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Short Communication

Unconscious structural knowledge of tonal symmetry: Tang poetry redefines limits of implicit learning

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ABSTRACT

The study aims to help characterize the sort of structures about which people can acquire unconscious knowledge. It is already well established that people can implicitly learn *n*-grams (chunks) and also repetition patterns. We explore the acquisition of unconscious structural knowledge of symmetry. Chinese Tang poetry uses a specific sort of mirror symmetry, an inversion rule with respect to the tones of characters in successive lines of verse. We show, using artificial poetry to control both *n*-gram structure and repetition patterns, that people can implicitly learn to discriminate inversions from non-inversions, presenting a challenge to existing models of implicit learning.

1. Introduction

Much of what we learn is to enable specific competencies in perceiving and acting. Such knowledge need not be conscious: It is enough that we do or see the right thing, not that we consciously know how we did it. Indeed, we cannot represent consciously everything that we know how to do, for logical reasons to do with the impossibility of a system completely modeling itself (Popper, 1982). Sometimes we just have to know things, without consciously knowing what we know. Implicit learning is the term coined by Reber (1967) to describe this process by which we come to be sensitive to structural regularities without necessarily intending to do so and without being conscious of the content of the knowledge (cf. e.g. Cleeremans, 2011; Dienes, 2008a, 2012; Williams, 2009; contrast e.g. Shanks, 2005). A fundamental issue is how to characterize the structures that can be implicitly learnt. We can in principle consciously learn about any structure, limited only by our imagination. But unconscious learning may be more defined (though there are as yet no well established limits). For example, there may be constraints on what natural grammars can consist of (e.g. Chomsky, 2002; Hawkins, 2004). Some have argued that implicit learning in more general domains may consist only of chunking (e.g. Perruchet & Vinter, 1998) or specific remembered patterns found in learned exemplars (e.g. Brooks & Vokey, 1991; Jamieson & Mewhort, 2009). Indeed, there is good evidence that both chunks and specific encountered patterns are learned in implicit learning paradigms (e.g. Pothos & Bailey, 2000; Scott & Dienes, 2008). So do chunks and learned exemplars define the limits of implicit learning?

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People do not readily implicitly learn arbitrary complex rules (Perruchet, Gallego, & Savy, 1990) or even arbitrary simple associations (Olson, Kendrick, & Fazio, 2009). Instead, people most readily implicitly learn about structures which have high prior probabilities for being relevant (Chen et al., 2011; Ziori & Dienes, 2008; cf. Williams, 2009). One type of regularity that is not arbitrary, but of relevance to several domains, is symmetry. Leyton (1992) argued that symmetries form the fundamental basis of perceptual and linguistic computations. The grammars above finite state in Chomsky's hierarchy uniquely produce various symmetries, such as, center embedding (e.g. "the monkey *the man stroked* sighed"). People are sensitive to symmetry in other domains as well (see e.g. Reber, Schwarz, & Winkielman, 2004). For example, we like symmetric faces (perhaps for evolutionary reasons to do with mate selection; Grammer & Thornhill, 1994), and we like art works and scientific theories exhibiting symmetry (Arnheim, 1988; Hunter & Von Hippel, 2003; Kempf, 1996; perhaps for evolutionary reasons to do with favoring simple models, Chater & Vitányi, 2002). Moreover, Perrig and Eckstein, 2005 found subliminal priming from mirror reflected words, thus suggesting that symmetries can be processed implicitly. To detect symmetry is, by definition, to find an invariant: That which is preserved across the different symmetric instantiations. Thus, detecting symmetry can be computationally important, and allows for compression, faster encoding and easier storage of information.

Mirror symmetries as applied to sequences of elements involve grammars non-reducibly above finite state, and in that sense involve genuine recursion (see Bar-Hillel, Perles, & Shamir, 1961; Dienes, Kuhn, Guo, & Jones, 2012; Hopcroft & Ullman, 1979). Language involves symmetric constructions, like center embedding and cross serial dependencies (in some Germanic languages, where a list of verbs follows a list of corresponding nouns in the same order; cf. Dutch relative clauses), so it seems people can learn symmetry implicitly in at least one domain. (Though pigeons find it difficult to learn visual symmetries, Huber et al., 1999.) There are analogies between music and language (Fitch, 2005; Jackendoff, 2009; Rebuschat, Rohrmeier, Cross, & Hawkins, 2012; Rohrmeier, 2007, 2011), specifically in that both music and language may both involve recursive processing. Consistently, Dienes and Longuet-Higgins (2004) provided preliminary evidence that people experienced in twelve-tone music could implicitly learn to detect the mirror symmetries (musical inversions and retrogrades) in such music. Kuhn and Dienes (2005) found musically unselected people apparently could acquire implicit sensitivity to musical inversions in their liking ratings. Desmet, Poulin-Charronnat, Lalitte, and Perruchet (2009) argued that subjects in the Dienes and Kuhn experiments had not become sensitive to inversions but retrogrades; Dienes and Kuhn (2012) showed that the subjects in Kuhn and Dienes were sensitive to inversions when sensitivity to retrogrades (and other confounds) were statistically accounted for. Either way, subjects appeared able to become implicitly sensitive to mirror symmetries. However, any set of stimuli will always allow correlated structures that subjects may actually have been responding to, even if relatively obvious ones have been identified and controlled. All we can say is that in previous experiments people learnt structures created by symmetries. Converging evidence with different sorts of stimuli structures is needed to establish that people can implicitly learn symmetry.

Learning symmetry involves learning paired nonadjacent dependencies, i.e. grammars above finite state, such as A^nB^n (where a succession of n A elements is paired with a succession of n B elements). For example, $A^1A^2A^3B^1B^2B^3$, where the first A element requires the first B element be its corresponding partner, and likewise for the second and third elements, is a structure produced by a mirror "inversion" in music (imagine putting a horizontal mirror under a music score) or a cross serial dependency in language (structures requiring a grammar above context free). $A^1A^2A^3B^3B^2B^1$ is a structure produced by a mirror "retrograde" in music (imagine putting a vertical mirror adjacent to a music score), or center embedding in language (structures requiring a context free grammar). (In these examples, $n = 3$.) It has been difficult to demonstrate implicit learning of A^nB^n in implicit learning paradigms like artificial grammar learning (contrast Fitch & Hauser, 2004, with De Vries, Monaghan, Knecht, & Zwitserlood, 2008). Mueller, Bahlmann, and Friederici (2010) provided evidence of learning A^nB^n under intentional conditions, but implicit learning was not investigated. Rohrmeier, Fu, and Dienes (submitted for publication) provided evidence of the implicit learning of hierarchical recursive structures in language, supporting the plausibility of the learnability of mirror symmetries. Thus, the current paper seeks to show implicit learning of an inversion in language – specifically, in Chinese poetry.

The poetry we used is tonal. Tonal languages, including many languages in South East Asia and Africa, use tones to signal different meanings. For example, in Chinese the syllable "ma" pronounced in tone 1 means "mother", but "horse" when in tone 3. By virtue of the rising and falling intonation in Chinese characters, Chinese is figuratively depicted as "the small waves adding on the large waves" (Chao, 1933), each tone superimposes on the overall intonation pattern of a sentence. Chinese Tang poetry (which flourished at the beginning of Tang Dynasty) is especially interesting in the current context because it uses inversion symmetry with respect to the tones of different lines, as we shall see.

The visual esthetic effects of Chinese characters in Tang poetry has been well investigated (Chen, 2006; Jiang, 2005; Liang & Chen, 2008), but the auditory effects of Chinese poetry have been relatively neglected. However, tones and rime are closely intertwined with meanings to achieve a musical and esthetic effect in Tang poetry. Rime usually occurs at the end of the even numbered lines in Tang poetry, one can either use one rime throughout or change the rime as one wishes. Nevertheless, variation in tone also plays an important part in Chinese versification, whose rhythm depends on the combination of four tones: tone 1, tone 2, tone 3, and tone 4, indicating flat, rising, falling-rising and falling phonetic characteristics in pitch respectively. Tone 1 and tone 2 are categorized into ping (level) tones, while tone 3 and tone 4 are categorized into ze (oblique) tones in Chinese. The metrical rules of Chinese Tang poetry include:

(1) The line must be of 5 or 7 tonal syllables (characters) which consists of a syllable and a fixed tone.
(2) For lines 1/2, 3/4, 5/6, 7/8, a tonal inversion rule is used. For example, if the tone type of the first character in line 1 is ping, then the tone type of the first character in line 2 must be ze; if the tone type of the second character in line 1 is ze, then the tone type of the second character in line 2 must be ping, and so on (Zhang, 2007; Zhou, 2006). This binary inversion is a symmetry, taking ping and ze to be opposite categories (a way of categorizing tones that all our participants would have been taught at school).

Tone as an irreplaceable yet rather neglected factor of this delicate combination, is one of the initial speech features that young children acquired long before any other area of phonology during language discrimination (Bosch & Sebastián-Gallés, 1997; Nazzi, Jusczyk, & Johnson, 2000; Nazzi & Ramus, 2003), and thus we can speculate tonal pattern might easily figure in implicit learning. Note also the co-development of processing syntax and intonational prosody (Männel & Friederici, 2011), suggesting that the pitch contour of speech can figure in implicit structural learning. In this study, we will focus on the tonal inversion rule of ping (level) and ze (oblique) tones using a five syllable pattern. Just as Dienes and Longuet-Higgins (2004) investigated the implicit learning of mirror symmetry in an esthetic domain where it was actually used (serialist music), we will do the same here (Tang poetry).

We know people can consciously detect symmetries, and hence can, at least some times, consciously learn about the presence of symmetry in stimuli (cf. Mueller et al., 2010). By contrast, in the current research we seek to investigate the limits of implicit learning, thus a methodology is required for determining whether any acquired knowledge is unconscious. Following Dienes (2008a, 2012) we define knowledge of *p* as unconscious if a person is not aware of knowing *p*, even as they use knowledge that *p*. Awareness of knowing is a metacognitive state, hence an appropriate measure of the conscious status of knowledge is a metacognitive one, by this approach. Thus, in the current case, a subject may learn that the lines of poetry are inversions, as shown by their tendency to classify new poetry as well-formed according to this feature, but not be aware that they know this feature. Such a subject may insist their classification was just a guess, or based on intuition. By contrast, if subjects were aware of the basis of their classification, they could claim they followed a rule. Thus, we use the "structural knowledge attributions" of Dienes and Scott (2005; see also e.g. Chen et al., 2011; Fu, Dienes, & Fu, 2010a; Fu, Dienes, & Fu, 2010b; Guo et al., 2011; Rebuschat & Williams, 2009; Scott & Dienes, 2010a, 2010b; Wan, Dienes, & Fu, 2008). Specifically, after each classification decision, subjects indicated if the decision was based on a pure guess, intuition (they have some confidence but have no idea why), rules, or memory. 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 (see Dienes 2008a, 2012, for detailed justification of the methodology).

To summarize, we presented subjects with strings of 10 syllables where the tone types of the first five syllables of a string predicted those of the last five by an inversion relation (Fig. 1), e.g., if the tone type of the first syllable was ping, then the tone type of the sixth syllable was ze, and if the tone type of the second syllable was ping, then the tone type of the seventh syllable was ze, and so on. This inverse pattern is similar to two adjacent lines in above-mentioned five-syllable pattern of Tang poetry. In training, participants listened to and then silently repeated the strings. In a subsequent test, participants classified new strings as grammatical or not and then gave the structural knowledge attributions of Dienes and Scott (2005) to assess awareness on a trial by trial basis. The materials were designed to control the structures we already know subjects can implicitly learn, chunks and the repetition patterns found in strings, as explained in detail in Section 2.2 below. Thus, ability to classify while subjects say they guessing or using intuition would be evidence that people can learn to detect symmetry unconsciously, at least for fixed-length-stimuli, a result that would help argue for new limits to implicit learning, beyond just chunking and memorization of repetition patterns. Our materials go beyond those of Kuhn and Dienes (2005), who also provided evidence of implicitly learning inversions, in that we controlled for whether retrogrades were present (cf. Desmet et al., 2009) and for repetition structure (neither of which Kuhn and Dienes controlled directly).

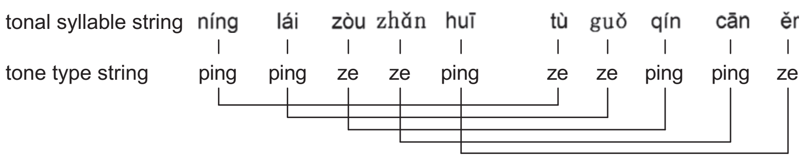

Fig. 1. An example of grammatical strings. Each string consisted of 10 tonal syllables and the tone types (pings or zes) of the previous five syllables predict the following inversion, e.g., if the tone type of the first syllable was ping, then the tone type of the sixth syllable was ze, and if the tone type of the second syllable was ping, then the tone type of the seventh syllable was ze, and so on. The inversion relation can be construed as an element to element mapping as shown; or as an operation on the whole of the first half which is then concatenated on the end. That is, if **V** represents the first half, −**V** is the inverse concatenated on (illustrating how symmetry is an "operation over variables"), taking ping to be - ze.

2. Method

2.1. Participants

Forty-two volunteers (33 female, aged 19–37, $M = 22.69$, $SD = 4.16$) from the university community participated in the experiment. They were randomly assigned to either experimental group or control group, with 21 in the experimental group. None of the participants reported a history of hearing difficulties and each of them received 20 RMB for participation.

2.2. Materials

Two types of tone were used to create the rhythm of Chinese Tang poetry: ping (level) tones and ze (oblique) tones. The grammar used in this experiment was an inversion rule of these two tones, where the inversion of ping was ze, and vice versa. Specifically, a total of 12 tonal syllables were selected: "cān jū huī níng lái qín", the tone type of which belongs to ping, and "guǒ ěr zhǎn zòu tù jùn", the tone type of which belongs to ze. Each string consisted of 10 different tonal syllables and the tone types (pings or zes) of the previous five syllables predicted the following inversion (Fig. 1).

Using the inversion rule, 32 grammatical tone type strings were generated, 16 of which were served as training strings and 16 were test strings. In addition, 16 ungrammatical tone type strings used in the test phase were created by exchanging the last one, two or three tone types of the previous five elements for the first one, two or three ones of the following five elements of the grammatical test strings, ensuring only two elements violated the inversion rule. Each training tone type string were shown three times, with 48 training items in all. Each test tone type strings were used twice, with 64 test items in all. See Appendix for stimuli. None of the strings had a clear semantic interpretation.

The material controlled both repetition structure and chunking. None of the test strings had the same repetition structures, in terms of being a succession of tone types, as any of the training strings. To clarify, the repetition structure of "ping ping ze ze ping", for example, is "11221" or that of "ze ping ping ze ze" is "12211" (cf. Vokey & Brooks, 1992). Furthermore, none of the test grammatical strings had the same repetition structures, in terms of tones 1–4, as any of the training strings. Because each string consisted of 10 different tonal syllables, the repetition structure of syllables was the same for inversions and non-inversions.

Furthermore, mean feature frequency (MFF), anchor associative chunk strength (ACS) and global ACS were counterbalanced between grammatical and ungrammatical test tone-type strings, $ps > .05$ (Table 1). MFF was calculated for each tone-type string by averaging the number of times each tone type appeared in the training phase in each of the ten positions. ACS was defined as the frequency with which a chunk occurred in the training phase and here the chunk was defined as tone-type bigrams and trigrams, then the mean ACS (global ACS) of each test tone-type string was calculated by averaging the above frequency scores across all of the chunks in the string. Anchor ACS was calculated the frequency with which tone-type bigrams and trigrams occurred in the beginning and ending positions. Grammatical and non-grammatical strings were also balanced along the same dimensions in terms of chunks of syllables and also separately of tones 1–4 rather than tone types (see Table 1).

Inversions can also sometimes be retrogrades, at least at an abstract level (Dienes & Longuet-Higgins, 2004). For example, in "ze ze ping ze ze, ping ping ze ping ping" the second half is not just the inverse of the first half but it is an inverse retrograde. None of the stimuli were literal retrogrades, but some were inverse retrogrades. In the test phase, 12 of the 32 test inversions were also retrogrades, as were 12 of the 32 non-inversions (see Appendix), so this feature is controlled.

The 12 tonal syllables were created by Chinese pronunciation software (*Xunfei interphonic 2.30*), each lasting for 450 ms. For each tonal syllable string, a 600 ms interval was interposed between the fifth and sixth tonal syllables to create a perceptual gap between the first half of the string and its inversion in the final half (cf. Mueller et al., 2010). Thus, each tonal syllable string lasted for 5100 ms.

Table 1
Mean MFF and ACS for grammatical and ungrammatical strings in terms of tone types (ping and ze), tones 1–4 and tonal syllables ($M \pm SD$).

	Tone types		Tones 1–4		Tonal syllables	
	G	UG	G	UG	G	UG
MFF	720.00 ± 0.00	720.00 ± 0.00	359.94 ± 0.30	359.96 ± 0.30	120.06 ± 1.28	119.86 ± 0.93
Global ACS	233.72 ± 2.27	234.28 ± 1.37	51.15 ± 2.87	50.49 ± 3.31	4.96 ± 0.57	4.91 ± 0.53
Anchor ACS	52.88 ± 3.02	52.31 ± 3.18	10.97 ± 2.19	10.97 ± 1.94	0.75 ± 0.50	0.82 ± 0.58

Note: G = grammatical; UG = ungrammatical; MFF = mean feature frequency; ACS = associative chunk strength.

2.3. Procedure

There were two phases: training and test phase. Only the experimental group received the training phase (cf. Dienes & Altmann, 2003).

2.3.1. Training phase

Participants in the experimental group were requested to listen to 144 trials in all, which consisted of 48 grammatical tonal syllable strings repeated three times in a random order. In each trial, a warning tone was presented for 450 ms, followed by a 5100 ms tonal syllable string and a 5000 ms blank. Participants were instructed to listen to each tonal syllable string carefully and silently repeat it during the 5000 ms delay before the next trial. The training phase lasted about 30 min.

2.3.2. Test phase

All the participants received the test phase. During test phase, participants were informed that the strings that they heard in the training phase were generated using a specific rule and were asked to listen to a set of 64 new strings presented in a random order. For each string, they were required to judge whether the given string was grammatical and attribute their decision basis to four categories (guess, intuition, memory and rules). As defined to participants, "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.

3. Results

An alpha level of .05 is used throughout.

3.1. Proportion of correct responses and conscious status of judgment knowledge

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).

The classification performance for experimental and control groups in the test phase were 0.58 (SD = 0.07) and 0.51 (SD = 0.05), respectively. Participants in the experimental group performed significantly better than the control group, $t(40) = 3.39$, $d = 1.05$, whereas the control group did not perform detectably different from chance, $t(20) = 1.04$, $d = 0.23$.

Table 2
Proportion of "yes" endorsements according to whether or not a test string was an inverse or a retrograde.

	I & R	I & NR	R & NI	NI & NR
Experimental group	0.52 ± 0.16	0.58 ± 0.13	0.39 ± 0.14	0.42 ± 0.10
Control group	0.54 ± 0.14	0.53 ± 0.08	0.45 ± 0.13	0.44 ± 0.12

Notes: I & R = inverse & retrograde; I & NR = inverse & non-retrograde; R & NI = retrograde & non-inverse; NI & NR = non-inverse & non-retrograde. A Group by Inverse by Retrograde analysis of variance indicated a significant effect of Inverse, $F(1,40) = 18.29$, and an Inverse by Group interaction, $F(1,40) = 10.52$, but no detectable effect of Retrograde, $F(1,40) = 1.94$, nor of the Retrograde by Group interaction, $F(1,40) = 1.29$.

Table 3
Response proportions of each attribution of the first and second test parts for the experimental and control group ($M \pm SD$).

		Implicit attributions		Explicit attributions	
		Guess	Intuition	Memory	Rule
Experimental group	1	0.25 ± 0.14	0.44 ± 0.19	0.21 ± 0.14	0.10 ± 0.10
	2	0.27 ± 0.19	0.43 ± 0.18	0.17 ± 0.15	0.13 ± 0.13
Control group	1	0.50 ± 0.25	0.45 ± 0.21	0.04 ± 0.10	0.01 ± 0.03
	2	0.44 ± 0.27	0.51 ± 0.24	0.05 ± 0.12	0.01 ± 0.02

Notes: 1 = the first half; 2 = the second half.

Table 4
Percentage of correct responses of each attribution of the first and second test parts for the experimental and control group (*M* ± *SD*).

		Implicit attributions		Explicit attributions	
		Guess	Intuition	Memory	Rule
Experimental group	1	0.47 ± 0.17	0.58 ± 0.13	0.54 ± 0.17	0.62 ± 0.14
	2	0.53 ± 0.12	0.58 ± 0.14	0.50 ± 0.19	0.54 ± 0.18
Control group	1	0.48 ± 0.13	0.54 ± 0.10	0.50 ± 0.12	0.50 ± 0.11
	2	0.50 ± 0.15	0.48 ± 0.14	0.52 ± 0.13	0.52 ± 0.09

Notes: 1 = the first half; 2 = the second half.

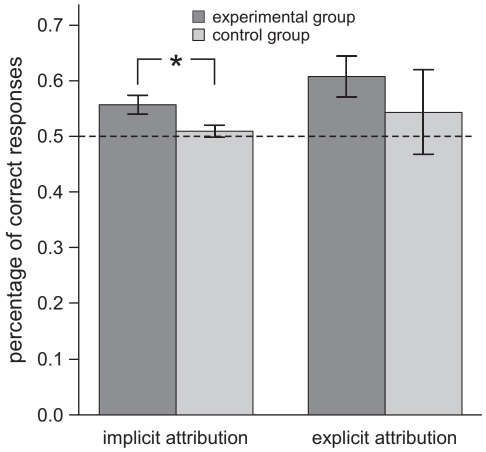

Fig. 2. Percentage of correct responses by implicit and explicit attributions, compared for experimental versus control group ($^*p < .05$). Error bars indicate standard error of the mean.

The classification performance cross-classified according to whether the test item was an inverse or a retrograde is illustrated in Table 2.

3.2. Conscious and unconscious structural knowledge

Guess and intuition attributions were combined as indicators of unconscious structural knowledge (implicit attributions), and memory and rule attributions were combined as indicators of conscious structural knowledge (explicit attributions) (Dienes & Scott, 2005).

To determine if there was any strategy change or learning over the test phase, response proportions and percentage of correct responses for each attribution for the first and second halves of the test phase for each group are shown in Tables 3 and 4. None of the differences between the first and second halves were significant, $ps > .05$.

The percentage of correct responses for implicit and explicit attributions is illustrated in Fig. 2. For the experimental group, judgments of implicit and explicit attributions were all significantly above chance (implicit: $t(20) = 3.38$, $d = 0.74$; explicit: $t(17) = 2.92$, $d = 0.69$). For the control group, judgments of implicit and explicit attributions were not detectably different from chance, $ps > .05$. Further, implicit knowledge for the experimental group differed significantly from the control group, $t(40) = 2.39$, $d = 0.74$, with sequential Bonferroni correction, whereas explicit knowledge for the experimental group did not differ significantly from the control group, $t(26) = 0.85$, $d = 0.31$, with sequential Bonferroni correction, indicating unconscious structural knowledge of the tonal inversion rule.

While we can conclude there was unconscious knowledge of the inversion, what can we conclude about conscious knowledge? Few attributions reflected conscious knowledge, so standard errors for proportion correct are high for such knowledge. The mean difference between the experimental and control group in percentage correct for conscious knowledge was 6%, with a standard error of the difference of 7%. Dienes (2008b, 2011) recommended interpreting non-significant results with Bayes Factors. Based on the accuracy of unconscious knowledge of 5%, we modeled an expectation for conscious knowledge with a half-normal with a mode of zero and a standard deviation of 5% (see Dienes, 2011, Appendix 1); that is, if conscious knowledge existed, we expected the most plausible population values to be between 0% and 10%. The Bayes Factor in favor of the existence of conscious knowledge over the null hypothesis of no conscious knowledge was 1.25, close to 1, indicating no sensitivity in the data for picking up how accurate conscious knowledge was (a Bayes Factor of greater than 3 would be strong evidence for the theory that conscious knowledge existed; a Bayes Factor of less than a 1/3 would be strong evidence in favor of the null of no conscious knowledge; and a Bayes Factor between 3 and a 1/3 indicates data insensitivity). So nothing can be concluded about conscious knowledge: Further research with more subjects or test trials is needed.

4. Discussion

The aim of the experiment presented here was to investigate whether a tonal inversion rule found in Chinese Tang poetry could be learnt implicitly. Participants indeed acquired the capacity to detect inversions, and most importantly, this occurred when the knowledge was unconscious, as determined by structural knowledge attributions.

Models of implicit learning have been based on the known capacities of chunking and learning specific repetition patterns (e.g. Boucher & Dienes, 2003; Cleeremans, 1993; Dienes, Altmann, & Gao, 1995; Servan-Schrieber & Anderson, 1990; Perruchet and Vinter, 1998; see Cleeremans & Dienes, 2008 for a review). Current computational models of implicit learning (Cleeremans & Dienes, 2008) would find learning symmetry per se difficult: Most models are connectionist, or reducible to a simple connectionist network, and connectionist networks have difficulty learning "operations over variables", as Marcus (2001) put it, because networks characteristically learn to map specific values to values. (We need not agree with Marcus that learning operations over variables is impossible for connectionist networks in order to note that it is difficult: Dienes, Altmann, & Gao, 1999.) However, Dienes and Longuet-Higgins (2004) and Kuhn and Dienes (2005) showed people could go beyond learning chunks and repetition patterns and implicitly learn to detect symmetries – or at least structures created by symmetries. Kuhn and Dienes (2008) showed that the SRN could learn the specific stimuli of Kuhn and Dienes (2005), though by learning a set of specific long distance associations rather than a symmetry per se. It is possible that this is what people did in the previous studies as well as in the current study. For example, people may have learnt the associations of ping/ze with ze/ping five characters along. If people had learned the inversion as such, they would be able to generalize to poems of different lengths of lines (and fixed length associations would no longer help). Further research needs to show whether people (and the SRN) can truly learn an inversion per se – e.g. something that can generalize to untrained lengths of stimuli. Nonetheless, showing implicit learning of associations of elements five steps apart is in itself an important finding, as most implicit learning research focuses on learning associations from only one or two or occasionally three elements back (for an exception see Remillard, 2010, who demonstrated implicit learning over seven items).

Studies of tonal language have focused mainly on cross-language listeners, that is whether or not tonal characteristics can be learnt or discriminated by adult speakers of non-tonal languages (Francis, Ciocca, Ma, & Fenn, 2008; Gandour et al., 2003; Wang, Spence, Jongman, & Sereno, 1999; Wayland & Guion, 2003, 2004; Wayland & Li, 2008). These results suggested that it is very difficult for non-tonal speakers to attempt to learn an unfamiliar tonal language which supports the view that linguistic experience plays an important role. Adult listeners often have difficulty perceptually discriminating a phonetic contrast that does not exist in their first language (Strange, 1995). However, it would be interesting to know whether speakers of a non-tonal language could learn the current stimuli as readily as Chinese speakers. Dienes and Longuet-Higgins (2004) found unselected people could not learn the symmetries in twelve-tone music, only dedicated specialists could, such symmetries had to be simplified by Kuhn and Dienes (2005) to obtain learning in unselected subjects. Consistently, Scott and Dienes (2010b) showed experimentally that exposure to unfamiliar elements to make them familiar enhanced the capacity to implicitly learn relations between them.

A further question is the role that fluency plays in unconscious symmetry detection. According to one argument, symmetries are useful to detect precisely because their detection speeds up processing. Consistently Reber et al. (2004) review evidence for symmetry producing fluency. Thus, maybe participants could pick out the symmetric poems because they were processed fluently. On the other hand, Scott and Dienes (2010c) showed fluency played no role in accuracy in standard artificial grammar learning of finite state grammars. The latter result suggests that participants might not in fact use fluency to pick out symmetric poems. Only future research can resolve this question.

We have argued that structures are most likely to be learned which have high prior probabilities. Many of the participants in the experiment would have learnt Tang poetry at school. While this was not sufficient for them to be sensitive to symmetry in the artificial poetry without training in the lab (as the untrained control group shows), prior experience may well have predisposed the learning system to detecting symmetry (cf. Dienes & Longuet-Higgins, 2004). Nonetheless, the learning was largely implicit as shown by the structural knowledge attributions (further, in debriefing, no participant mentioned symmetry, directly or indirectly). If conditions are found in which a control group shows implicit sensitivity to symmetry in poetry, future research could determine if an implicit preference for symmetry could be unlearned as well as learned.

To conclude, we argue that in investigating the limits of implicit learning we should consider ecologically valid structures and that symmetry is a structure with good prior plausibility of being useful and thus learnable. In dealing with a domain where symmetry is used for esthetic purposes, people can learn to discriminate instances of inversions from non-inversions, controlling for people's known ability to implicitly learn *n*-grams and repetition patterns. Future research still needs to pin down more precisely under what description such inverses are unconsciously known by. The hypothesis that they were known as inverses, as symmetries, remains viable.

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Appendix A

A.1. Training phase

Sixteen tone strings in the training phase. Note that each string repeats three times, with 48 training items in all.

Notes: 平 = ping, 仄 = ze

仄仄仄仄仄	平平平平平
平平平平平	仄仄仄仄仄
仄平仄仄仄	平仄平平平
平仄平平平	仄平仄仄仄
仄仄仄平仄	平平平仄平
平平平仄平	仄仄仄平仄
平平仄仄仄	仄仄平平平
仄仄平平平	平平仄仄仄
平仄仄平仄	仄平平仄平
仄平平仄平	平仄仄平仄
仄平平仄仄	平仄仄平平
平仄仄平平	仄平平仄仄
仄平仄仄平	平仄平平仄
平仄平平仄	仄平仄仄平
仄仄平仄平	平平仄平仄
平平仄平仄	仄仄平仄平

A.2. Test phase

Thirty-two tone strings for different rules in the test phase. Note that each string repeats twice, with 64 test items in all.

Notes: 平 = ping, 仄 = ze, 1 = retrograde & inversion, 2 = inversion & non-retrograde, 3 = retrograde & non-inversion, 4 = non-retrograde & non-inversion.

平仄仄仄仄	仄平平平平	2
仄平平平平	平仄仄仄仄	2
仄仄平仄仄	平平仄平平	1
平平仄平平	仄仄平仄仄	1
仄仄仄仄平	平平平平仄	2
平平平平仄	仄仄仄仄平	2
平仄平仄仄	仄平仄平平	2
仄平仄平平	平仄平仄仄	2
平仄仄仄平	仄平平平仄	1
仄平平平仄	平仄仄仄平	1
仄平仄平仄	平仄平仄平	1
平仄平仄平	仄平仄平仄	1
仄仄平平仄	平平仄仄平	2
平平仄仄平	仄仄平平仄	2
仄仄仄平平	平平平仄仄	2
平平平仄仄	仄仄仄平平	2
平仄仄仄平	仄仄平平平	4
仄平平平仄	平平仄仄仄	4
仄仄平仄平	仄平仄平平	3
平平仄平仄	平仄平仄仄	3
仄仄仄平平	仄平平平仄	4
平平平仄仄	平仄仄仄平	4
平仄平仄平	仄仄仄平平	4
仄平仄平仄	平平平仄仄	4
平仄仄仄仄	平平平平仄	3
仄平平平平	仄仄仄仄平	3
仄平仄平平	仄仄平仄平	3
平仄平仄仄	平平仄平仄	3
仄仄平平平	平仄仄仄平	4
平平仄仄仄	仄平平平仄	4
仄仄平平平	仄平平仄仄	4
平平仄仄仄	平仄仄平平	4

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