THE QUARTERLY JOURNAL OF EXPERIMENTAL PSYCHOLOGY
2006, 59 (10), 1725–1744

Psychology Press
Taylor & Francis Group

Differences in the types of musical regularity learnt in incidental- and intentional-learning conditions

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Several studies have found learning of biconditional grammars only under intentional rule-search conditions (e.g., Johnstone & Shanks, 2001). Memorization of strings merely led to the learning of chunks. We used a musical grammar, a diatonic inversion, that is a type of biconditional grammar. Participants either were required to memorize a set of grammatical tunes (incidental learning), or were asked to search for the underlying rule whilst being given feedback about their performance (intentional learning). The results showed that participants in the incidental-learning condition did not learn the inversion rule and merely acquired explicit knowledge about chunks. However, participants in the intentional-learning condition learnt both the inversion rule and chunks.

People have an impressive ability to learn about the structure of objects and events and apply this knowledge to new situations, such as judging whether a sentence is grammatically correct, or whether a particular piece of music fits a certain genre. This process of generalization can occur incidentally, with little conscious effort to learn the structure per se. The conditions under which the underlying knowledge is acquired, the form it takes, and the extent to which people are consciously aware of it, are the issues that define the field of implicit learning.

In a typical implicit-learning experiment, participants are asked to memorize a set of letter strings, all of which were generated using a complex set of rules. Subsequently they are required to classify a new set of items according to whether they follow the rules or not. Even though participants had no intention of learning the rules and claim to be unaware of the rules, typically they are still capable of distinguishing between grammatical and ungrammatical letter strings (Reber, 1989). Implicit learning has been predominantly investigated using visual stimuli, such as letter strings, and relatively few published papers have dealt with auditory stimuli, such as music (Altmann, Dienes, & Goode, 1995; Bigand, Perruchet, & Boyer, 1998; Dienes & Longuet-Higgins, 2004, Kuhn & Dienes, in press). Yet the perception of music appears to involve the implicit learning of underlying structure. Our appreciation of music relies on becoming in some way sensitive to rules that govern the way in which notes are combined to form melodies (Aiello, 1994; Tillmann, Bharucha, & Bigand, 2000). Further, certain aspects of this musical grammar, or syntax, are thought to be learnt through repeated exposure: a process known as acculturation (Frances, 1988;

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http://www.psypress.com/qjep
DOI:10.1080/17470210500438361

Krumhansl et al., 2000). Moreover, nonmusicians with no formal music education, and who are largely unaware of these rules, are able to appreciate musical structures (Holleran, Jones, & Butler, 1995).

The aim of the experiments presented in this paper was to investigate whether some of the claims made about artificial-grammar learning using letter strings also apply to the learning of musical rules. The focus of this paper is on three areas, typically investigated in the implicit-learning literature. First, what are the types of rule or regularity that can be learnt, and what do they tell us about the form of knowledge that is acquired? Secondly, what are the conditions under which these regularities can be learnt? Finally, how much awareness do participants have of the knowledge used to classify test items? These issues are addressed in more detail in the following section, while focusing on some of the methodological issues involved in using musical notes, rather than letter strings.

Form of knowledge acquired

Numerous studies have shown that participants can incidentally learn the structure of stimuli constructed by complex rules such as those used in artificial-grammar learning (e.g., Reber, 1989). However, the way in which the grammar is mentally represented has caused much controversy. Early theories of implicit learning claimed that the knowledge acquired is represented in an abstract form (Reber, 1989). Participants were thought to acquire information about the structural relationships amongst items independent of and distinct from the surface features of the training items. Instance-based accounts, on the other hand, suggest that correct classifications are based on participants having stored relatively unprocessed training items, rather than having learnt an abstract rule. This could take the form of storing whole items (Brooks, 1978; Brooks & Vokey, 1991), or adjacent elements making fragments or chunks, also known as bigrams[1] and trigrams (Dulany, Carlson, & Dewey, 1984; Perruchet & Pacteau, 1990; Servan-Schreiber & Anderson, 1990; see Johnstone and Shanks, 2001, for a review).

Simply arguing whether implicit knowledge is abstract or not is problematic, and rather than forcing nature to give a yes/no answer to whether the knowledge is abstract, it may therefore be more fruitful to investigate the type of rule that can be learnt. For example, showing that people can learn a rule based on nonlocal dependencies would have serious consequences for current models of implicit learning that propose that people merely acquire knowledge in the form of chunks of adjacent dependencies (Perruchet & Vinter, 1998; Servan-Schreiber & Anderson, 1990).

The biconditional grammar designed by Mathews et al. (1989) is a grammar in which the rules determine the relationship between letters in nonneighbouring positions.[2] This type of grammar allows for the independent manipulation of the bigrams and trigrams and the grammaticality of an item. Several studies have found that people did not learn this type of grammar under incidental-learning conditions (Mathews et al., 1989; Shanks, Johnstone, & Staggs, 1997; St. John & Shanks, 1997). Instead participants tended to classify test items according to the co-occurrences of neighbouring letters. However, there is evidence from other domains such as language acquisition suggesting that nonlocal dependencies can be learnt incidentally. In a study looking at language acquisition participants were exposed to a stream of speech produced by an artificial language, in which there was a relationship between the first and the third segment of the language. It was shown that under certain conditions, both adults and infants were capable of learning these nonlocal dependencies (Gomez, 2002; Newport & Aslin, 2004). Similarly, Creel, Newport, and Aslin (2004) showed that when all

[1] Bigram is a term use to define two adjacent elements, trigrams are three adjacent elements, *n*-grams are *n* adjacent elements.

[2] The letter strings were generated from six different letters and were six elements long. There was a rule that linked the letter in Position 1 with the letter in Position 5, 2 with 6, and so on.

the elements of a sequence of tones were similar in pitch range and timbre, participants readily learnt about the statistical regularities among adjacent tones, but failed to learn consistent nonlocal dependencies. However, when the elements differed in pitch range or timbre, participants learnt the regularities among the elements in the same pitch range or timbre, even though these elements were temporally nonadjacent. Thus if tones can be grouped by certain Gestalt principles, learning can go beyond the learning of adjacent elements. Although learning in these studies was incidental, participants' awareness of this knowledge was never directly assessed, thus leaving open the question as to whether their knowledge was implicit or explicit.

Musical grammars are often based on nonlocal dependencies. In a recent study Dienes and Longuet-Higgins (2004) investigated whether people could learn musical transformations as used in serialist music. These musical transformations are of particular interest as they do not rely on chunks of adjacent elements, but take the form of algebraic rules or what Marcus (2001) refers to as operations over variables. These studies showed that highly selected participants with an interest in serialist music could implicitly learn to detect melodies that instantiated these rules. Furthermore, by using a regression analysis, it was shown that participants' decisions were independent of *n*-gram statistics, thus suggesting that learning went beyond the learning of chunks of adjacent elements.

The aim of the present study was to investigate whether people could learn a musical rule that was based on nonlocal dependencies. Unlike in the Dienes and Longuet-Higgins (2004) study, we directly pitted knowledge of nonlocal dependencies against fragment knowledge. We also used musically unselected participants, in contrast to the musically highly sophisticated participants used in the Dienes and Longuet-Higgins study. Dienes and Longuet-Higgins' participants had an extensive history of learning the transforms before coming to the experiment. Furthermore, we manipulated the different strategies that could be used to distinguish between grammatical and ungrammatical tunes, so as to gain an insight into the type of knowledge that people acquired. The musical grammar in the present experiment was the diatonic inversion[3] (cf. Balch, 1981). An inversion turns the intervals of an original tone series upside down, thus changing its contour, without changing the magnitude of the intervals. Figure 1 shows an example of one of the tunes used.

All tone series consisted of eight notes, selected from the C-major scale (C_3, D_3, E_3, F_3, G_3, A_3, B_3).[4] The first four notes were picked pseudorandomly, whilst the last four formed the inversion. From Figure 1 it can be seen that the inversion has the same number of diatonic steps but in the opposite direction. The advantage of using this type of rule over typical finite-state grammars is that the rule is independent of the *n*-gram structure. This inversion rule can also be described in terms of a biconditional rule, in the sense that the first note is linked to the fifth note, the second note to the sixth note, and so on. For simplification, knowledge about the inversion rule is henceforth referred to as rule knowledge, whilst knowledge about the co-occurrences of specific diatonic and chromatic intervals and pitches are referred to as fragment knowledge.

Three different test sets were created, each of which required different strategies to distinguish between grammatical and ungrammatical tunes. In the first two sets (*magnitude* and *contour*) both grammatical and ungrammatical test tunes were created from a novel set of diatonic intervals, which never occurred during training. This meant that the inversion rule was independent of the fragment structure, and thus classifications could not be based on knowledge of specific intervals. In the contour set the inversion rule was defined both in terms of the interval magnitude and in terms of its contour, whilst in the magnitude

[3] That is, intervals between two adjacent notes were defined not in terms of numbers of semitones between them but in terms of number of steps in the scale of C major that separated them.

[4] C_3 indicates Middle C.

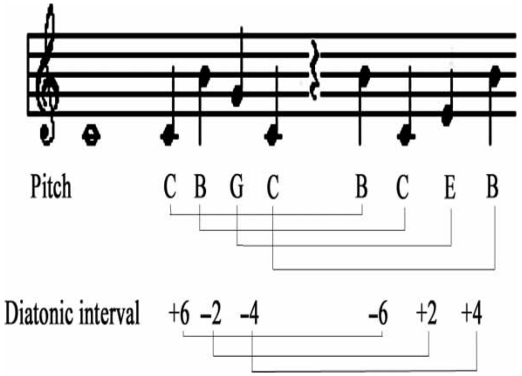

Figure 1. *Example of a grammatical training tune. The tune is represented in terms of the diatonic and chromatic intervals and pitch.*

set the inversion rule was defined by the interval magnitude alone. In the final set, the chunk set, knowledge about chunks was set in opposition to knowledge about the inversion. Comparing classification performances between the different test sets therefore provided an insight into the type of knowledge that participants acquired.

Conditions under which learning occurs

It has been suggested that implicit learning is an automatic nonconscious process, in which regularities of the environment are learnt without effort (Lewicki, 1986; Reber, 1969, 1976; Reber & Allen, 1978). Several studies have shown that instructions to search for rules have little influence on participants' abilities to learn material generated from standard finite-state grammars (Dulany et al., 1984; Mathews et al., 1989; Perruchet & Pacteau, 1990; Reber, 1976; Shanks et al., 1997; Turner & Fischler, 1993). However, training instructions appear to influence the way other grammars, such as biconditional rules, are learnt (Mathews et al., 1989; Shanks et al., 1997; St. John & Shanks, 1997). In these experiments subjects in the "match" condition were presented with a single grammatical letter string, which they were asked to hold in memory for a few seconds until five choices appeared on a computer screen. One of these choices was identical to the one held in memory, whilst the others were ungrammatical distractors. Participants were required to select the string that matched the memorized one. This procedure did not encourage participants to search for the underlying rule. The "edit" task, on the other hand, was designed to encourage participants to discover the rule. In this paradigm participants were presented with a single letter string and were required to mark any letter that they thought violated the rule of the grammar. After each trial they were presented with the correct string, which could be used as feedback. The results consistently showed that subjects only learnt the biconditional grammar when engaged in intentional rule-searching behaviour. Subjects in the match condition consistently failed to do so and merely acquired fragment knowledge (Johnstone & Shanks, 2001).

The following set of experiments investigated the effect that different orienting tasks had on peoples' abilities to learn a musical grammar. Similar to the previous studies, two different training procedures were used: a rule-searching condition and a memorization condition. The rule-search procedure was designed to encourage rule-searching behaviour, analogous to the edit group in the previous studies (Mathews et al., 1989; Shanks et al., 1997; St. John & Shanks, 1997). The procedure for the incidental-learning group was designed to resemble a typical short-term memory experiment, which did not encourage rule searching. Participants in the memorization group were not informed about the existence of a rule and were merely required to hold a tune in memory for 3 seconds and compare it to a tune played subsequently. Both the memorization and the rule-searching group were exposed to the same tunes, the same number of times. The only difference between these two groups therefore lay in the orienting task and the way in which the tunes were presented. Any difference in performance could therefore be attributed to a difference in the training procedure.

Role of awareness

One of the major issues in implicit-learning experiments is how to determine the implicitness of implicit knowledge. In artificial-grammar experiments participants tend to classify items correctly according to the grammar, but fail to report the rule when asked to do so. Participants' failure to report the grammatical rule correctly has been used to assert that the knowledge acquired was tacit, or implicit (Reber, 1989). However, the use of verbal recall to assess participants' explicit knowledge has been criticized by many authors, on the grounds that it is an insensitive and incomplete measure of participants' knowledge (see Berry & Dienes, 1993; Shanks & St. John, 1994). This is very likely to be the case when dealing with the type of material used in the present study. People with little or no formal musical education find it very difficult to fit verbal labels to musical stimuli. Any failure to describe the knowledge used for classifying test items may reflect a lack of appropriate vocabulary, rather than a lack of awareness.

There are more rigorous ways of measuring subjective awareness. Following Dienes and Perner (1999), we define unconscious (or implicit) knowledge as occurring when a person is in an occurrent mental state of knowing some content (e.g., that a tune follows the rule), but the person is not aware that they are in that mental state (they do not know that they are occurrently representing and taking for true a particular content). One way of measuring the participants' awareness of their knowledge is to ask them sequentially to rate how confident they feel about their classification. A participant need not be able to put in words their knowledge of musical structures to demonstrate, with a confidence rating, awareness of knowing that a string has that structure. Classification performance is then plotted against confidence ratings. If participants' classification performance improves with increasing confidence (positive slope) we can claim that participants are aware of the epistemic status of their mental states and hence have at least some conscious knowledge. However, if there is no such relationship participants appear to lack metaknowledge, and hence their knowledge can be claimed to be implicit. This zero-correlation criterion was first put forward by Chan (1992) and has subsequently been used by Dienes, Altmann, Kwan, and Goode (1995), who showed that participants could classify letter stings correctly even though there was no correlation between their confidence ratings and their performance (see also Dienes & Altmann, 1997, 2003; Dienes et al., 1995; Dienes & Longuet-Higgins, 2004; Kelley, Burton, Kato, & Akamatsu, 2001; Newell & Bright, 2002; Tunney & Altmann, 2001; Tunney & Shanks, 2003). Participants can also be shown to lack metaknowledge if they perform significantly above chance on trials for which they believe they are literally guessing. This method of assessing metaknowledge is known as the guessing criterion (Dienes et al., 1995). It is important to note that the guessing criterion implies that there is implicit knowledge without ruling out the possibility of explicit knowledge on other trials; conversely, a positive correlation between confidence ratings and classification performance does not rule out the presence of implicit knowledge on the same trials. The zero-correlation and the guessing criterion are therefore used in unison to detect the different implicit and explicit components of the participants' knowledge (see Dienes, 2004; Dienes & Perner, 2004; and Dienes & Scott, 2005, for discussions of the assumptions of these measures).

EXPERIMENT 1

The aims of Experiment 1 were threefold. The first aim was to discover the influence on participants' classification performance of manipulating whether subjects were intentionally searching for rules. The second aim was to identify the type of knowledge that participants acquired by the use of magnitude, contour, and chunk sets. The third aim was to evaluate participants' awareness about their acquired knowledge. This was achieved by measuring their metaknowledge with the use of confidence ratings, given after each response. One way of controlling for the fact that participants might be bringing prior knowledge into the experiment that could influence the classification response is to use a cross-over design (Dienes & Altmann, 1997). However, due to several constraints in the design of the test material an untrained control group was used to control for prior knowledge (see Dienes & Altmann, 2003).

Method

Participants

A total of 36 participants from the University of Sussex were randomly allocated to one of the three groups, with an equal number in each group. Payment was commensurate with experiment duration (rule-searching group 75 minutes, memorization group 45 minutes, control group 30 minutes). Participants in the rule-searching group were paid £7, whilst participants in the memorization group were paid £5, and those in the control group were paid £3. None of the participants had previously taken part in any implicit-learning experiments.[5] All three groups carried out the same classification test.

Material

The grammar used was an inversion rule. All tunes consisted of eight notes, which were selected from the C-major scale. These notes can be numbered from 1 to 7 (pitch number): $C_3 = 1$; $D_3 = 2$; $E_3 = 3$; $F_3 = 4$; $G_3 = 5$; $A_3 = 6$; $B_3 = 7$. The first four notes formed the prime and were selected semirandomly, while the last four notes formed the inversion, which was created by subtracting the pitch number from a constant (8). The prime 1 7 5 1 therefore leads to the following inversion 7 1 3 7, and thus the tune 1 7 5 1 – 7 1 3 7. Tunes can be represented as a series of pitches, or as diatonic or chromatic intervals. Diatonic intervals were defined as the number of diatonic steps between two adjacent notes. The above tune would therefore be represented as +6 −2 −4 +6 −6 +2 + 4. Chromatic intervals are defined as the number of semitones between two adjacent notes. The contour of these tunes refers to the direction of the interval, up (+) versus down (−). All tunes were preceded by a longer C_3, which was introduced to give participants a reference point.

A total of 36 different grammatical training tunes were created from a unique set of diatonic intervals (±2, ±4, ±6). Care was taken to balance the contour patterns. The following contour patterns each occurred six times as a prime: ++ −; − − +; +− +; − + −; +−−; −−+. A further 36 ungrammatical training tunes were created using the same diatonic intervals, which violated the inversion rule, in terms of either interval contour or interval magnitude.

Three different test sets were created in which the tunes' grammaticality was defined by different features. In the magnitude and the contour set both grammatical and ungrammatical tunes were created from a novel set of diatonic intervals, which never occurred during training (±1, ±3, ±5). However, training tunes and the test tunes (grammatical and ungrammatical) were created from the same seven pitches. Grammatical and ungrammatical tunes were balanced in terms of diatonic and chromatic interval and pitch first-order frequencies. The same intervals and pitches therefore occurred the same number of times in each location for both grammatical and ungrammatical tunes.

In the magnitude set ungrammatical tunes violated the inversion rule in terms of the interval magnitude, but not contour. The ungrammatical items were created by swapping the inversion part of the tune between two grammatical items that had the same contour. In the contour set, grammaticality of the tunes was determined by the interval magnitude and the contour. The ungrammatical items of the contour set were

[5] There was no difference in musical experience between participants in the control group and those in the experimental group, $\chi^2 = 1.56$, $p = .48$ (memorization group, 5 musically experienced subjects; rule-searching group, 6 musically experienced subjects; control group, 10 musically experienced subjects). Musical experience was defined in terms of whether participants had more than 3 years of formal music education. Furthermore, having musical education as an extra variable led to no significant main effects or interactions.

created by swapping the inversion part of the tune between two grammatical tunes that had different contours. Ungrammatical tunes therefore violated the inversion rule in terms of both interval magnitude and the contour. In the final set, the chunk set, grammatical tunes were created from a novel set of intervals, similar to those in the previous two test sets. Similar to the situation in the contour set, the ungrammatical tunes violated the inversion rule in terms of both their interval magnitude and the contour. However, the ungrammatical tunes were created from intervals that occurred in the training set (± 2, ± 4, ± 6). Rule knowledge and fragment structure were therefore set in opposition. Chunk similarity between test tunes and training tunes, known as associative chunk strength, was based on a theoretical framework put forward by Servan-Schreiber and Anderson (1990) and applied by Knowlton and Squire (1994; Shanks et al., 1997). Three separate measures were used, which calculated associative chunk strengths with regard to the elements of pitch, diatonic intervals, or chromatic intervals. Chunks were defined as bigrams (two elements) and trigrams (three elements). Two measures of associative chunk strength were used. The global associative chunk strength was defined as the frequency with which these chunks occurred in the training set, whilst the anchor associative chunk strength only took initial and terminal chunks into consideration. From Table 1 it can be seen that the only difference in associative chunk strength occurred in the chunk set. In order to ensure that classifications could not be based on contour fragments the grammatical and the ungrammatical tunes were balanced in terms of contour bi- and trigrams.[6,7]

The music notes (C_3, D_3, E_3, F_3, G_3, A_3, H_3) were sampled (22.5 kHz) using a Yamaha P50 Sound Box (Grand Piano). The starting note lasted 1,200 ms and remained the same for each tune (C_3), whereas the duration of the other notes was 600 ms. Individual tunes were created by concatenating these individual sound files and adding 600-ms silences between the 4th and the 5th note, to create a perceptual gap between the two sets of notes.

Application

The tunes were presented over a pair of headphones, using a Power Mac. Custom software presented the tunes in a new random order for each participant and recorded the participants' keyboard responses.

Procedure

Training. Participants in the memorization group were told that they were taking part in a memory experiment. They were played two tunes separated by a 3-s gap. In half of the trials the two tunes were identical, and in the other half they were different. Participants were asked to memorize the first tune and to indicate whether it was same or different from the second one by pressing the appropriate key. After each response participants were required to press the space bar, which initiated the next tune. The order of presentation was randomized. On half of the trials the first tune was a grammatical item followed by the identical tune, and on the other half of the trials the first tune was an ungrammatical tune followed by its grammatical counterpart (see Figure 2 for a schematic diagram of the procedure).

Participants in the rule-searching group were told they were taking part in a rule-searching experiment and that their aim was to discover a musical rule. They heard a total of 72 tunes, half of which were generated using a specific set of rules, whilst the other half were random. Their

[6] Contour bigram was defined in terms of two adjacent contours (e.g., an up followed by a down is defined as a + − bigram). In the contour and the chunk sets, the ungrammatical tunes violated the inversion rule in terms of their contour, thus leading to differences in contours between the grammatical and the ungrammatical items. In the magnitude set the inversion rule was only violated in terms of interval magnitude, not contour, and thus the grammatical and the ungrammatical tunes had identical contours.

[7] For the training and the test materials and some audio samples see http://www.lifesci.sussex.ac.uk/home/Gustav_Kuhn/QJEP2006

Table 1. *Global and anchor associative chunk strengths for each of the three test sets*

		G		*U*	
Test set	*Statistic*	*M*	*SD*	*M*	*SD*
Magnitude	Global ACS diatonic intervals	0	0	0	0
	Global ACS pitches	0	0	0	0
	Global ACS chromatic intervals	0	0	0	0
	Anchor ACS diatonic intervals	0	0	0	0
	Anchor ACS pitches	0	0	0	0
	Anchor ACS chromatic intervals	0	0	0	0
Contour	Global ACS diatonic intervals	0	0	0	0
	Global ACS pitches	0	0	0	0
	Global ACS chromatic intervals	0	0	0	0
	Anchor ACS diatonic intervals	0	0	0	0
	Anchor ACS pitches	0	0	0	0
	Anchor ACS chromatic intervals	0	0	0	0
Chunk	Global ACS diatonic intervals	0	0	29.98**	5.47
	Global ACS pitches	0	0	30.21**	2.7
	Global ACS chromatic intervals	0	0	17.46**	6.31
	Anchor ACS diatonic intervals	0	0	5.06**	2.67
	Anchor ACS pitches	0	0	4.44**	2.31
	Anchor ACS chromatic intervals	0	0	3.04**	1.21

Note: G = Grammatical. U = Ungrammatical. ACS as applied by Knowlton and Squire (1994; Shanks et al., 1997). Associative chunk strengths were calculated in terms of both diatonic and chromatic intervals and pitches. Zero implies that the test tunes had no chunks in common with the training tunes.
$^{**}p < .001$ = significant difference between grammatical and ungrammatical tunes.

task was to identify this rule. Participants were played a tune after which they had to indicate, by pressing the appropriate key, whether they felt the tune was generated by the rule or not. This was followed by auditory feedback indicating whether the presented tune was grammatical or not. Finally they were either played the same grammatical tune again, or its grammatical counterpart. All tune pairs were presented in a different random order for each participant. Participants completed a total of 72 training trials, and after every 24 trials, they were questioned about their progress by the experimenter, who enquired about their hypothesis.

Test. After the training phase participants in the memorization group were informed about the existence of a rule used to generate the pitch sequences of all the tunes heard before. The participants in the rule-searching group were informed that half of the tunes that they were about to hear obeyed the same rule as the one that they were asked to discover in the initial part of the experiment. Participants in the control group were merely told that half of the tunes that they were about to hear were generated using a specific set of rules, and it was their task to discover which of the tunes obeyed the rule (see Dienes & Altmann, 2003, for a discussion of using an untrained control group). The test procedure was identical for all three groups. Participants were asked to listen to a new set of tunes, half of which were grammatical, and were asked to classify the new set according to whether they thought they followed the same pattern or structure as the tunes just memorized, by pressing the appropriate key. After each classification, participants were asked to rate how

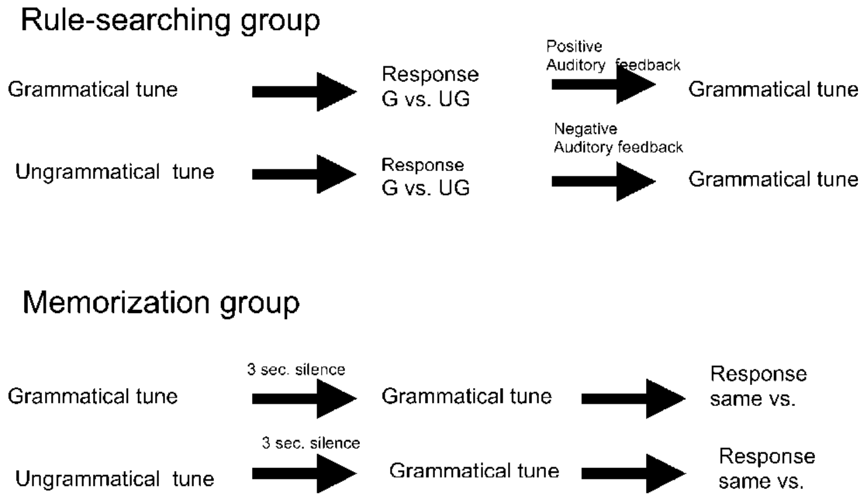

Figure 2. *A schematic depiction of the events on each training trial for the rule-searching and the memorization groups (G = Grammatical; UG = Ungrammatical).*

confident they felt about their decision, using a confidence rating, which ranged from 50% to 100% (50%, 51–60%, 61–70%, 71–80%, 81–90%, 91–100%). Participants were explicitly informed about the nature of this scale and that 50% confidence meant a literal guess. After each of the three test sets participants were asked to write down the strategy that they used to classify the tunes. The presentation order of the test sets was fully counterbalanced, and each participant completed all three test sets. The tunes were presented in a different random order for each participant.

Results and discussion

Training data

The memorization group's discrimination performance on the training task was 67.3% correct ($SD = 9.28$), which was significantly better than chance (50%), $t(11) = 6.48$, $p < .0005$, Cohen's $d = 1.87$. The rule-searching group's overall discrimination performance was 54% ($SD = 8.67$), which was not significantly different from chance $t(11) = 1.71$, $p = .12$, $d = 0.49$. Furthermore, their discrimination performance did not improve over test blocks;[8] first block ($M = 51.7$, $SD = 10.3$), second block ($M = 56.2$, $SD = 15.7$), third block ($M = 54.8$, $SD = 10.7$), $F(2, 22) = 0.53$, $MSE = 122.0$, $p = .60$, $\eta_p^2 = .046$.

Classification performance

There were no main effects or interactions involving the presentation order of the test sets. The data were therefore collapsed over this variable. Figure 3 shows the mean percentage of correct classifications of each group for each of the three test sets, including the 95% confidence intervals.

A two-way analysis of variance (ANOVA) with group (memorization vs. rule-searching vs. control) as the between-subjects variable and test set (magnitude vs. contour vs. chunk) as the within-group variable on classification performance found a significant test set by group interaction, $F(4, 66) = 7.90$, $MSE = 43.0$, $p < .0005$, $\eta_p^2 = .32$, a significant effect of group, $F(2, 33) = 11.87$, $MSE = 91.6$, $p < .005$, $\eta_p^2 = .42$, and a significant effect of test set, $F(2, 66) = 5.82$, $MSE = 43.0$, $p = .005$, $\eta_p^2 = .15$. The data were analysed further by looking at participants' classification

[8] Each training block consisted of 24 trials.

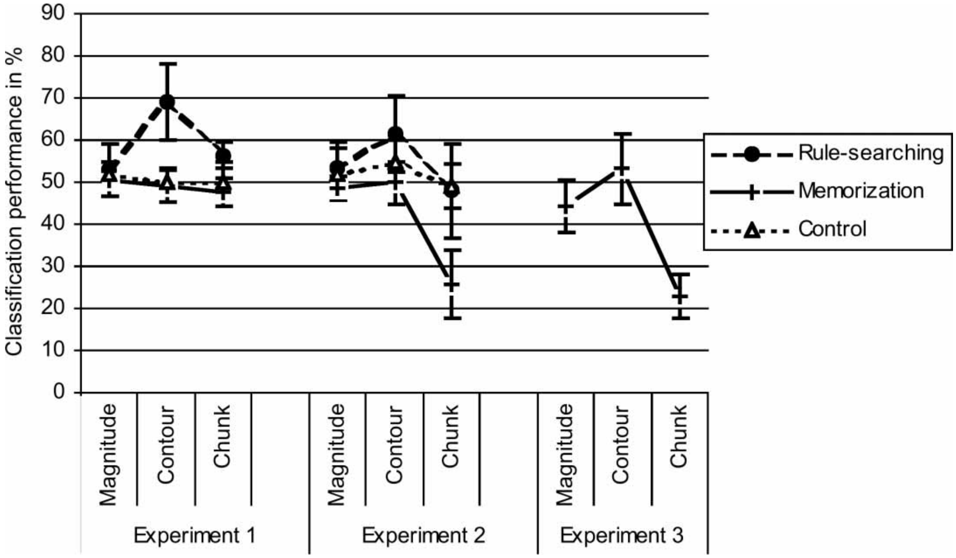

Figure 3. *Mean classification performances on the magnitude, contour, and chunk test sets for the rule-searching, memorization, and control groups for Experiments 1–3.*

performance on the individual test sets. All p values were evaluated using the Bonferroni–Holm procedure.

Magnitude set. None of the groups performed significantly different from chance: memorization group, $t(11) = 0.39$, $p = .70$, $d = 0.11$; rule-searching group, $t(11) = 1.00$, $p = .341$, $d = 0.29$; control group, $t(11) = 1.56$, $p = .15$, $d = 0.45$.

Contour set. The rule-searching group performed significantly better than chance, $t(11) = 4.57$, $p = .001$, $d = 1.31$, whereas the memorization group, $t(11) = 0.48$, $p = .64$, $d = 0.14$, and the control group, $t(11) = 0.12$, $p = .91$, $d = 0.03$, performed at chance.

Chunk set. The rule-searching group performed significantly better than chance, $t(11) = 4.61$, $p = .001$, $d = 1.33$, whereas the memorization group, $t(11) = 1.52$, $p = .16$, $d = -0.44$, and the control group, $t(11) = 0.00$, $p = 1.00$, $d = 0.00$, performed at chance.

Participants in the memorization group therefore acquired neither knowledge about the inversion rule nor knowledge about the chunks. Participants in the rule-searching group, on the other hand, learnt the inversion rule, as long as ungrammatical items violated the rule in terms of their contour pattern rather than magnitude alone.

The contributions that both rule and fragment knowledge made in participants' classification responses were assessed by comparing the scores between the chunk and the contour set. As the memorization group's classification performance was no different from chance, it could be concluded that they acquired neither rule nor fragment knowledge. In the chunk set rule and fragment knowledge were set in opposition. If participants' responses were immune to fragment knowledge we would expect the same levels of performance on these two sets. However, the rule-searching group performed significantly better on the contour than on the chunk set, $t(11) = 3.88$, $p = .003$, $d = 1.12$, implying that their responses were influenced by both rule and fragment knowledge.

Awareness data

Participants' awareness of the acquired knowledge was assessed by looking at classification responses where participants were guessing (guessing responses), the zero-correlation criterion (see Dienes et al., 1995), and their verbal reports. Table 2 shows the mean classification performance when participants were guessing. A two-way ANOVA with group (memorization vs. rule-searching vs. control) as the between-subjects variable and test set (magnitude vs. contour vs. chunk) as the within-group variable on classification performance found no significant test set by group interaction, $F(4,\ 42) = 0.733$, $MSE = 540.0$, $p = .58$, $\eta_p^2 = .065$, no significant effect of group, $F(2,\ 21) = 2.52$, $MSE = 439.7$, $p = .11$, $\eta_p^2 = .19$, and no significant effect of test set, $F(2,\ 21) = 0.437$, $MSE = 540.0$, $p = .65$, $\eta_p^2 = .02$. Furthermore, the overall mean was not significantly different from 50%, $F(1,\ 21) = 0.732$, $MSE = 439.7$, $p = .40$, $\eta_p^2 = .034$, therefore showing that participants did not classify significantly better than chance when they believed they were guessing. Therefore, according to the guessing criterion, none of the participants acquired any implicit knowledge.

Participants' awareness was also measured using the zero-correlation criterion. For each participant the gamma correlation between confidence rating and classification performance was calculated. According to the zero-correlation criterion, knowledge is explicit if there is a correlation between confidence ratings and classification accuracy. The zero-correlation criterion was only calculated in cases where there was evidence of knowledge, as an absence of knowledge automatically indicates that there is no explicit knowledge. Table 3 shows the mean gamma correlation coefficient for each of the groups and test sets where classification performance was different from chance. The zero-correlation criterion for the Contour set was significantly greater than zero, $t(11) = 2.13$, $p = .026$, $d = 0.62$ (one-tailed), thus demonstrating the presence of some explicit knowledge. Participants' awareness was also analysed with regards to the verbal knowledge given in the debriefing questionnaires. A total of 9 participants in the rule-searching condition successfully identified the inversion rule, whilst the remaining 3 reported rather random rules. Furthermore, post hoc analysis revealed that the participants who managed to described the inversion rule performed significantly better on the contour set ($M = 75.0$, $SD = 16.3$) than those participants who failed to describe the inversion rule ($M = 60.8$, $SD = 5.6$), $t(11) = 2.33$, $p = .042$, $d = 0.96$. Participants in the rule-searching group therefore acquired some explicit knowledge about the inversion rule. On the chunk set the mean correlation coefficient was not significantly different from zero, $t(11) = -1.05$, $p = .38$, $d = 0.30$. In fact, the mean correlation coefficient for the chunk set was numerically negative, suggesting that confidence was associated with knowledge about chunks as well as possibly the inversion rule. The verbal report of the memorizing group revealed no mention of the inversion rule.

Table 2. *Mean classification responses for the trial where participants were guessing*

		Test set					
		Magnitude		*Contour*		*Chunk*	
Experiment	*Group*	*M*	*SD*	*M*	*SD*	*M*	*SD*
1	Rule-searching	50.43	13.93	63.31	19.93	64.42	14.47
1	Memorization	48.13	28.44	52.35	23.08	38.51	14.90
1	Control	54.45	36.72	51.40	14.68	46.14	27.14
2	Rule-searching	26.81	24.75	52.87	22.55	53.48	27.60
2	Memorization	46.93	10.19	53.97	13.92	43.64	17.15
2	Control	61.48	21.44	44.98	25.80	46.61	18.83
3	Memorization	43.51	41.90	50.12	26.15	50.33	34.26

Table 3. *Mean gamma correlation coefficients between confidence ratings and classification responses for conditions where learning was observed*

Experiment	*Group*	*Test set*	*M*	*SD*	*N*
1	Rule-searching	Contour	.416	0.675	12
1	Rule-searching	Chunk	− .195	0.642	12
2	Rule-searching	Contour	.049	0.600	10
2	Rule-searching	Chunk	− .375	0.607	12
2	Memorization	Chunk	− .418	0.639	12
3	Memorization	Chunk	− .401	0.591	12

Note: Correlation coefficients could only be calculated for participants who showed variations in confidence ratings.

Participants in the memorizing group typically claimed to rely on intuition.

Similar to Johnstone and Shanks (2001) we found a dissociation between the memorization and the rule-searching group, in the sense that the inversion rule could only be learnt when participants were asked to search for the rule. However, unlike the subjects in the Johnstone and Shanks study, the memorization group did not acquire knowledge of fragments. Furthermore, consistent with the claims of Johnstone and Shanks, the knowledge acquired by the rule-searching group was shown to be explicit rather than implicit.

EXPERIMENT 2

Surprisingly, participants in the memorization group learned neither the fragment structures nor the inversion rule. Postexperimental questionnaires revealed that the tunes were perceived as sounding unmusical and dull. This could have resulted from the slow presentation rate (600 ms per note). Frensch and Miner (1994) suggested that the activation level of the representation in working memory affects implicit learning. The memorization group's lack of learning may therefore have resulted from the tunes being very unengaging. Frensch and Miner manipulated activation levels by varying the presentation rates of the stimuli, showing that increasing the presentation rate facilitated implicit learning. Using a similar task, Destrebecqz and Cleeremans (2001) showed that decreasing the interstimulus times impaired explicit knowledge, whilst having no effect on implicit knowledge. However, using an artificial-grammar learning task, in which participants were required to learn sequences of musical timbres, Bigand et al. (1998) showed that presentation rates had only marginal effects on both intentional and incidental learning. Thus, presentation rates have effects on implicit and explicit learning that are difficult to predict, but some rates may be more optimal than others for either sort of learning depending on the material. Experiment 2 used the same material and procedure as those in Experiment 1. However, the tunes were played at 300 ms, rather than 600 ms, per note. The aim of this experiment was to look at the effects that this increase in tempo had on both intentional and incidental learning, in terms of both learning fragments and learning rules.

Method

Participants

A total of 36 participants from the University of Sussex took part in the experiment. Payment was in accordance to experiment duration; participants in the rule-searching group were paid £5, participants in the memorization group were paid £4, and those in the control group were paid £3. None of the participants had previously taken part in any implicit-learning experiments.[9] Participants were randomly allocated to one of the three groups, with an equal number allocated to each group. All three groups carried out the same classification test.

[9] There was no difference in musical experience between participants in the control group and those in the experimental group, $\chi^2 = 1.63$, $p = .44$ (memorization group, 5 musically experienced subjects; rule-searching group, 3 musically experienced subjects; control group, 6 musically experienced subjects). Furthermore, having musical education as an extra variable led to no significant main effects of interactions.

Material

There were two differences between the material used for Experiment 1 and that used for Experiment 2. First, the tunes were played at double the speed. The initial note (C) lasted 600 ms, whilst the subsequent notes lasted 300 ms. Secondly, the gap between the 4th and the 5th note lasted 300 ms.

Procedure

The procedure for each of the groups was identical to that in Experiment 1.

Results and discussion

Training data

The memorization group's discrimination performance on the training task was 58.7% correct ($SD = 4.24$), which was significantly better than chance (50%), $t(9) = 6.52$, $p < .0005$, $d = 2.06$.[10] The rule-searching group's overall discrimination performance was 54% ($SD = 8.67$), which was not significantly different from chance $t(11) < 1$, $d = 0.10$. Furthermore, their discrimination performance did not improve over test blocks;[11] first block ($M = 47.9$, $SD = 7.00$), second block ($M = 51.38$, $SD = 8.40$), third block ($M = 52.4$, $SD = 12.0$), $F(2, 22) = 0.85$, $MSE = 78.6$, $p = .44$, $\eta_p^2 = .072$.

Classification performance

There were no main effects or interactions involving the presentation order of the test sets. The data were therefore collapsed over this variable. Figure 2 shows participants' mean percentages of correct responses for each of the three test sets, including the 95% confidence intervals. A two-way ANOVA with group (memorization vs. rule-searching vs. control) as the between-subjects variable, and test set (magnitude vs. contour vs. chunk) as the within-group variable on classification performance found a significant test set by group interaction, $F(4, 66) = 6.46$, $MSE = 66.0$, $p < .0005$, $\eta_p^2 = .28$, a significant effect of group, $F(2, 33) = 7.51$, $MSE = 226.4$, $p = .002$, $\eta_p^2 = .31$, and a significant effect of test set, $F(2, 66) = 31.0$, $MSE = 66.0$, $p < .0005$, $\eta_p^2 = .48$. The data were analysed further by looking at participants' classification performance on the individual test sets. All p values were evaluated using the Bonferroni–Holm procedure.

Magnitude set. None of the groups performed significantly different from chance: memorization group, $t(11) = -1.22$, $p = .25$, $d = 0.35$; rule-searching group, $t(11) = 1.21$, $p = .25$, $d = 0.35$; control group, $t(11) = 0.79$, $p = .45$, $d = 0.23$.

Contour set. The rule-searching group performed significantly better than chance, $t(11) = 2.75$, $p = .019$ (one-tailed), $d = 0.79$, whereas the memorization group, $t(11) = 0.00$, $p = 1$, $d = 0$, and the control group, $t(11) = 2.23$, $p = .047$, $d = 0.64$, performed at chance.

Chunk set. The memorization group performed significantly lower than chance, $t(11) = -6.49$, $p < .0001$, $d = 1.87$, implying that their classification responses were based on chunks. However, the rule-searching group, $t(11) = -0.41$, $p = .69$, $d = 0.11$, and the control group, $t(11) = -0.43$, $p = .68$, $d = -0.12$, performed at chance.

In the same way as in Experiment 1 we assessed the contributions that both fragment and rule knowledge made to participants' classification responses, by comparing their performance between the contour and the chunk set. In the contour set, the memorization group did not perform significantly above chance, implying that the memorization group did not learn the inversion rule. However, the memorization group's classification performance on the chunk set was significantly lower than that on the contour set, $t(11) = -8.64$, $p < .0005$, $d = 2.49$, implying that their classification responses were based on

[10] Data from 2 participants were lost due to a problem in the presentation program.

[11] Each training block consisted of 24 trials.

fragment rather than rule knowledge. The rule-searching group performed significantly lower on the chunk set than on the contour set, $t(11) = -5.24$, $p < .0005$, $d = 1.51$. Combined with the fact that the rule-searching group performed significantly better than chance on the contour set, these results imply that the rule-searching group acquired both fragment and rule knowledge.

Awareness data

Table 2 shows the mean classification performance when participants were guessing. A two-way ANOVA with group (memorization vs. rule-searching vs. control) as the between-subjects variable and test set (magnitude vs. contour vs. chunk) as the within-group variable on classification performance found no significant test set by group interaction, $F(4, 44) = 2.37$, $MSE = 461.6$, $p = .066$, $\eta_p^2 = .17$, no significant effect of group, $F(2, 22) = 0.84$, $MSE = 266.5$, $p = .45$, $\eta_p^2 = .071$, and no significant effect of test set, $F(2, 22) = 0.373$, $MSE = 1{,}721$, $p = .69$, $\eta_p^2 = .017$. Furthermore, the overall mean was not significantly different from 50, $F(1, 22) = 1.16$, $MSE = 266.5$, $p = .40$, $\eta_p^2 = .06$, therefore showing that participants did not classify significantly better than chance when they believed they were guessing.

Participants' explicit knowledge was uncovered using the zero-correlation criterion and verbal reports. Table 3 shows the mean gamma correlation between confidence ratings and classification performance for each group where there was evidence of knowledge. The data from the rule-searching group on the abstract set were also included. Although the rule-searching group did not perform significantly differently from chance on the chunk set, it appears that this group acquired both fragment and rule knowledge. For the rule-searching group the mean correlation coefficient for the contour set was not significantly different from zero, $t(11) < 1$, $d = 0.082$, nor was it significantly different form zero on the chunk set, $t(11) = -2.26$, $p = .056$, $d = 0.62$.[12] For the memorization group, the correlation coefficients on the chunk set were significantly smaller than zero, $t(11) = -2.27$, $p = .045$, $d = 0.65$, implying that their knowledge about the chunks was explicit.

The verbal reports from the rule-searching group revealed that 2 participants gave an accurate description of the inversion rule, 2 participants gave a description of the inversion rule plus some irrelevant information, and the remaining participants gave incorrect responses. A typical response was that the second set of notes was identical to the first one, but in a different order. Participants in the rule-searching group appear to have found it more difficult to verbalize the strategies used to classify the tunes than they did in Experiment 2. Similarly to Experiment 1, the participants who were able to verbalize the inversion rule correctly scored higher on the contour set ($M = 72.9$ %, $SD = 13.7$) than did those participants who failed to verbalize the rule ($M = 57.6$ %, $SD = 13.2$). However, this difference was not significant, $t(11) = 1.72$, $p = .055$, $d = 1.15$ (one-tailed). Only 2 participants in the rule-searching group, compared to 8 in Experiment 1, were able to give an accurate description of the inversion rule, thus leading to a significant reduction in their ability to verbalize the inversion rule ($\chi^2 = 6.17$, $p = .018$). Similar to the findings of Destrebecqz and Cleeremans (2001), the increase in tempo led to a reduction in explicit knowledge, as measured using free reports. None of the participants in the memorization group revealed any knowledge about the inversion rule, or any strategy concerning bigrams.

In sum, when the tempo at which the tunes were played was increased, the memorization group learnt chunks, but did not learn the inversion rule. The rule-searching group still acquired knowledge about the inversion rule and the chunks. Although none of the verbal reports gave any indication that participants' classification responses were influenced by typical combinations

[12] These nonsignificant results should be treated with some caution, as the confidence intervals were very large, reflecting a lack of statistical power for detecting metaknowledge.

of notes or intervals, the zero-correlation criterion indicated that the knowledge about chunks was largely explicit, reflecting a greater sensitivity of the zero-correlation criterion rather than free verbal reports for detecting explicit knowledge. For the memorization group there was a significant negative zero-correlation criterion on the chunk set. This negative correlation implies that although participants were unable to verbally explain the strategy used to classify the test tunes, the knowledge that a melody was grammatical or not was conscious knowledge at least some of the time.

EXPERIMENT 3

In the previous two experiments, the memorization group failed to learn the inversion rule. In the training phase participants were required to memorize grammatical tunes and were asked whether they matched a subsequent tune. In half of these trials the second tune was ungrammatical. It is possible that participants' failure to learn the inversion rule may have resulted from the presence of these ungrammatical tunes in the training phase, which could have interfered with the rule knowledge. In Experiment 3 we tried to maximize participants' rule learning by only presenting participants with grammatical tunes. In order to assess performance using only grammatical training tunes a new procedure was implemented, whereby in the "different" trial, participants were presented with a different grammatical rather than an ungrammatical tune. Participants were therefore exposed to each tune four times. The presentation speed and procedure were identical to those in Experiment 2. Experiment 3 only involved participants in the memorization group.

Method

Participants
A total of 12 participants from the University of Sussex took part and were paid £5 for their participation. None of the participants had previously taken part in any implicit-learning experiments.[13]

Material
The grammatical training tunes were identical to those in Experiment 2. The ungrammatical tunes were replaced with one of the grammatical training tunes. Participants were therefore only exposed to grammatical tunes, even on the trials where they did not match. The test material was identical to that in Experiment 2.

Procedure
The procedure was the same as that used in Experiment 2.

Results and discussion

Training data
The memorization group's discrimination performance on the training task was 74.8% correct ($SD = 11.2$), which was significantly better than chance (50%), $t(11) = 7.61$, $p < .0005$, $d = 2.22$.

Classification performance
There were no main effects or interactions involving the presentation order of the test sets. The data were therefore collapsed over this variable. Figure 2 shows the mean percentage correct classifications for each of the three test sets, including the 95% confidence intervals. A one-way ANOVA with set (magnitude vs. contour vs. chunk) as the within-subject factor found a significant effect of set, $F(2, 22) = 34.12$, $MSE = 85.6$, $p < .0001$, $\eta_p^2 = .76$. Participants performed significantly lower than chance on the chunk set, $t(11) = 0.682$, $p > .0001$, $d = 2.00$, but no different from chance on the magnitude test, $t(11) = -2.34$, $p = 0.039$, $d = 0.68$, or the contour test, $t(11) = 2.55$, $p = 0.03$, $d = 0.73$ (evaluating p values using the Bonferroni–Holm procedure).

[13] There was no significant difference between the number of subjects with musical experience between the memorization group in Experiment 3 (6 musically experienced subjects) and the memorization group in Experiment 2 (5 musically experienced subjects), $\chi^2 = 0.19$, $p = .68$.

Substituting the ungrammatical training items for grammatical items did not lead to a significant improvement on the contour set, $t(22) = 1.27$, $p = .21$, $d = 0.51$, Furthermore, the pooled mean of Experiments 2 and 3 ($M = 51.64$, $SD = 6.4$) was not significantly different from chance, $t(23) = 1.25$, $p = .22$, $\beta = .03$. We can therefore confidently accept that the memorization group did not perform significantly better than chance.

Awareness data

Table 3 shows participants' classification response for the trials where they were guessing. An ANOVA with set (magnitude vs. contour vs. chunk) as the within-subjects factor on guessing scores found no significant effect of set, $F(2, 18) = 0.17$, $MSE = 907.3$, $p = .85$, $\eta_p^2 = .02$. Furthermore, these scores were not significantly different from chance, $F(1, 18) = 1.20$, $MSE = 907.3$, $p = .29$, $\eta_p^2 = .063$. According to the guessing criterion there was no evidence to suggest the presence of implicit knowledge. Table 3 shows participants' mean gamma correlation coefficients. The mean correlation coefficient on the chunk set was significantly smaller than zero, $t(11) = 2.35$, $p = .038$, $d = 0.68$, suggesting that learning of chunks led to at least some knowledge of which participants were conscious. The verbal reports revealed no meaningful strategy that could be applied.

In sum, even when participants were only exposed to grammatical tunes, the memorization group still failed to learn the inversion rule, but acquired knowledge about chunks. Using the zero-correlation criteria, we showed that this knowledge was at least partially explicit. That is, participants' memory for fragments led to conscious knowledge of whether the test melodies were structured.

GENERAL DISCUSSION

The aim of this series of experiments was to investigate the conditions under which the musical rule of diatonic inversion could be learnt. These conditions included differences in orienting task (rule-searching vs. memorization) and the tempo at which the musical tunes were played. The grammar used allowed us to unconfound knowledge about the inversion rule from knowledge about the fragment features, such as the co-occurrences of diatonic intervals. Three different test sets were created, which enabled us to look at the type of knowledge acquired under these different learning conditions.

In the first experiment tunes were played at a rate of 600 ms per note. At this tempo, participants in the memorization group failed to learn the inversion rule, nor did they learn about co-occurrences of intervals or pitches. In Experiment 2 the tunes were played at double the speed (300 ms per note), which made them sound more musical. In this condition, the memorization group still failed to learn the inversion rule. However, when fragment knowledge was set in opposition to the rule knowledge, the memorization group based their classification responses on fragment knowledge. In Experiments 1 and 2, participants were exposed to both grammatical and ungrammatical training tunes. It is possible, therefore, that the memorization group's inability to learn the inversion rule incidentally was due to the interference from ungrammatical training tunes. In Experiment 3 we tried to maximize rule learning by exposing participants only to grammatical tunes. However, even under these conditions participants still failed to learn the inversion rule incidentally and merely acquired fragment knowledge supporting the view that memorization did not lead to the learning of the inversion rule.

Many authors have suggested that implicit learning is independent of the learning instructions (e.g., Dulany et al., 1984; Perruchet & Pacteau, 1990; Reber, 1976; Turner & Fischler, 1993). These theories were based on artificial-grammar learning tasks using finite-state grammars. Finite-state grammars are very complex, which makes them difficult to learn by hypothesis testing. Results using a biconditional grammar, in which the rules define long-distance, rather than local, dependencies, have shown a different pattern of results. Several studies have shown that nonlocal rules cannot be learnt through memorization (Johnstone & Shanks, 2001; Mathews et al., 1989; Shanks et al., 1997); in those studies this type of rule was only learnt when participants were asked to actively search for the rule. The current results concur with these previous studies. Even though participants in the memorization group failed to learn the inversion rule, participants in the rule-searching group succeeded, as long as ungrammatical tunes violated the rule in terms of the interval contour, rather than magnitude alone. Furthermore, a meta-analysis showed that, pooled across all experiments, on the contour set the rule-searching group performed significantly better than the control group, $t(46) = 3.03$, $p < .0001$, $d = 1.11$, whereas the memorization group performed no better than the control group, $t(58) = 1.03$, $p = .31$, $d = 0.27$. Similarly to the previous studies we have shown that the inversion rule was only learnt if participants were encouraged to search for the rule and were given feedback on their performance. Memorization of the tunes merely led to the acquisition of fragment knowledge rather than knowledge about the inversion rule. The orienting task therefore greatly influenced the type of knowledge acquired.

Recent experiments have shown that under certain conditions incidental learning can go beyond the learning of adjacent regularities. Dienes and Longuet-Higgins (2004) showed that people with extensive experience in serialist music could implicitly learn serialist transformations, which were independent of chunks. Furthermore, in a recent series of experiments, Kuhn and Dienes (in press) showed that a diatonic inversion rule could be learnt incidentally. However, both the learning and test conditions differed from those used in the present experiment. First, participants in these experiments were exposed to a much larger repertoire of training items than were those in the present study. Secondly, participants' learning was measured using an indirect rather than a direct measure. When participants were asked to rate the test tunes according to how much they were liked, these participants were able to distinguish between grammatical and ungrammatical tunes. However, when they were asked to make classification responses, identical to those used in the present study, participants failed to classify the tunes correctly.

The present study has shown that the learning instructions greatly influence the type of regularities that are learnt. Although the majority of studies suggest that under most conditions incidental learning predominantly involves the learning of adjacent regularities, there is growing evidence from the artificial-language learning literature showing that the types of dependency that can be learnt depend on a variety of factors such as the linguistic constraints of the language (Newport & Aslin, 2004), the physical properties of the stimuli (Creel et al., 2004), and the statistical variability of the intervening elements (Gomez, 2002). The exact nature of the rules that can be learnt incidentally may therefore depend on a larger range of parameters than that assessed here.

Several studies have looked at the effect of presentation rate on different types of learning. Using a serial reaction time task, Frensch and Miner (1994) showed that an increase in presentation rate improved implicit learning. They argued that the increase in presentation rate led to an increased activation level of the relevant representations in working memory, thus enhancing the learning process. Similarly, it can be argued that the increase in tempo in the second experiment led to a higher level of activation, resulting in more active notes in working memory and thus enhancing incidental learning. This interpretation could explain why the memorization groups only classified the test tunes according to chunks once the tunes were played at a relatively fast rate. These results seem to suggest that at slow speeds, tunes are encoded in terms of a specific sequence of diatonic intervals only if people are encouraged to do so. However, once these tunes are played at a reasonable speed the process of chunking becomes automatic.

Participants' awareness was assessed using three different measures: the guessing criterion, the zero-correlation criterion, and verbal reports given after the discrimination test. The guessing criterion measures participants' classification performance when they believe they are literally guessing—a measure of implicit knowledge. The zero-correlation criterion, on the other hand, is designed to detect the presence of explicit knowledge of whether test items have the structure of the training items. If participants show a relationship between their classification performance and their confidence ratings, they have metaknowledge and thus have explicit knowledge of whether a tune is grammatical or not. However, if there is no such relationship, we can conclude that participants lack metaknowledge, and thus their knowledge is implicit, rather than explicit (see Dienes & Perner, 1999). Furthermore, participants' explicit knowledge was also assessed using verbal reports. It seems unlikely that classification responses are process pure; that is, people's decisions are often likely to be simultaneously influenced by both implicit and explicit knowledge (Jacoby, 1991). By combining the guessing criterion, the zero-correlation criterion, and the verbal reports we can discover the contributions that both types of knowledge make.

According to the guessing criterion, there was no evidence to suggest that participants acquired any implicit knowledge, as none of the classification responses were significantly different from chance or different from the control group on any of the test sets, when participants believed they were guessing. Conversely, both the zero-correlation criterion and the verbal reports revealed the presence of at least some explicit knowledge. The rule-searching group performed significantly better than chance on the contour set, suggesting that they learnt the inversion rule in terms of the contour pattern. In Experiment 1 there was a positive correlation between participants' confidence ratings and their classification accuracy, thus demonstrating that learning of the inversion rule produced conscious knowledge. Participants' explicit knowledge was also reflected in their verbal reports, as the majority of participants accurately described the inversion rule. However, in Experiment 2 the zero-correlation criterion was no longer significantly greater than zero. Furthermore, fewer participants accurately described the inversion rule, thus suggesting that the increase in tempo led to a decrease in participants' explicit knowledge.

The use of verbal reports has been criticized by many as being an insensitive measure of people's awareness. Although participants' classification responses were greatly influenced by chunks, this strategy was not reflected in participants' verbal reports. However, the memorization group was shown to have a negative zero-correlation criterion on the chunk set, indicating explicit knowledge. These results demonstrate that under certain conditions participants can be shown to have explicit knowledge, without necessarily being able to verbalize freely the strategy used. These results concur with findings by Ziori and Dienes (in press) who showed that in concept learning zero-correlation measures can be more sensitive than verbal report, and they further demonstrate the advantage of zero-correlation measures over free report (see also Dienes & Scott, 2005, for further discussion of the use of the zero-correlation and guessing criteria).

CONCLUSION

Using a musical rule it was shown that memorization merely led to the learning of chunks of adjacent elements, and that the inversion rule was only learnt when participants were encouraged to search for the rule. These results are similar to those from previous studies using biconditional rules (Johnstone & Shanks, 2001; Mathews et al., 1989; Shanks et al., 1997) and show that these principles also apply to certain musical grammars. Furthermore, using subjective measures of awareness, we showed that fragment learning produced predominantly conscious knowledge of whether test items had the structure of the training items. Even when participants were unable to verbalize the rule and strategies used to classify the test items, there was a significant correlation between the classification accuracy and their confidence ratings, thus demonstrating conscious knowledge of whether melodies were appropriately structured.

Original manuscript received 18 January 2005
Accepted revision received 19 October 2005
First published online 6 March 2006

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