effect would demonstrate the importance of having a language-based implicit learning paradigm for understanding the implicit learning of language: Generic arbitrary stimuli would not allow us to understand implicit learning generally.

2. Experiment 1

2.1. Method

2.1.1. Participants

Forty undergraduate and graduate students (aged from 18 to 35, $M = 23.52$, $SD = 4.24$; 18 male and 22 female) from East China Normal University participated in the experiment in exchange for credits. Mandarin was their first language, and English their second.

[1] There are at least two types of knowledge acquired in AGL which can be either conscious or unconscious: judgment knowledge and structural knowledge (Dienes & Scott, 2005). Judgment knowledge is knowing whether or not a string is grammatical, while structural knowledge is knowing why a string is or is not grammatical e.g. knowing that a string is ungrammatical because of the presence of a particular combination of letters.

2.1.2. Materials

Noun phrases (nouns modified by determiners) were used as materials in the present study (Appendix A). Four characters were taken as determiners in noun phrases (亍, 夬, 疋, 乇). They were selected from Dictionary Editing Office of Institute of Language in Chinese Academy of Social Science (1990), with frequencies lower than 1/1000,000 (National Language Committee, 1992). None of our participants knew the actual meaning of these characters.

In the experiment, all the noun phrases were presented in the context of a sentence. Following Williams (2005), there were two critical rules for the use of determiners before nouns: the distance rule and the animacy rule. The distance rule specified whether the objects or entities specified by the noun phrases were within an arm's length from the subject in the sentence. The animacy rule referred to whether the nouns modified by the determiners were animate (e.g., lion) or inanimate (e.g. table). For example, "狼想吃树上的夬鸟。" means "A wolf wants to eat a chu(夬) bird on the tree". The "Chu" indicated that the bird was out of the touchable distance of the wolf, i.e., "far" from the wolf, so that "夬" corresponded to "far". For another example, "所有的孩子都坐在疋桌前玩棋盘游戏。" means "The children all played chess on the yu(疋) table". The situation implies that the table was within an arm's length from the children and was consequently defined as "near". When combining the two features together, "夬" (chu) was designed to modify animate and far nouns, "疋" (yu) was designed to modify inanimate and near nouns. In the same way, we constructed "亍" to modify animate and near nouns, and "乇" to modify inanimate and far nouns.

A second version of the materials was constructed, in which the assignment of the determiners was changed, so that "乇" and "疋" modified animate objects and "夬" and "亍" modified inanimate objects. Thus, assignment of determiner to animacy was counterbalanced across participants.

In training, ten noun phrases were created for each determiner. Eight used the same nouns in far and near situations and two used different nouns for far and near situations. In order to make each noun appear exactly twice, the two noun phrases for each determiner with different nouns for far and near situations were repeated. Therefore, there were 48 training items in all, each presented in different sentence context.

During test, 32 old noun phrases accompanied by 32 new sentences (trained items) and 8 new noun phrases repeated four times with 32 new sentences (generalization items) were used as testing items. For instance, "亍狗" was a trained item, because that determiner–noun combination was presented in the training phase, whereas "亍猴子" was a generalization item because it obeyed the animacy rule, but the determiner–noun combination was not presented in the training phase (though the determiner and the noun had been presented in the training phase in other combinations). Thus, there were 64 testing items in all, 32 of which were trained items and 32 generalization items.

2.1.3. Procedure

2.1.3.1. Training. Participants were informed of the existence of the distance rule before training, but not of the hidden rule of animacy. The training items were presented sequentially. Participants were instructed to read each sentence aloud and respond as accurately as possible to the distance of the indicated noun phrase (e.g., "亍" indicated near distance between the subject and the object of the sentence) by pressing the corresponding keys (near versus far). If the participants did not respond within 20 s, the next sentence was displayed. Accuracy feedback was given after every response. The training set was presented three times, i.e. for three blocks. The presentation order within each block was randomized (with the restriction that each noun was presented once before any were repeated) and a 30 s break was interposed between each block.

2.1.3.2. Testing. Immediately after the training phase, participants were tested on the animacy rule by a sentence completion task. A blank appeared in a sentence and two options were presented, namely, the grammatical and ungrammatical noun phrases. The participants were required to choose the option suitable for the sentence context and indicate what they believed to be the basis for their judgment (guess, intuition, memory or rule). For example, one test sentence was "夏天来了，我把______身上的毛剃光了，让它凉快一些。" ('Summer is coming, I shaved _____ in order to make it nice and cool.') Its two options were "亍狗" ("chu dog") (grammatical) and "疋狗" ("yu dog") (ungrammatical). The determiner of the two options indicated the same distance (e.g., both "亍狗" and "疋狗" indicated "near"). Half of the participants were tested first on the trained items, whereas the other half were tested first on the generalization items. The presentation order within each block was randomized (with the restriction that each noun was presented once before any were repeated) and a 30 s break was interposed between each block.

2.2. Results

2.2.1. Proportion of correct responses

The proportion of correct response was calculated by $\frac{N_C+0.5}{N+1}$ (N_C being the number of correct responses; and N the total number of responses), the correction corresponding to a Bayesian prior of chance performance worth just one observation, useful when some participants have low N for some conditions (Dienes & Scott, 2005).

Overall correct classification performance (M = 58%, SD = 10.2%) was significantly better than chance, $t(39) = 4.92$, $p < .05$, $d = 0.78$. For the trained items, participants correctly responded at a rate of 59% (SD = 11.3%), which was significantly better than chance ($t(39) = 5.32$, $p < .05$, $d = 0.84$); for the generalization items, the performance (M = 56%, SD = 11.5%) was also significantly better than chance ($t(39) = 3.39$, $p < .05$, $d = 0.54$). Accuracy for generalization items was not significantly lower than for trained items ($t(39) = 1.98$, $p > .05$, $dz = 0.31$).

2.2.2. Conscious versus unconscious structural knowledge

The response frequency of each attribution is shown in Table 1 and the proportion of correct responses for each attribution for both trained and generalization items is shown in Fig. 1. Responses based on both guess and intuition, indicating unconscious structural knowledge, were grouped together. Only one participant did not use either guess or intuition attributions. Accuracy for responses based on unconscious structural knowledge (0.56 ± 0.10) was significantly better than chance ($t(38) = 3.85$, $p < .05$, $d = 0.62$). The accuracy for trained items (0.58 ± 0.14) and for generalization items (0.55 ± 0.12) were each significantly better than chance (trained: $t(38) = 3.50$, $p < .05$, $d = 0.56$; generalization: $t(38) = 2.76$, $p < .05$, $d = 0.44$). Similarly, responses based on rule and memory were combined together for conscious structural knowledge. Three participants never ascribed their judgments to rule or memory. Accuracy for responses based on conscious structural knowledge (0.61 ± 0.19) was significantly better than chance ($t(36) = 3.63$, $p < .05$, $d = 0.60$). The accuracy for trained items (0.61 ± 0.20) and generalization items (0.58 ± 0.17) were each significantly better than chance (trained: $t(34) = 3.33$, $p < .05$, $d = 0.56$; generalization: $t(31) = 2.80$, $p < .05$, $d = 0.49$). Further, a 2 (test set (trained set versus generalization set)) × 2 (attribution (conscious versus unconscious)) repeated measures ANOVA indicated no significant effects.

2.3. Discussion

Experiment 1 conceptually replicated Williams' (2005) finding that people could acquire unconscious knowledge about form–meaning connections, but using trial by trial measures of awareness. Our studies together provide evidence for the possibility of forming linguistically relevant unconscious structural knowledge in the lab (see also Guo et al. (2011), Rebuschat (2008) and Rebuschat and Williams (2009), for application of trial by trial subjective measures to linguistically relevant material). Further, following Williams, we show form–meaning connections can be implicitly learned when participants are not required to consciously notice the relevant aspects of meaning.

In the Williams' (2005) experiment, participants who reported that they were aware of the relevancy of animacy were nearly perfect on the generalization test. In our experiment, performance on generalization items was significantly above chance for memory (0.58) though not rule attributions (see Fig. 1). In our case, people who formed conscious rules did not do so accurately. The memory responses may be based on explicit analogies e.g. between the "亍" (chu) describing "狗" (dog) being based on the trained "亍" describing "鸟" (bird). Alternatively a memory response may indicate false memory produced by the relevant semantic similarity of the items grouped by determiner. Such false memory could in fact be an

Table 1
Response frequency of each attribution for the trained and generalization sets (*M* ± *SD*).

	Unconscious structural knowledge		Conscious structural knowledge	
	Guess	Intuition	Memory	Rule
Experiment 1				
Trained sets	10.83 ± 8.84	9.30 ± 7.42	6.53 ± 5.88	5.35 ± 9.00
Generalization sets	10.98 ± 9.67	9.70 ± 8.12	6.55 ± 6.69	4.78 ± 7.83
Experiment 2				
Trained sets	9.07 ± 4.49	13.27 ± 4.80	7.40 ± 4.69	2.27 ± 2.95
Generalization sets	10.67 ± 6.41	14.93 ± 5.38	2.97 ± 3.76	3.43 ± 3.56
Experiment 3				
Trained sets	10.07 ± 6.07	13.13 ± 6.73	6.80 ± 5.02	2.00 ± 3.11
Generalization sets	9.73 ± 6.07	15.20 ± 7.32	3.23 ± 4.57	3.83 ± 4.26

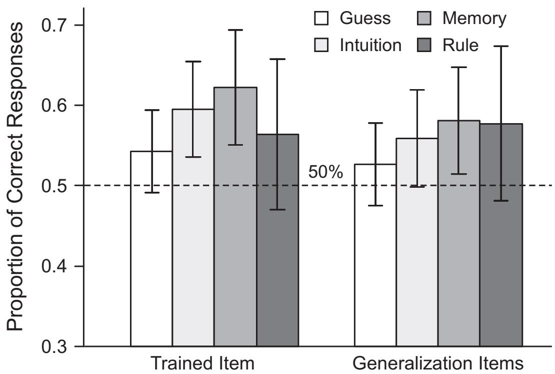

Fig. 1. Proportion of correct responses for each attribution in Experiment 1. Error bars indicate 95% confidence intervals.

indication of unconscious structural knowledge, if people were not consciously aware of the relevant regularity defining list similarity.

In Experiment 1, no participant reported anything about the rules in post task debriefing. Indeed a problem with free oral report is that participants can avoid reporting any rules unless they're quite confident. In our case, they seemed not willing to report at all and this is why use of trial by trial structural knowledge attributions was important.

One plausible artifactual explanation of Experiment 1 is that that participants did not learn anything about animacy at all; but rather that a noun can be used with only two of the four determiners. That is, participants may have learned to group determiners into two categories: If a noun takes "chu" it can take "guai" and vice versa, and the same for "ya" and "tuo". Experiment 2 aimed at addressing this possibility.

3. Experiment 2

In Experiment 1, all nouns in the test phase had been used in the training phase. Thus, people could learn that a given noun happens to belong with a set of two determiners simply by experiencing it together with just one of those determiners. Thus, in order to establish if people have learnt about animacy per se, it is necessary to use new nouns as generalization items. Experiment 2 used the same procedure as Experiment 1, but with more generalization items, which all contained new nouns. We predict that if people have learned the animacy rule they should still perform above chance on the generalization items; if they merely learned to group determiners, they will perform at chance on the generalization items (but well on the trained items).

3.1. Method

3.1.1. Participants

Thirty undergraduate and graduate students from East China Normal University (aged from 19 to 28, $M = 20.27$, $SD = 1.57$, nine men and 21 women) participated in this experiment. None of them had participated in Experiment 1.

3.1.2. Materials and procedure

The noun phrases used for training and testing are displayed in Appendix B. Ten noun phrases accompanied by sentence context were created for each determiner as training items. Therefore, there were 40 training items in all. In addition, 32 old noun phrases accompanied by 32 new sentences (trained items) and 32 new noun phrases embedding in 32 new sentences (generalization items) were used as testing items. None of the nouns of the generalization items had appeared in the training phase.

The procedure was identical to that of Experiment 1.

3.2. Results and discussion

3.2.1. Proportion of correct responses

Overall classification accuracy (0.60 ± 0.09) was higher than chance ($t(29) = 5.98$, $p < .05$, $d = 1.09$). Accuracy for the generalization items was not detectably lower than for the trained sets ($t(29) = 1.55$, $p > .05$, $dz = 0.28$). Indeed, the accuracy for the trained items (0.61 ± 0.08) and the generalization items (0.58 ± 0.14) were each significantly higher than chance (trained: $t(29) = 7.91$, $p < .05$, $d = 1.44$; generalization: $t(29) = 3.09$, $p < .05$, $d = 0.56$).

3.2.2. Conscious and unconscious structural knowledge

The response frequency of each attribution is illustrated in Table 1. The proportion of correct responses for each attribution in both trained and generalization sets is shown in Fig. 2. As before, responses based on guess and intuition were combined to indicate unconscious structural knowledge and responses based on memory and rules were combined to indicate conscious structural knowledge. Accuracy for responses based on unconscious (0.60 ± 0.10) and conscious (0.57 ± 0.14) structural knowledge were each significantly higher than chance (unconscious: $t(29) = 5.55$, $p < .05$, $d = 1.01$; conscious: $t(29) = 2.58$, $p < .05$, $d = 0.47$). Accuracy for responses based on unconscious structural knowledge was not significantly lower than for those based on conscious structural knowledge ($t(29) = 1.29$, $p > .05$, $dz = 0.23$).

For the trained items, accuracy for responses based on unconscious (0.62 ± 0.10) and on conscious (0.56 ± 0.14) structural knowledge were each above chance (unconscious: $t(29) = 7.05$, $p < .05$, $d = 1.29$; conscious: $t(29) = 2.40$, $p < .05$, $d = 0.44$). For the generalization items, accuracy for responses based on unconscious structural knowledge (0.58 ± 0.14) was significantly higher than chance ($t(29) = 3.05$, $p < .05$, $d = 0.56$), whereas accuracy for responses based on conscious knowledge (0.55 ± 0.23) was not ($t(28) = 1.08$, $p > .05$, $d = 0.20$).

Finally, a 2 test set (trained versus generalization) × 2 responses (conscious versus unconscious) revealed no significant effects.

In sum, participants did not learn simply to group determiners into classes. They could instead generalize to nouns that had not been associated with either determiner in training, so they must have generalized on the basis of a similarity or regularity between the new nouns and the trained ones. We suggest the regularity is the linguistically relevant feature of animacy. If linguistic relevance is important for allowing or potentiating implicit learning in linguistic contexts, then a nonlinguistically relevant feature should be difficult to learn. Experiment 3 was designed to test this prediction.

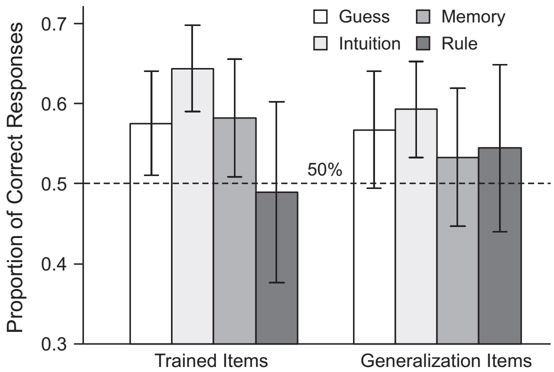

Fig. 2. Proportion of correct responses for each attribution in Experiment 2. Error bars indicate 95% confidence intervals.

4. Experiment 3

In Experiment 3, we used the same procedure as Experiment 2, except that the feature to be learnt was not linguistically relevant but arbitrary. We constructed a list of large and small animals (e.g. cow versus mouse). The feature employed can be characterized as: Prototypical size larger or smaller than that of a dog. If people learn this feature just as readily as animacy, then the hypothesis that linguistic relevance is important for implicit learning in linguistic contexts would be challenged. Conversely, if people fail to learn it would show implicit learning does not automatically occur for arbitrary rules, even if the rule refers to a simple concrete feature and is easy to apply when consciously known.

4.1. Method

4.1.1. Participants

Thirty undergraduate and graduate students (aged from 18 to 23, $M = 20.00$, $SD = 1.08$, 9 male and 21 female) from East China Normal University participated in this experiment. None of them had participated in Experiment 1 or 2.

4.1.2. Materials and procedure

The noun phrases used for training and testing are shown in Appendix C. The materials were similar to those of Experiment 2 except that all the nouns were animals. These animals were divided into two categories according to their prototypical sizes: larger or smaller than an average dog. There were two critical rules regulating determiners before nouns: the distance rule and the body size rule. In the first version of materials, "夬" was used to modify larger and far nouns, "疋" was used to modify smaller and near nouns, "亍" was used to modify larger and near nouns and "乇" was used to modify smaller and far nouns. A second version of the materials was constructed, in which the assignment of the determiners was changed, so that "乇" and "疋" modified larger objects and "夬" and "亍" modified smaller objects. Thus, assignment of determiner to animacy was counterbalanced across participants.

The procedure was the same as that of Experiment 2.

4.2. Results and discussion

4.2.1. Proportion of correct responses

The overall accuracy (0.49 ± 0.04) was not significantly different from chance ($t(29) = -0.86$, $p > .05$, $d = 0.16$): Not for the trained items (0.51 ± 0.09, $t\,(29) = 0.48$, $p > .05$, $d = 0.09$), nor for the generalization items (0.48 ± 0.11, $t(29) = -1.09$, $p > .05$, $d = 0.20$). Accuracy for the generalization items was not significantly different from that for the trained items ($t(29) = 0.89$, $p > .05$, $dz = 0.16$).

4.2.2. Structural knowledge

The response frequency of each attribution is illustrated in Table 1 and the proportion of correct responses for each attribution in both trained and generalization sets is shown in Fig. 3. None of the performance levels for the four attributions was significantly different from chance.

Overall accuracy in Experiment 3 (0.49) was significantly lower than that in Experiment 2 (0.60), $t(41.852) = 5.75$, $p < .05$, $d = 1.49$. That is, despite following the same procedure, a linguistically relevant variable (animacy) was considerably easier to learn than a linguistically arbitrary one (size relative to a dog). The results support the importance of linguistic relevance to implicit learning in linguistic contexts. Like Experiment 2, they also provide evidence against the hypothesis that people learnt simply to associate individual nouns with a pair of determiners; such a strategy would allow learning of trained items

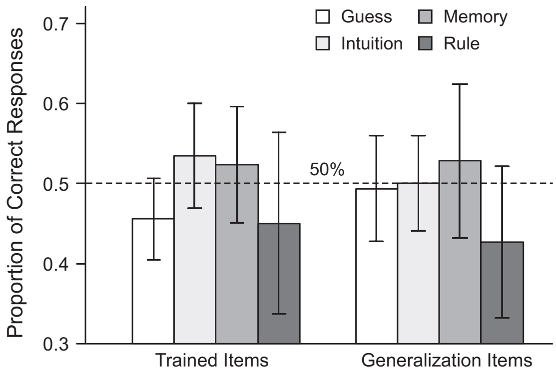

Fig. 3. Proportion of correct responses for each attribution in Experiment 3. Error bars indicate 95% confidence intervals.

just as readily in Experiment 3 as in the previous experiments. More strongly, the results count against a theory that people used accurate memory for individual items at all; if they had, the trained items in Experiment 3 should be as easy to classify as in Experiment 2. Instead, performance on trained items in Experiment 3 (0.51) was significantly less than in Experiment 2 (0.61) ($t(58) = 4.80$, $p < .05$, $d = 1.24$). The regularities in the material were vital to successful performance, and a regularity defined by animacy was easier to learn than one based on size.

5. General discussion

Experiments 1 and 2 showed that people could learn to use an appropriate determiner based on the animacy of the noun. In natural languages determiners can be sensitive to a range of features. For example, in English, the determiners 'this' versus 'that' make a near–far distinction, equivalent to 'zhege' versus 'nage' in Mandarin. In Mandarin, animacy is also relevant: for example, "只" always modifies living things whereas "支" always modifies nonliving things. Thus, animacy is a linguistically relevant feature, that is, a feature that in natural languages selects different determiner forms for different nouns. Without the experimenter directing people's attention to this feature, people nonetheless learnt to be sensitive to it, conceptually replicating Williams (2004, 2005). In addition, we showed with trial by trial subjective measures that such knowledge could be unconscious. Thus we showed genuine implicit learning of this form–meaning connection.

Experiment 3 showed that use of another feature (smaller or larger than a prototypical dog) did not result in learning under the same conditions. Thus, implicit learning only becomes sensitive to some of the available regularities. We propose it is those regularities with a high prior probability of being relevant within a particular domain. Consistent with the proposal of domain specific constraints in what structures can be implicitly learnt, Ziori and Dienes (2008) showed prior beliefs influenced what was learnt in implicit concept formation; Kuhn and Dienes (2005) and Dienes, Kuhn, Guo, and Jones (in press) showed implicit learning of a structure in music not apparently learned in letter strings (Shanks, Johnstone, & Staggs, 1997) but used in music composition; and Rohrmeier, Rebuschat, and Cross (2011) and Rohmeier and Cross (2010) found the same finite state grammar was more or less easy to implicitly learn in a musical context depending on whether the notes assigned as terminals led to structures that obeyed standard rules of melody.

Future work is needed to determine more precisely what makes a feature more learnable than another. Do Chinese native speakers implicitly learn about animacy because animacy is a feature relevant to specifically Chinese determiners? Or are humans all born and continue to be sensitive to the possible relevance of a set of features, regardless of whether their first language uses that feature to distinguish different determiners? A further issue is raised by the fact that we did not direct attention to either the size or animacy feature. What would happen if we directed attention? Implicit learning is sensitive to whether a feature is attended to as such (e.g. Eitam et al., 2009; Jiménez & Méndez, 1999; Tanaka et al., 2008); thus it remains an open question as to whether people could implicitly learn about the size feature when attention is directed towards it, or whether any learning that occurs would be entirely conscious for such linguistically irrelevant cues.

Learning in these experiments may be based on a super-positional connectionist system (McClelland & Rumelhart, 1986) whereby animacy, while never singled out for attention for any training item, nonetheless was the feature not averaged out over all training items. Maybe there are pre-existing biases in the weights for certain features in certain domains (e.g. animacy versus size for learning about determiner forms). Or a language learning device may be based on a pre-set list of possible rules, which includes the form of determiners and the animacy of the noun. Our results do not distinguish these possibilities. But they do indicate that when modeling implicit learning (see Cleeremans & Dienes, 2008), using networks with randomly assigned pre-training weights is unlikely to accurately model real people (cf. Altmann, 2002).

In sum, we demonstrate the acquisition of unconscious knowledge of a form–meaning connection when the regularity is linguistically relevant rather than arbitrary, showing that construction of materials for implicit learning experiments should be guided by theories of a prior likely structures in given domains (e.g. chunking for letters) and not the use of arbitrary rules.

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Appendix A. Noun phrases used in Experiment 1

Animate				Inanimate			
Near		Far		Near		Far	
Training							
亍狮子	Chù lion	夬猴子	Guài monkey	疋桌	Yǎ table	乇凳	Tuō stool
亍鸟	Chù bird	夬蜜蜂	Guài bee	疋花瓶	Yǎ vase	乇钟	Tuō cbck
亍狗	Chù dog	夬狗	Guài dog	疋沙发	Yǎ sofa	乇沙发	Tuō sofa
亍鼠	Chù mouse	夬鼠	Guài mouse	疋杯	Yǎ cup	乇杯	Tuō cup
亍奶牛	Chù cow	夬奶牛	Guài cow	疋电视	Yǎ television	乇电视	Tuō television
亍猫	Chù cat	夬猫	Guài cat	疋垫子	Yǎ cushion	乇垫子	Tuō cushion
亍苍蝇	Chù fly	夬苍蝇	Guài fly	疋书	Yǎ book	乇书	Tuō book
亍蛇	Chù snake	夬蛇	Guài snake	疋盘子	Yǎ plate	乇盘子	Tuō plate
亍猪	Chù pig	夬猪	Guài pig	疋箱子	Yǎ box	乇箱子	Tuō box
亍狗熊	Chù bear	夬狗熊	Guài bear	疋画	Yǎ picture	乇画	Tuō picture
Trained item test							
亍狗	Chù dog	夬狗	Guài dog	疋沙发	Yǎ sofa	乇沙发	Tuō sofa
亍鼠	Chù mouse	夬鼠	Guài mouse	疋杯	Yǎ cup	乇杯	Tuō cup
亍奶牛	Chù cow	夬奶牛	Guài cow	疋电视	Yǎ television	乇电视	Tuō television
亍猫	Chù cat	夬猫	Guài cat	疋垫子	Yǎ cushion	乇垫子	Tuō cushion
亍苍蝇	Chù fly	夬苍蝇	Guài fly	疋书	Yǎ book	乇书	Tuō book
亍蛇	Chù snake	夬蛇	Guài snake	疋盘子	Yǎ plate	乇盘子	Tuō plate
亍猪	Chù pig	夬猪	Guài pig	疋箱子	Yǎ box	乇箱子	Tuō box
亍狗熊	Chù bear	夬狗熊	Guài bear	疋画	Yǎ picture	乇画	Tuō picture
Generalization item test							
亍猴子	Chù monkey	夬狮子	Guài lion	疋凳	Yǎ stool	乇桌	Tuō table
亍蜜蜂	Chù bee	夬鸟	Guài bird	疋钟	Yǎ clock	乇花瓶	Tuō vase

Appendix B. Noun phrases used in Experiment 2

Animate				Inanimate			
Near		Far		Near		Far	
Training (40)							
亍猴子	Chù monkey	夬猴子	Guài monkey	疋桌	Yǎ table	乇桌	Tuō table
亍狗	Chù dog	夬狗	Guài dog	疋沙发	Yǎ sofa	乇沙发	Tuō sofa
亍蜜蜂	Chù bee	夬蜜蜂	Guài bee	疋钟	Yǎ clock	乇钟	Tuō cbck
亍鼠	Chù mouse	夬鼠	Guài mouse	疋杯	Yǎcup	乇杯	Tuō cup
亍奶牛	Chù cow	夬奶牛	Guài cow	疋电视	Yǎ television	乇电视	Tuō television
亍猫	Chù cat	夬猫	Guài cat	疋垫子	Yǎ cushion	乇垫子	Tuō cushion
亍苍蝇	Chù fly	夬苍蝇	Guài fly	疋书	Yǎbook	乇书	Tuō book
亍蛇	Chù snake	夬蛇	Guài snake	疋盘子	Yǎ plate	乇盘子	Tuō plate
亍猪	Chù pig	夬猪	Guài pig	疋箱子	Yǎbox	乇箱子	Tuō box
亍狗熊	Chù bear	夬狗熊	Guài bear	疋画	Yǎ picture	乇画	Tuō picture
Trained item test (32)							
亍蜜蜂	Chù bee	夬蜜蜂	Guài bee	疋钟	Yǎ cbck	乇钟	Tuō cbck
亍鼠	Chù mouse	夬鼠	Guài mouse	疋杯	Yǎ cup	乇杯	Tuō cup
亍奶牛	Chù cow	夬奶牛	Guài cow	疋电视	Yǎ television	乇电视	Tuō television

Appendix B (*continued*)

Animate				Inanimate			
Near		Far		Near		Far	
亍猫	Chù cat	夬猫	Guài cat	疋垫子	Yǎ cushion	乇垫子	Tuō cushion
亍苍蝇	Chù fly	夬苍蝇	Guài fly	疋书	Yǎ book	乇书	Tuō book
亍蛇	Chù snake	夬蛇	Guài snake	疋盘子	Yǎ plate	乇盘子	Tuō plate
亍猪	Chù pig	夬猪	Guài pig	疋箱子	Yǎ box	乇箱子	Tuō box
亍狗熊	Chù bear	夬狗熊	Guài bear	疋画	Yǎ picture	乇画	Tuō picture
Generalization item test (32)							
亍狮子	Chù lion	夬狮子	Guài lion	疋凳	Yǎ stool	乇凳	Tuō stool
亍鸟	Chù bird	夬鸟	Guài bird	疋花瓶	Yǎvase	乇花瓶	Tuō vase
亍鲸鱼	Chù whale	夬鲸鱼	Guài whale	疋床	Yǎbed	乇床	Tuō bed
亍象	Chù elephant	夬象	Guài elephant	疋柜子	Yǎ cabinet	乇柜子	Tuō cabinet
亍豹	Chù leopard	夬豹	Guài leopard	疋窗帘	Yǎ curtain	乇窗帘	Tuō curtain
亍马	Chù horse	夬马	Guài horse	疋灯	Yǎ lamp	乇灯	Tuō lamp
亍乌龟	Chù tortoise	夬乌龟	Guài tortoise	疋镜	Yǎ mirror	乇镜	Tuō mirror
亍绵羊	Chù sheep	夬绵羊	Guài sheep	疋抽屉	Yǎ drawer	乇抽屉	Tuō drawer

Appendix C. Noun phrases used in Experiment 3

Big				Small			
Near		Far		Near		Far	
Training (40)							
亍鹿	Chù deer	夬鹿	Guàideer	疋鸡	Yd cock	乇鸡	Tu6 cock
亍熊猫	Chù panda	夬熊猫	Guài panda	疋青蛙	Yǎ frog	乇青蛙	Tuō frog
亍奶牛	Chù cow	夬奶牛	Guài cow	疋猴子	Yǎ monkey	乇猴子	Tuō monkey
亍猪	Chù pig	夬猪	Guài pig	疋蜜蜂	Yǎ bee	乇蜜蜂	Tuō bee
亍狗熊	Chù bear	夬狗熊	Guài bear	疋鼠	Yǎ mouse	乇鼠	Tuō mouse
亍狮子	Chù lion	夬狮子	Guài lion	疋猫	Yǎ cat	乇猫	Tuō cat
亍鲨鱼	Chù shark	夬鲨鱼	Guài shark	疋苍蝇	Yǎ fly	乇苍蝇	Tuō ffy
亍象	Chù elephant	夬象	Guài elephant	疋虫	Yǎ insect	乇虫	Tuō insect
亍豹	Chù leopard	夬豹	Guài leopard	疋鸟	Yǎ bird	乇鸟	Tuō bird
亍马	Chù horse	夬马	Guài horse	疋乌龟	Yǎ tortoise	乇乌龟	Tuō tortoise
Trained item test (32)							
亍奶牛	Chù cow	夬奶牛	Guàicow	疋猴子	Yǎ monkey	乇猴子	Tuō monkey
亍猪	Chù pig	夬猪	Guài pig	疋蜜蜂	Yǎ bee	乇蜜蜂	Tuō bee
亍狗熊	Chù bear	夬狗熊	Guài bear	疋鼠	Yǎ mouse	乇鼠	Tuō mouse
亍狮子	Chù lion	夬狮子	Guài lion	疋猫	Yǎ cat	乇猫	Tuō cat
亍鲨鱼	Chù shark	夬鲨鱼	Guài shark	疋苍蝇	Yǎ fly	乇苍蝇	Tuō fly
亍象	Chù elephant	夬象	Guài elephant	疋虫	Yǎ insect	乇虫	Tuō insect
亍豹	Chù leopard	夬豹	Guài leopard	疋鸟	Yǎ bird	乇鸟	Tuō bird
亍马	Chù horse	夬马	Guài horse	疋乌龟	Yǎ tortoise	乇乌龟	Tuō tortoise
Generalization item test (32)							
亍绵羊	Chù sheep	夬绵羊	Guài sheep	疋兔	Yǎ rabbit	乇兔	Tuō rabbit
亍袋鼠	Chù kangaroo	夬袋鼠	Guài kangaroo	疋金鱼	Yǎ goldfish	乇金鱼	Tuō goldfish
亍虎	Chù tiger	夬虎	Guài tiger	疋蜗牛	Yǎ snail	乇蜗牛	Tuō snail
亍鳄	Chù crocodile	夬鳄	Guài crocodile	疋蝉	Yǎ cicada	乇蝉	Tuō cicada
亍河马	Chù hippo	夬河马	Guài hippo	疋虾	Yǎ shrimp	乇虾	Tuō shrimp
亍骆驼	Chù camel	夬骆驼	Guài camel	疋鹰	Yǎ eagle	乇鹰	Tuō eagle
亍驴	Chù donkey	夬驴	Guài donkey	疋蚂蚁	Yǎant	乇蚂蚁	Tuō ant
亍狼	Chù wolf	夬狼	Guài wolf	疋蜻蜓	Yǎ dragonfly	乇蜻蜓	Tuō dragonfly

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