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COMMENTARY

Implicit Learning of Nonlocal Musical Rules: A Comment on Kuhn and Dienes (2005)

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In a recent study, G. Kuhn and Z. Dienes (2005) reported that participants previously exposed to a set of musical tunes generated by a biconditional grammar subsequently preferred new tunes that respected the grammar over new ungrammatical tunes. Because the study and test tunes did not share any chunks of adjacent intervals, this result may be construed as straightforward evidence for the implicit learning of a structure that was only governed by nonlocal dependency rules. It is shown here that the grammar modified the statistical distribution of perceptually salient musical events, such as the probability that tunes covered an entire octave. When the influence of these confounds was removed, the effect of grammaticality disappeared.

Keywords: biconditional grammar, nonadjacent dependencies, rule, abstraction, music

Much of what people learn about complex rule-governed domains such as language and music is acquired incidentally, that is, not from explicit parental or academic instruction and, more generally, without any intentional attempts to acquire information about those domains. The most common view of cognitive researchers is that this state of affairs attests to the human ability to implicitly learn the complex abstract rules that underlie complex domains. The first laboratory studies on implicit learning seemingly confirmed this view by showing that participants learned from artificial rule-governed situations. Further studies replicated the empirical outcome that participants' performance improved in those situations, but, crucially, they showed that improved performance was not due to implicit rule abstraction but to the learning of low-level regularities that emerged as a by-product of the rules (for reviews, see Perruchet, 2008; Shanks, 2005). For instance, the idea that participants learned the rules of a finite-state grammar from their exposure to a subset of the letter strings that this grammar generates (A. S. Reber, 1967) was challenged by subsequent studies showing that participants only learned perceptually salient correlated features (e.g., Dulany, Carlson, & Dewey, 1984).

In most cases, the initial conclusion according to which participants abstracted the genuine rules serving to generate the materials was replaced by the idea that participants merely learned about small fragments or chunks of adjacent elements. This form of learning makes them perform as if they learned the rules, because the statistical distribution of the chunks in those situations is at least partially a by-product of the rules. As a consequence, some forms of chunking or associative processes are now at the heart of the currently dominant theories of implicit learning (for a review, see Perruchet & Pacton, 2006). In this context, a recent study by Kuhn and Dienes (2005) appears as an intriguing exception. The authors showed that participants performed above chance in an implicit learning setting governed by a rule that generated nonlocal dependencies, whereas the information provided by the chunks was carefully controlled. This result suggests that participants did learn the rule and hence that the shift away from rule-based models of implicit learning could have been premature.

The Kuhn and Dienes (2005) Study

In Kuhn and Dienes (2005), participants were required to listen to musical tunes that consisted of eight notes, with a medial silence between the first four notes and the last four

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notes. The tunes were constructed in such a way that the diatonic intervals between the last four notes were the inverse of the intervals between the first four notes. Each note was numbered from 1 to 8 as a function of its pitch, with 1 and 8 standing for C_3 and C_4, respectively. The diatonic inversion was obtained by subtracting each of the notes of the first part from 9 to generate the corresponding notes of the second part (see Figure 1 for an example).[1] Note that this grammar is a version of a biconditional grammar as used previously in implicit learning research (each element of the first part of a sequence is paired with the element in the corresponding location of the second part; see, e.g., Shanks, Johnstone, & Staggs, 1997), except that the pairings are determined by a common, abstract transformation instead of being arbitrary.

In the test phase, participants received new tunes. Half of them were constructed in the same way as the tunes from the study phase, whereas the others violated the inversion rule. In the present comment, we focus on a subset of the data (namely, Experiment 1, abstract set, and Experiments 2 and 3) in which the test tunes comprised none of the pairs of intervals (and hence no longer chunks of intervals) composing the study tunes. When submitted to the conventional grammaticality judgment task, participants were unable to discriminate between grammatical and ungrammatical test tunes. However, Kuhn and Dienes (2005) argued that the knowledge of musical structures would express itself on an aesthetic judgment rather than on a grammatical judgment. Indeed, numerous studies have shown that mere exposure to a stimulus leads to a greater appreciation of that stimulus (e.g., Zizak & Reber, 2004). Thus, Kuhn and Dienes also asked their participants to rate every tune on a liking scale. In three experiments using the same study tunes but differing in the selection of test tunes, participants showed a preference for grammatical tunes. On the basis of these results, Kuhn and Dienes concluded that the learning of music goes beyond the learning of chunks of adjacent elements and that participants learned some form of the inversion rule that served to generate the tunes.

Toward a Reappraisal

Because researchers in earlier studies concluded that participants failed to learn about biconditional grammars in incidental conditions (Johnstone & Shanks, 1999; Mathews et al., 1989; Shanks et al., 1997), at least when chunks of adjacent elements were controlled (Johnstone & Shanks, 2001), Kuhn and Dienes's (2005) study seems to go further than previous evidence for the implicit learning of a rule based on nonlocal dependencies. This study opens the intriguing possibility that using musical stimuli reveals learning abilities that earlier investigations, which primarily involved strings of letters, kept hidden.

Before pursuing this line of thought, however, a closer look at Kuhn and Dienes's (2005) data is needed. The results for the three experiments are reported in Section A of Table 1. Note that for Experiments 1 and 3, the values differ from those reported in Kuhn and Dienes's article. For Experiment 1, the authors mentioned that "the experimental group rated grammatical tunes as more likable than ungrammatical tunes, $t(47) = 3.61$, $p = .001$" (Kuhn & Dienes, 2005, p. 1422). Using the raw data that the authors kindly made available to us, we obtained, in fact, $t(15) = 1.78$, $p = .096$, and, hence, the correct wording would have been that the difference just approached significance. For Experiment 3, Kuhn and Dienes reported a one-tailed *t* test, which is unsound in the present conditions. Indeed, prior studies that used liking scores in the context of artificial grammar learning (e.g., Zizak & Reber, 2004) do not provide compelling evidence for predicting the direction of the effect. There are only a handful of these studies, and, moreover, the situations were different, notably regarding the grammars and the sensory modalities. Moreover, there were more study trials in Kuhn and Dienes (120) than in other artificial grammar learning studies (typically around 80). It does not appear implausible that an initial preference for familiar tunes changes to a preference for novelty with extensive training. This would be in line with the extensive literature on infant preference, which indicates that infants show a tendency to shift their preference from familiar to novel stimuli with increasing exposure to the stimuli (for a review, see Houston-Price & Nakai, 2004). Unquestionably, the crucial issue is whether liking judgments differed between grammatical and ungrammatical tunes, irrespective of the direction. When assessed with a two-tailed test (as the other tests performed by Kuhn and Dienes) and after we corrected a small error in the *t* value, the *p* value for the difference in liking scores for grammatical and ungrammatical tunes rose to $p = .098$. Thus, over the three experiments, a difference that fell below the conventional .05 threshold of significance was obtained only in Experiment 2.

Kuhn and Dienes's (2005) experiments also included a control group. It could be argued that even though comparing the rating scores for grammatical and ungrammatical tunes of experimental participants was not conclusive for Experiments 1–3, firmer evidence of learning emerged from the interaction between groups and grammaticality. Indeed, these interactions reached significance for both Experiment 1, $F(1, 30) = 4.55$, $p = .041$, and Experiment 3, $F(1, 94) = 4.96$, $p = .028$, suggesting that grammatical and ungrammatical tunes were better discriminated by the experimental groups than by the control groups. Unfortunately,

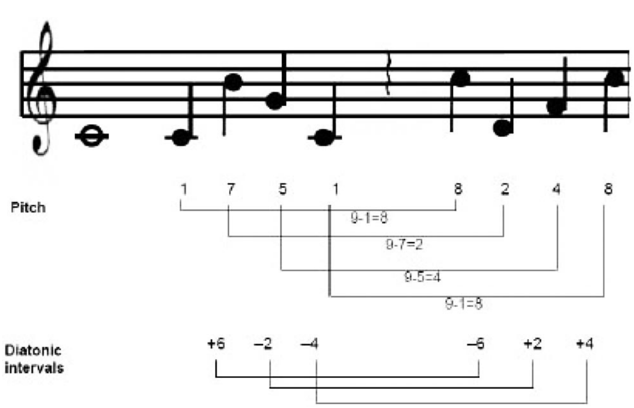

Figure 1. Example of a grammatical tune represented in terms of pitch and diatonic intervals.

[1] A diatonic inversion is akin to the transformations used in 12-tone music or serial music. However, the rule used in 12-tone music is a chromatic inversion. This inversion is operated in the modulo 12, a rising minor third becoming a falling minor third (E/G becomes E/C#; with the diatonic inversion rule, E/G becomes E/C).

Table 1

Summary of Kuhn and Dienes's (2005) Results (A), Quantitative Assessment of the Confounds Between Grammaticality and Octave (B), and Values Obtained After Controlling for Octave (C), tor Each of the Three Experiments

	A: Initial data				B: Octave	C: Controlling for octave			
Experiment or tune	*M*	*t*	*df*	*p*	*M* per tune	*M*	*t*	*df*	*p*
Experiment 1		1.78	15	.096			1.16	15	.266
G	5.40				0.833	5.27			
NG	5.09				0.333	5.10			
Experiment 2		2.48	47	.017			1.02	47	.312
G	5.06				0.722	5.00			
NG	4.88				0.222	4.90			
Experiment 3		1.69	47	.098			1.68	47	.100
G	5.20				1.409	5.18			
NG	5.08				1.136	4.99			
Study					1.383				

Note. Values reported in A and C are liking ratings reported on a 9-point scale. For Experiment 1, only the abstract set condition was considered. G = grammatical test tunes; NG = ungrammatical test tunes; Study = study tunes, which were the same for all three experiments.

inspection of Table 2 (abstract group) and Table 6 in Kuhn and Dienes's article shows that these interactions came as much from the controls' greater mean preference for ungrammatical tunes as from the experimentals' greater preference for grammatical tunes. This specific pattern makes the interpretation of the interactions difficult. As claimed by R. Reber and Perruchet (2003) in their examination of the role of control groups in artificial grammar learning studies,

> The main function of a control group is to check whether the material is well balanced with regard to non-specific variables . . . . if it turns out that the performance of control participants departs from chance level, there is no proper way to assess the amount of learning in experimental participants. In any case, a difference score would provide a flawed estimation. (p. 113)

The problem is further strengthened by the type of control implemented in Kuhn and Dienes (2005). Participants from the control groups were exposed to the test tunes without having been exposed to any training tunes. R. Reber and Perruchet (2003; see also Perruchet & Reber, 2003) showed that this type of control is unsound, because it relies on postulates that were empirically invalidated.

The analysis above clearly indicates that the empirical basis on which Kuhn and Dienes's (2005) conclusion is grounded is rather tenuous. Even in Experiment 2, where the experimental group reliably rated grammatical tunes as more likable than ungrammatical tunes, statistical significance was reached thanks to the use of a large sample ($N = 48$). The observed difference was, in fact, quite tiny. The effect size, as assessed by a partial η^2, was .059,[2] indicating that the proportion of total variability attributable to grammaticality was about 6%. Given that the reported effect runs against the outcome of a vast amount of earlier research on implicit learning, one could have expected more robust evidence. This state of affairs is not sufficient to dismiss Kuhn and Dienes's conclusion about the learning of the inversion rule, but it calls for a detailed examination of its support. Indeed, even a quite minor confound should be enough to wipe out such tenuous evidence. We take it for granted that the regularities concerning chunks of adjacent events, which are the main confound in most implicit learning situations, have been carefully controlled. However, other salient by-products of the inversion rule are possible. In the remaining part of this comment, two of them will be examined in turn.

The Case of Octave Intervals

Let us first examine the probability that the tunes covered an entire octave. Recall that the diatonic inversion was obtained by subtracting each of the notes of the first part from 9 to generate the corresponding notes of the second part of the tune. This procedure entails that whenever Note 1 occurs in the first part, Note 8 ($9 - 1$) appears in the related location of the second part, and likewise for 8 and 1. Thus, the diatonic inversion rule, when applied with the present parameters, tends to generate tunes covering an octave (namely, C_3–C_4; hereafter, we refer to the presence of both C_3 and C_4 in the tune as an *octave interval*, even though C_3 and C_4 are not adjacent). Certainly, octaves can still occur in ungrammatical test tunes at unrelated locations, but it is likely that, without special control, octave occurrence would be more frequent in grammatical tunes than in ungrammatical tunes. Results from our analysis of the Kuhn and Dienes (2005) stimuli made available on their Web site are shown in Section B of Table 1. It appears that, at least for the first two experiments, (a) the proportion of octaves notably differs between grammatical test tunes and ungrammatical test tunes and (b) the proportion of octaves in the study tunes is closer to the proportion of octaves in the grammatical test tunes than in the ungrammatical ones.

This imbalance is potentially damaging, because it is reasonable to think that whether an eight-note melody covers an octave or not is a perceptually salient event. Indeed, the frequencies of two tones separated by one octave have the simplest ratio (2:1), leading these two tones to be perceived as highly similar (cf. the so-called octave equivalence effect). In addition, in Kuhn and Dienes's (2005)

[2] A note of caution is in order for the readers who would like to estimate the effect sizes from the values reported in the Kuhn and Dienes (2005) article. Indeed, the values they present as *MSE*s are in fact the mean square effects, and not the mean square errors.

stimuli, octave intervals were between C tones. It is worth noting that in the scale of C major (the one used by Kuhn and Dienes), the C tone (called the *tonic*) is the central reference pitch, which confers the best feeling of musical resolution.

The first question to be addressed is, Were participants actually sensitive to the occurrence of octave intervals? We focus here on Experiment 2, which is the only one to get significant results. We computed the mean rating score of each experimental participant for the test tunes including at least one octave ($N = 16$) and for the test tunes including no octave ($N = 20$). The resulting values significantly differed (5.12 and 4.85, respectively), $t(47) = 2.77$, $p = .008$. Thus, experimental participants were sensitive to the occurrence of octave intervals. Given that there were many more octave intervals in grammatical than in ungrammatical test tunes, this result suggests that higher liking ratings for grammatical test tunes may have been a by-product of the preference for octaves. To test this hypothesis, we computed a score for each experimental participant for the following four categories of test tunes: grammatical–octave ($N = 12$), grammatical–no octave ($N = 6$), ungrammatical–octave ($N = 4$), and ungrammatical–no octave ($N = 14$). The unweighted mean between the first two values provided the new score for grammatical tunes, and the unweighted mean between the last two values provided the new score for ungrammatical tunes. In this way, the test tunes including an octave interval and the test tunes that did not include an octave interval contributed equally to the score for grammatical tunes, and likewise for the ungrammatical tunes, so that, crucially, the comparison between grammatical and ungrammatical tunes was no longer plagued by the imbalance in octave interval.

The new mean scores of experimental participants for grammatical tunes and ungrammatical tunes were 5.00 and 4.90, respectively, a difference that was no longer significant, $t(47) = 1.021$, $p = .312$.[3] Likewise, the interaction between grammaticality and groups was no longer significant, $F(1, 94) = 1.979$, $p = .162$. Note that there was no significant effect of octaves in the no-training control group, $t(47) = 0.831$, $p = .409$, hence confirming that preference for the test tunes including an octave in the experimental group was learned during the study phase. Therefore, when the imbalance in octave intervals is controlled, the effect of grammaticality observed in Experiment 2 vanishes.

What about Kuhn and Dienes's (2005) Experiments 1 and 3? In both cases, the tunes including at least one octave were preferred to the tunes including no octave. The differences did not reach significance: In Experiment 1, $M = 5.40$ versus $M = 5.05$, respectively, $t(15) = 1.58$, $p = .136$; in Experiment 3, $M = 5.18$ versus $M = 4.96$, respectively, $t(47) = 1.25$, $p = .217$. However, the effect of octaves was, in fact, descriptively larger than the effect of grammaticality, which approached significance in these experiments (the difference is presumably due to the fact that, in contrast with grammaticality, tunes with and without octave intervals were not evenly distributed). Section C in Table 1 reports for each experiment the mean rating scores for grammatical and ungrammatical test tunes (and the *t* test of the difference) after controlling for the distribution of octaves as described above for Experiment 2. Regarding Experiment 1, results are closely similar to those for Experiment 2. The effect of grammaticality is attenuated when the imbalance in octave intervals is controlled. However, controlling for octave intervals has virtually no effect in Experiment 3. This result is probably due to the specific distribution of octaves in this experiment. The imbalance of octaves between grammatical and ungrammatical test tunes is much smaller in Experiment 3 than in the first two experiments, and, moreover, unlike the first two experiments, the mean number of octaves per tune in the two categories of test tunes is near to the mean number of octaves observed in the study tunes (see Section B of Table 1).

Is the Distribution of Octave Intervals the Single Confound?

The fact that controlling for octave intervals does not reduce the effect of grammaticality in Experiment 3 may hardly be thought of as a strong argument against our reappraisal. From a strict statistical standpoint, the effect of grammaticality did not reach significance in this experiment, despite the strong power of the test ($N = 48$). In addition, the analyses were performed after removing four test tunes from the analyses, for reasons that appear somewhat obscure.[4] Given the level of significance of the grammaticality effect observed after elimination (with p around .10), the usual policy should have been to provide the results before elimination. However, it is worth examining whether this experiment could have been plagued by a problem other than octave intervals.

Looking at the test tunes used in Kuhn and Dienes's (2005) Experiment 3, it appears that 6 out of the 22 grammatical tunes displayed the same, very striking pattern. With the sequence of chromatic intervals for the first half of the tune labeled AXB, the sequence of chromatic intervals for the second half of the tune was BXA, hence inducing a symmetry around the medial silence. None of the ungrammatical tunes exhibited an even partially similar regularity (i.e., there was no symmetry at all around the medial silence). A Monte Carlo simulation shows that the probability of generating such a pattern when the eight notes of the tunes are drawn randomly (with no immediate repetition) is about .0035. Thus, the absence of the pattern over the 22 ungrammatical tunes is all but surprising. This probability jumps to .041 (i.e., increases

[3] To ensure that this result is not a mandatory consequence of the method itself, we ran a Monte Carlo simulation in which the proportion of tunes containing an octave interval was kept identical to the observed values, but the selection of the tunes was randomized on each run. Over 100,000 runs, we obtained no trend toward a decrement (in fact, the mean computed from the raw data and from the randomly weighted values differed only from the fourth decimal onward). Thus, the fact that the effect of grammaticality is reduced when the imbalance in the number of octave intervals is controlled ought to be attributed to the fact that at least a part of the effect of grammaticality is due to the correlation between grammaticality and the presence of octave intervals.

[4] Kuhn and Dienes (2005, p. 1426) claimed that they obtained a significant preference for ungrammatical tunes by the control group, predominantly due to one ungrammatical tune. Surprisingly, the score given for this tune ($M = 3.6$) is notably lower than the mean rating score for this group provided in Kuhn and Dienes's Table 6 ($M = 5.15$). Kuhn and Dienes (2005) eliminated this tune, as well as three other tunes, "to keep the material in balance" (p. 1426), although they added in their footnote 13 that "the removal of the four tunes led to a slight imbalance in the test material" (p. 1426). Because the eliminated data were not made available to us, we were unable to examine whether their reintegration would have changed the conclusions.

more than a factor of 10) when the second half of the tune is generated by following the inversion rule. This indicates that the frequency of the AXB–BXA pattern is itself a remote consequence of the rule, through quite indirect causal links.

One hypothesis is that experimental participants may have preferred the test tunes that displayed the AXB–BXA pattern after having gained familiarity with this pattern during the study phase.[5] Note that it is not even necessary to assume that the overall symmetry pattern has been detected. Indeed, the AXB–BXA pattern may be decomposed into two very salient identity relations. Participants may have learned that the same interval (A) occurred at the beginning and at the end of each tune and/or that the same interval (B) occurred just before and just after the medial silence. These relations are fairly simple to learn; in any case, these relations are much simpler to learn than the inversion rule that served to generate the tunes.[6]

To test this hypothesis, we computed the mean rating score of each participant for three categories of test tunes: (a) the grammatical test tunes sharing the AXB–BXA pattern ($N = 6$), (b) the remaining grammatical test tunes ($N = 16$), and (3) the ungrammatical test tunes ($N = 22$, none of which composed the pattern). The mean rating score of experimental participants was higher for the grammatical test tunes matching the AXB–BXA pattern than for the other grammatical test tunes, with a difference that approached significance ($M = 5.39$ vs. $M = 5.12$, respectively), $t(47) = 1.81$, $p = .076$, despite the low number of items in one of the categories. Crucially, the mean rating score for the grammatical test tunes that did not match the pattern did not differ significantly from the mean rating score for the ungrammatical test tunes in experimental participants ($M = 5.12$ vs. $M = 5.08$), $t(47) = 0.58$, $p = .568$. Likewise, the interaction between grammaticality and groups (experimental vs. control) was no longer significant, $F(1, 94) = 0.92$, $p = .340$, when the six grammatical tunes matching the AXB–BXA pattern were removed from the analysis. Note that control participants tended to prefer the grammatical test tunes that did not match the pattern to those matching the pattern, although the difference was not significant ($M = 5.09$ vs. $M = 4.93$, respectively), $t(47) = 1.12$, $p = .268$, hence confirming that preference for the test tunes matching the AXB–BXA pattern in the experimental group was learned during the familiarization phase.

Can this pattern have been also influential in Experiments 1 and 2? Examination of the material shows that the AXB–BXA pattern occurred once in the grammatical test tunes for each of the experiments. It is interesting to note that for each of the two experiments, the mean liking score for this tune was the highest one. This result confirms the observation from Experiment 3 that participants are sensitive to the presence of this pattern. The presence of this pattern accounts for an additional part of the liking differences observed in Experiments 1 and 2 between grammatical and ungrammatical tunes, but, given that only one tune was involved in each case (over 12 grammatical tunes in Experiment 1 and 18 tunes in Experiment 2), this influence was far more limited than in Experiment 3.

An Overall Analysis

It could be argued that prior analyses fail to capture the overall picture and, notably, that they do not take advantage of the power of Kuhn and Dienes's (2005) data when all three experiments are considered together. Indeed, the total number of experimental participants increased to 112 (16 + 48 + 48). Does an effect of grammaticality subsist after controlling for octave distribution and the symmetry pattern when the full power of the data is exploited? To answer, we performed a multilevel regression analysis, using the linear mixed effect models as implemented in the statistical software SPSS (Version 11.5). Grammaticality, octaves, and symmetry were treated as fixed effects, and participants (nested in experiments) were treated as random effects. The individual scores on the 9-point Liking Scale served as dependent variable. The effects of octaves and symmetry were highly significant, $F(1, 4025.79) = 13.42$, $p < .001$, and $F(1, 4177.06) = 8.98$, $p = .003$, respectively. However, despite the impressive power of the analysis, there was no reliable effect of grammaticality, $F(1, 4173.24) = 0.31$, $p = .579$.

The Kuhn and Dienes (2008) Follow-Up Study

Recently, Kuhn and Dienes (2008) returned to the results that were the target of this comment. Taking for granted that these results "showed that people could implicitly learn a musical rule that was solely based on non-local dependencies" (Kuhn & Dienes, 2008, p. 184), they examined how the results could be accounted for by two different connectionist models, a standard simple recurrent network (SRN) and a somewhat ad hoc memory buffer model. They found that an SRN could learn the biconditional mapping used in the inversion rule (although they also noted that the SRN does not characteristically behave in this way). In their simulations, Kuhn and Dienes (2008) exploited the material from

[5] The AXB–BXA pattern occurred for 7 out of the 120 study tunes, hence giving a proportion of .058, which is near the proportion predicted by our Monte Carlo simulations. However, the proportion of grammatical test tunes presenting the pattern (6/22 = .273) in Experiment 3 largely exceeded what the simulations predicted. This departure is likely a remote consequence of Kuhn and Dienes's (2005) attempt to control for contour in this experiment, although the causal link remains unclear.

[6] For the sake of comparison with the symmetry pattern, write the sequence of intervals generated by Kuhn and Dienes's (2005) inversion rule as ABC/−A−B−C, with the minus sign marking the inversion of the interval. It is immediately obvious that all of the relevant relations are distant (there are two intervals between the to-be-matched intervals). Moreover, in the AXB–BXA symmetry pattern, the A intervals are identical on the two sides of the medial silence, and likewise for the B intervals. In the ABC/−A−B−C rule-governed pattern, the to-be-matched intervals are different. The difference partly arises from the inversion as such, but it is deeply strengthened by the fact that Kuhn and Dienes used a diatonic inversion instead of a (perceptually relevant) chromatic inversion (see footnote 1). To illustrate the difference between our and Kuhn and Dienes's hypotheses, we note that the first grammatical tune that displays the symmetry pattern in Kuhn and Dienes's Experiment 3 ($DFEC_3/BGAC_4$) generates the following sequence of chromatic intervals: 3 −1 −4/−4 2 3 (e.g., −1 indicates that there is one descending semitone separating F and E). We assume that participants have learned that the very same interval occurs in the first and last locations and/or that participants have learned that the very same interval occurs before and after the medial silence. By contrast, Kuhn and Dienes assumed that participants have learned the dependency relations between the following chromatic intervals: 3 (in Location 1) and −4 (in Location 4), −1 (in Location 2) and 2 (in Location 5), and −4 (in Location 3) and 3 (in Location 6).

Kuhn and Dienes's (2005) Experiment 1, in which participants were mainly sensitive to the distribution of octave intervals. There is no reason for the SRN to be sensitive to this feature: C_3 and C_4 were simply coded 1 and 8, respectively, hence masking their communality (C), and the network was not informed that an octave interval is endowed with specific properties for a human ear. As a consequence, irrespective of how an SRN learns biconditional mappings between distant events, it does not provide a model of how people implicitly deal with such a structure, given that there is no evidence to date that people are able to learn such a structure. People may perform (slightly) above chance as an SRN sometimes does, but they do so thanks to their sensitivity to the distributional properties of events to which an SRN is blind.

Discussion

To resume, we argue that the effect of grammaticality reported by Kuhn and Dienes (2005) may be due entirely to some confounds between grammaticality and the statistical distribution of a few features (other than chunks), which were more or less remote by-products of the inversion rule. We reported an empirical demonstration that when the influence of these confounds is removed from Kuhn and Dienes's data, the genuine effect of grammaticality disappears. The confounds differed between experiments: The distribution of octave intervals was identified as the main confound for Experiments 1 and 2, whereas the presence of a specific pattern played the same role for Experiment 3. It is worth stressing, however, that our conclusion is not that participants learned different features in different experiments. This would be somewhat unparsimonious, given that participants were exposed to the same study tunes across the three experiments. There is evidence, at least at a descriptive level, that participants were sensitive to both the presence of octave intervals and the presence of an AXB–BXA pattern in all three experiments. What generates the differences between experiments is not the knowledge participants have gained from the study phase but the specific imbalances displayed in the test tunes. Our claim is that participants learned from several simple correlated features during the study phase and that whether one or another of these features turned out to be influential during the test depends on the specific characteristics of the test items.

In a subsequent article, Kuhn and Dienes (2006) again used the same diatonic inversion rule, and they failed across their three experiments to find learning in incidental learning conditions. It is noteworthy that although the same diatonic inversion rule was involved, the authors applied it on a set of seven notes (from C_3 to B_3) instead of eight. As a consequence, the study and test tunes no longer contained octaves. In addition, the AXB–BXA pattern was present only twice over the three sets of test tunes involved in these experiments. Although it is tempting to link the disappearance of learning with the disappearance of the main sources of confounds in Kuhn and Dienes (2005), it is fair to add that the two sets of experiments also differed on other characteristics. Notably, Kuhn and Dienes (2006) used a classification (direct) test instead of a liking (indirect) test. Whatever the reasons for the differences between the two sets of results are, the findings by Kuhn and Dienes (2006) are consistent with the general conclusion that participants are unable to learn incidentally a diatonic inversion rule, irrespective of the test used to assess learning. Overall, our reanalyses suggest that the implicit learning of a rule governing the biconditional mapping between distant events is still in need of empirical evidence (Johnstone & Shanks, 1999; Mathews et al., 1989; Shanks et al., 1997).

This being said, Kuhn and Dienes (2005) were right when they claimed that their study shows that "implicit learning can go beyond the learning of chunks" (Kuhn & Dienes, 2005, p. 1430). In fact, there is earlier evidence that a variety of perceptually salient events other that small chunks of adjacent elements can be learned implicitly. For instance, a number of studies have shown that participants could learn about the first letter of a string (e.g., Gómez & Schvaneveldt, 1994), the location of the chunks (Johnstone & Shanks, 1999), and the repetition of nonadjacent letters (Lotz & Kinder, 2006) in artificial grammar learning settings; the back-and-forth movement of a target in serial reaction time tasks (Perruchet, Gallego, & Savy, 1990); and the repetition of digits in invariant learning (Wright & Burton, 1995), among others. The present study adds new elements to the list. Certainly those results challenge strict chunk-based models of implicit learning (e.g., Perruchet & Pacteau, 1990; Servan-Schreiber & Anderson, 1990). However, they are in keeping with a more general model positing that what is learned is the content of the momentary attentional focus, with chunks of adjacent events being only a case in point (e.g., Pacton & Perruchet, 2008).

References

Dulany, D. E., Carlson, A., & Dewey, G. I. (1984). A case of syntactical learning and judgment: How conscious and how abstract? *Journal of Experimental Psychology: General, 113,* 541–555.

Gómez, R. L., & Schvaneveldt, R. W. (1994). What is learned from artificial grammar? Transfer tests of simple association. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20,* 396–410.

Houston-Price, C., & Nakai, S. (2004). Distinguishing novelty and familiarity effects in infant preference procedures. *Infant and Child Development, 13,* 341–348.

Johnstone, T., & Shanks, D. R. (1999). Two mechanisms in implicit artificial grammar learning? Comment on Meulemans and Van Der Linden (1997). *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25,* 524–531.

Johnstone, T., & Shanks, D. R. (2001). Abstractionist and processing accounts of implicit learning. *Cognitive Psychology, 142,* 61–112.

Kuhn, G., & Dienes, Z. (2005). Implicit learning of nonlocal musical rules: Implicitly learning more than chunks. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 31,* 1417–1432.

Kuhn, G., & Dienes, Z. (2006). Differences in the types of musical regularity learnt in incidental- and intentional-learning conditions. *Quarterly Journal of Experimental Psychology, 59,* 1725–1744.

Kuhn, G., & Dienes, Z. (2008). Learning non-local dependencies. *Cognition, 106,* 184–206.

Lotz, A., & Kinder, A. (2006). Transfer in artificial grammar learning: The role of repetition information. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32,* 707–715.

Mathews, R. C., Buss, R. R., Stanley, W. B., Blanchard-Fields, F., Cho, J. R., & Druhan, B. (1989). Role of implicit and explicit processes in learning from examples. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15,* 1083–1100.

Pacton, S., & Perruchet, P. (2008). An attention-based associative account of adjacent and nonadjacent dependency learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 34,* 80–96.

Perruchet, P. (2008). Implicit learning. In J. H. Byrne (Ed.-in-Chief) & H. L. Roediger III (Vol. Ed.), *Learning and memory: A comprehensive* reference: Vol. 2. Cognitive psychology of memory (pp. 597–621). Oxford, England: Elsevier.

Perruchet, P., Gallego, J., & Savy, I. (1990). A critical reappraisal of the evidence for unconscious abstraction of deterministic rules in complex experimental situations. *Cognitive Psychology, 22,* 493–516.

Perruchet, P., & Pacteau, C. (1990). Synthetic grammar learning: Implicit rule abstraction or explicit fragmentary knowledge? *Journal of Experimental Psychology: General, 119,* 264–275.

Perruchet, P., & Pacton, S. (2006). Implicit learning and statistical learning: Two approaches, one phenomenon. *Trends in Cognitive Sciences, 10,* 233–238.

Perruchet, P., & Reber, R. (2003). Why untrained control groups provide invalid baselines: A reply to Dienes and Altmann. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 56*(A), 125–130.

Reber, A. S. (1967). Implicit learning of artificial grammars. *Journal of Verbal Learning and Verbal Behavior, 6,* 855–863.

Reber, R., & Perruchet, P. (2003). The use of control groups in artificial grammar learning. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 56*(A), 97–115.

Servan-Schreiber, D., & Anderson, J. R. (1990). Learning artificial grammars with competitive chunking. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16,* 592–608.

Shanks, D. R. (2005). Implicit learning. In K. Lamberts & R. Goldstone (Eds.), *Handbook of cognition* (pp. 202–220). London: Sage.

Shanks, D. R., Johnstone, T., & Staggs, L. (1997). Abstraction processes in artificial grammar learning. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 50*(A), 216–252.

Wright, R. L., & Burton, A. M. (1995). Implicit learning of an invariant: Just say no. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 48*(A), 783–796.

Zizak, D. M., & Reber, A. R. (2004). Implicit preferences: The role(s) of familiarity in the structural mere exposure effect. *Consciousness and Cognition, 13,* 336–362.

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Correction to Pirog Revill et al. (2008)

In the article "Context and Spoken Word Recognition in a Novel Lexicon," by Kathleen Pirog Revill, Michael K. Tanenhaus, and Richard N. Aslin (*Journal of Experimental Psychology: Learning, Memory, and Cognition*, 2008, Vol. 34, No. 5, pp. 1207–1223), Figure 9 was inadvertently duplicated as Figure 10 (see pp. 1219–1220). Figure 9 in the original article was correct. The correct Figure 10 is shown below.

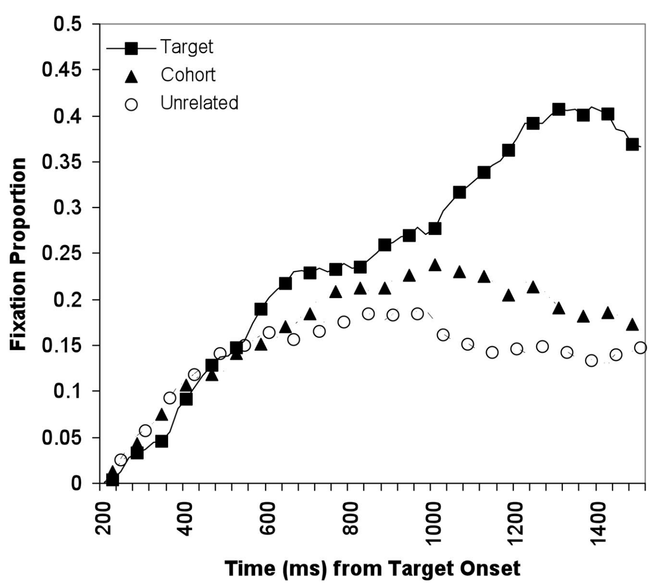

Figure 10. Fixation proportions to target, cohort (collapsed across consistency), and unrelated distracter objects in Experiment 3. All fixations beginning 200ms after object target word onset are included.

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