(AD, CONGRUENT): Of the people who won prizes in a competition last year 20% were NOVELISTS and 80% were POETS. The critics congratulate the winner on his great sensitivity. [78%].
(AD, INCONGRUENT): Of the students who went to parties last year 20% lived in UNIVERSITY HALLS and 80% lived with their FAMILIES. A student who is going to a party stops at the cash-machine of a bank. [90%].
(AD, CONGRUENT): Of the clothes that a woman bought in a shop last year 80% were EXPENSIVE and 20% were CHEAP. The owner has just put a discount on one of the pieces of clothing. [90%].
(AD, INCONGRUENT): Of the people in the country who played last year 80% played BINGO and 20% did the FOOTBALL POOLS. A player's friends congratulate him on his strategies. [74%].
(AD, INCONGRUENT): Of the drivers in a city who were fined last year 20% were fined for BAD PARKING and 80% were find for SPEEDING. The driver who is fined has a heated argument with the police. [81%].

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Implicit learning of an artificial grammar of musical timbres

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Abstract

This study investigates how the artificial grammars of timbres are learned. In Experiment 1, the participants listened to sequences of timbres produced using an artificial grammar. They were then asked to differentiate between sequences which either did or did not violate the grammar. The participants in the explicit condition were informed of the existence of rules underlying the sequences. Those in the implicit condition received no such information (Reber, 1967). Experiment 2 addressed the influence of the learning mode on the content of the knowledge acquired. At the end of the learning phase, the participants were asked to judge the grammaticality of new sequences of timbres (test condition) or letters (transfer condition). The results confirmed the advantage of the implicit condition over the explicit condition but suggest that the knowledge acquired pertained more to surface regularities than to abstract rules. The results are discussed within the framework of current work on implicit learning and musical cognition.

Key words: Implicit learning, music cognition, timbres, artificial grammar.

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INTRODUCTION

Implicit learning describes a form of learning in which subjects become sensitive to the structure of a complex environment through the simple, passive exposure to that environment. Reber (1992) considers this type of learning to be a fundamental cognitive process which permits the acquisition of complex information that is inaccessible to deductive reasoning. Implicit learning has some specific characteristics which distinguish it from explicit forms of learning. Knowledge acquired implicitly remains longer in memory (Allen & Reber, 1980), is less sensitive to interindividual differences (Reber, Walkenfeld, & Hernstadt, 1991), and is more resistant to cognitive and neurological disorders (Abrams & Reber, 1988).

Seger (1994) distinguishes between nine experimental protocols used to study implicit learning. Their sheer variety emphasizes the diversity of situations in which this type of learning can be observed. One of the most common paradigms consists of presenting subjects with sequences of events generated using an artificially defined grammar. Figure 1 presents a sample grammar first used by Reber (1967, 1989) and reused in numerous subsequent studies, including the one presented here. The arrows represent the legal transitions permitted between the different letters (T-S, S-X, P-T, for example). A loop indicates that a letter (S or T) may be repeated any number of times in succession. During the initial phase, subjects have to memorize sequences of letters which conform to the rules of the grammar (TSSXXTKK, for example). One group is asked to discover the rules used to generate the letters (Explicit condition), while the other group is unaware that any such rules exist (Implicit condition). During the second phase, the subjects are asked to judge the grammaticality of new sequences of letters, half of which are agrammatical (in PTXKPS, for example, the PTX transition does not obey the grammar). In general, the subjects in the Implicit condition perform better than those in the Explicit condition (varying between 60% and 80% correct responses). However, only very few of the former subjects are able to describe the rules used to generate the letters. According to Reber (1967, 1989), they have acquired an implicit knowledge of the abstract rules of the grammar.

This internalization of the regularities underlying the variations in the external environment plays a central role in almost all human activities, including artistic ones. Numerous studies of musical cognition have

shown that explicit learning is not necessary for the development of sensitivity to the underlying rules of musical works. Western tonal music possesses a certain number of structural characteristics which resemble those of finite state grammars comparable to the one presented in Figure 1. It is based on a 12-note alphabet (the chromatic scale). These notes are combined in accordance with specific rules in order to produce musically well-formed sequences. Many studies have shown that listening to works written using this musical system leads to the development of an implicit knowledge of the rules of tonal harmony (for a review, see Bigand, 1993; for a similar conclusion drawn from Indian music see Castellano, Bharucha, & Krumhansl, 1984). As far as the cognitive system is concerned, this phenomenon of "tonal acculturation" consists of internalizing the predominant statistical regularities of tonal music works (Francès, 1958; Krumhansl, 1990). A self-associative, connectionist model is able to simulate this learning through the progressive adaptation of the weighting of the connections between the three key elements of the tonal music grammar: notes, chords, and keys (Bharucha, 1987). To a certain extent, these studies of musical cognition, undertaken in a natural environment, confirm the current conclusions of studies of implicit learning.

Research into the perception of contemporary music may, however, lead to a completely different conclusion. Unlike many of the systems

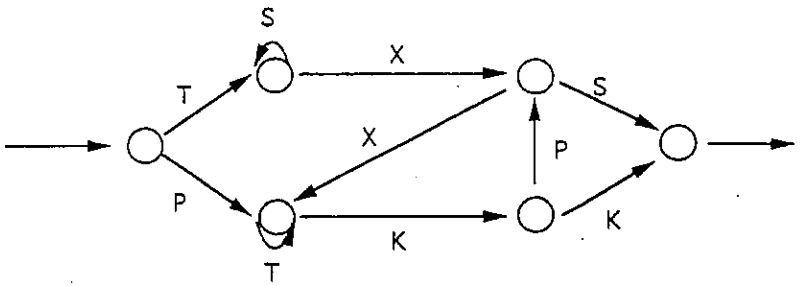

Figure 1. Artificial letter grammar used by Turner and Fischler (1992; after Reber, 1967, 1969). The sequence TXXTKK is grammatical whereas the sequence TXXPS is not.

present in our environment (linguistic systems, for example), musical systems are likely to disappear in order to make way for new musical grammars which express specifically contemporary aesthetic sensitivities. Thus in the West, the tonal musical system gradually waned in the early 20th century as it was overtaken by serial composition systems developed, in particular, by Schoenberg, Berg, and Webern (Griffiths, 1978). Musical works that are serial are generated using totally different rules from those governing tonal music and therefore do not possess the same surface regularities. The considerable and persistent confusion experienced by contemporary listeners in the face of such works raises the question of whether it is possible to internalize these new musical grammars (Lerdahl, 1988; McAdams, 1989). Francès (1958, exp. 6) showed that it is impossible to detect flagrant violations of the grammars of serial music. Moreover, the fact that subjects who are experts in this type of music (mostly composers) perform no better than subjects with no musical training suggests that extensive exposure to serial music is not sufficient for the internalisation of this new musical system. Certain musical grammars may therefore be too "artificial" to be learned (McAdams, 1989).

To a certain extent, the research on the perception of contemporary music contradicts current conclusions concerning implicit learning. If the cognitive system is indeed capable of detecting the complex regularities which underlie changes in the external environment, then these new grammars, however "artificial" they may be, should be assimilated without excessive difficulty. Though rare, experiments on implicit learning in the auditory modality testify to the considerable difference that subjects experience in learning artificial musical grammars (Perruchet, Bigand, & Benoit-Gonin, 1997). This difficulty learning artificial musical grammars suggests that acoustic material imposes specific constraints on this form of learning.

The aim of the current study was to examine this question in greater detail by considering artificial grammars of musical timbres. Timbre was preferred to all other acoustic parameters (such as pitch) because it makes it possible to define musical grammars which subjects cannot already have encountered in the natural environment, and because many contemporary composers consider it to be a potentially significant dimension of musical form (Barrière, 1989; Boulez, 1963). The identification of an ability to learn the relations between musical timbres on the basis of artificial systems would therefore contribute to research on

implicit learning and to our understanding of musical composition and cognition.

The first aim of Experiment 1 was to use sequences of timbres to replicate some of the results usually observed using the artificial letter grammars developed by Reber (1967) and many other authors. The second objective was to show that the implicit learning of sound sequences is based on different processes from those involved in explicit learning. The distinction between these two forms of learning has recently been challenged at both the theoretical and methodological levels (Dulany, Carlson, & Dewey, 1984 ; Perruchet & Amorim, 1992; Perruchet & Pacteau, 1990). However, certain experimental precautions make it possible to separate these two forms of learning. Turner and Fischler (1993) consider that implicit learning makes the rapid, effective processing of information possible, whereas the conscious, voluntary mobilization of explicit knowledge requires more time. Manipulating the time alloted for judging whether new sequences are grammatical (or agrammatical) therefore makes it possible to distinguish between these two types of learning. Although performance is not as good for short time limits (2 seconds vs. 6 seconds), this effect tends to be less pronounced in subjects in the implicit condition. Similarly, the number of responses obtained after the expiration of the permitted response time (timed-out responses) is greater for short response times. However, this effect is again less pronounced for subjects in the implicit condition. These interactions, even though they are only weakly significant, suggest that each learning situation relies on different processes. Experiment 1 of the present study uses a similar method involving sequences of timbres. Both the response time and the tempo of the sequences were varied systematically. Following the same reasoning, a rapid tempo should represent a major disruption to learning in the Explicit condition but not in the Implicit condition.

EXPERIMENT 1

Method

Participants. One hundred and twenty psychology students at the Université de Bourgogne (first year) participated in this study as part of their practical work for a cognitive psychology course.

Material. The grammatical sequences were generated using the grammar depicted in Figure 1 and were identical to those used by Turner and Fischler (1993). Twenty-one grammatical sequences were presented during the training phase. Twenty new grammatical sequences and twenty agrammatical sequences were used in the test phase. The agrammatical sequences were matched with the grammatical ones as to structure, with the exception of 1.45 letters (on average) which were changed in order to violate the grammar (see Table 1A, Appendix). Five well-differentiated timbres were used: gong, trumpet, piano, violin, and voice. Each belonged to a different family of instruments (percussion, wind, struck string, bowed string, voice). These timbres were produced by a very high quality sampler (Proteus 2XR) which held the pitch and intensity parameters constant. The duration of the sounds was varied systematically. In one experimental condition (slow tempo), each timbre lasted 600 ms, whereas in the other (fast tempo) they lasted 300 ms. The timbre sequences were defined by arbitrarily associating one timbre with each of the letters used by Turner and Fischler (1993). The sequences were recorded and played by Sound Designer software with a sampling quality of 16 bits and 44 kHz.

Procedure. During the training phase, each sequence was followed by 5 seconds of silence. The participants in the Implicit group had to memorize the sequences and indicate whether or not they had already heard each new sequence. The participants in the Explicit condition were told that they had to memorize sequences of timbres produced by a computer program which followed a certain number of rules. The experimenter encouraged them to try to identify the rules by telling them that discovering the rules would help them memorize the sequences. During the test phase, all participants were told that the sequences they had heard had been produced by a computer program and that their task consisted of differentiating between new sequences that had been produced by that program ("Grammatical" response) and sequences that had not ("Agrammatical" response). The participants were told that they would hear the same number of grammatical and agrammatical sequences. A control group which had not taken part in the training phase also participated in the test phase. The participants had to respond within a specified period which was either long (6 seconds after the end of the last timbre) or short (2 seconds). An acoustic signal indicated that the response time had expired. Following the method used by Turner and Fischler (1993), all participants performed the test phase with the long followed by the short response period (for a justification of this method, see Turner & Fischler, 1993). Participants were tested individually in one session and were not informed of whether their responses were correct or incorrect.

Results

The mean numbers of correct responses obtained in each of the 12 experimental conditions (3 learning conditions × 2 tempos × 2 time limits) are presented in Figure 2. The participants in the Explicit and Implicit conditions consistently succeeded in differentiating between the grammatical and agrammatical sequences at an above random response level (Table 1). Despite this, performance was only moderately good (52% to 57% success) and, taken overall, was not as good as that observed by Turner and Fischler (1993) in letter sequence tasks sharing the same structure (between 58% and 65% success). The performance of the control groups was significantly below the random response level when the sequences were played at the slower tempo (600 ms per timbre). After the experiment, the participants in this group frequently referred to response strategies that were totally inappropriate for the structure of the material (for example, "the 5-timbre sequences seem to be more grammatical than the others"). This observation suggests that when the sequences were played at a slower tempo, the control group participants tended to invent generative rules that rarely corresponded to the structure of the material. A faster tempo would not give participants enough time to develop this type of strategy, thus resulting in performance close to the random response level. In any case, the results obtained by the control group indicate that it is unlikely that the participants learned the grammar during the test phase. The performance observed in the Explicit and Implicit groups was thus highly dependent on the initial training phase.

We performed a 3 × 2 × 2 × 2 Anova with the first factor (the three learning conditions – Control, Implicit, Explicit) as the between-subject factor and the other three (two tempos – Slow vs. Fast, two response deadlines – 6 vs. 2 seconds, and two types of sequence – Grammatical vs. Agrammatical) as the within-subject factors. As Figure 2 shows, the number of correct responses varied as a function of the learning condi-

Table 1
Experiment 1: values of Student-*t* (one tail) for rejecting null hypothesis of the random responses ($df = 19$).

	Slow tempo		Fast tempo	
	2 sec.	6 sec.	2 sec.	6 sec.
Control	$t = -3.04$ $p < .01$	$t = -5.72$ $p < .001$	$t < 1$	$t = 1.56$ $p > .05$
Explicit	$t = 2.56$ $p < .01$	$t = 1.76$ $p < .05$	$t = 2.53$ $p < .01$	$t = 1.88$ $p < .05$
Implicit	$t = 6.53$ $p < .001$	$t = 8.32$ $p < .001$	$t = 2.68$ $p < .01$	$t = 1.79$ $p < .05$

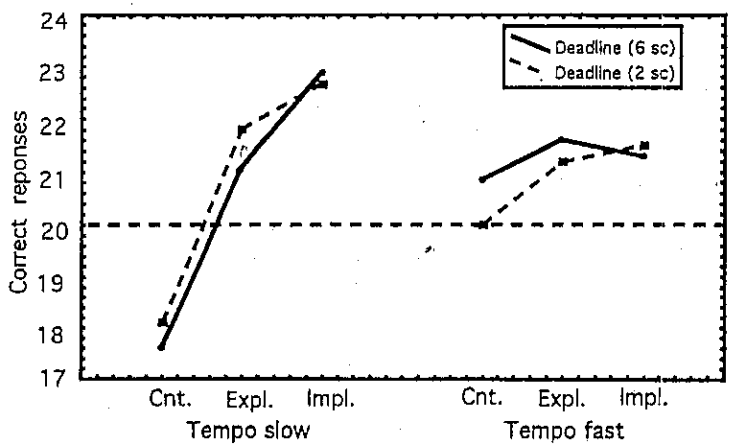

Figure 2. Number of correct responses observed in each group (CNT = control, EXPL = explicit learning, IMPL = implicit learning) as a function of the permitted response period (6 sec. vs. 2 sec.) when the sequences were played at a fast or slow tempo. The dashed line represents the level of the random response.

tion, $F(2, 114) = 25.01$, $p < .001$. Contrast analysis indicated that performance was better in the Explicit condition than in the Control condition, $F(1, 114) = 27.27$, $p < .001$, and was also better in the Implicit condition than in the Control condition, $F(1, 114) = 45.47$, $p < .001$. Although there were more correct responses in the Implicit than in the Explicit condition, this difference was not significant, $F(1, 114) = 2.31$, $p < .13$.

The effect of the learning situation was highly dependent on the tempo of the sequences, $F(2, 114) = 10.50$, $p < .001$. Decomposing this interaction revealed that the contrast between the Control and the Explicit and Implicit learning situations was much greater at the slow tempo, $F(1, 114) = 18.69$, $p < .001$. In fact, the performance achieved by the Control group was only marginally different from that of the Explicit and Implicit groups at the fast tempo, $F(1, 114) = 3.34$, $p = .07$. Whatever the tempo, the performance of the Explicit group was never significantly different from that of the Implicit group. This result contradicts our hypothesis relating to the effect of tempo: since implicit processes are thought to operate much more quickly than explicit processes, a fast tempo should put participants working in the Explicit condition at a disadvantage. Similarly, we imagined that short time limits would be a greater disadvantage to participants in the Explicit condition. This hypothesis was not confirmed: there is no main effect of the time limit factor on correct responses and there was also no significant interaction between the time limit and learning situation factors ($F < 1$): when participants responded before the time limit expired, their responses were often correct, irrespective of whether the allotted time was short or long, and regardless of the learning situation. No other significant effects were observed.

The second dependent variable was the number of responses made after the time limit had expired. These responses were not included in the preceding analyses. As Figure 3 shows, the mean number of timed-out responses was low overall, although it did vary considerably as a function of the experimental condition. The Anova indicated that the number of timed-out responses was higher for short time limits, $F(1, 114) = 80.63$, $p < .001$, that it was dependent on the learning situation, $F(2, 114) = 3.38$, $p < .05$, and that the effect of the time limit factor was greater in certain learning situations than in others, $F(2, 114) = 3.02$, $p = .05$. A breakdown of this interaction showed that the short time limit was more disruptive for the participants in the Explicit condi-

tion, $F(1, 114) = 5.60$, $p < .02$. This result confirms our hypothesis: participants who learned in the Explicit condition succeeded in giving a response within the allotted time less frequently than those who worked in the Implicit condition.

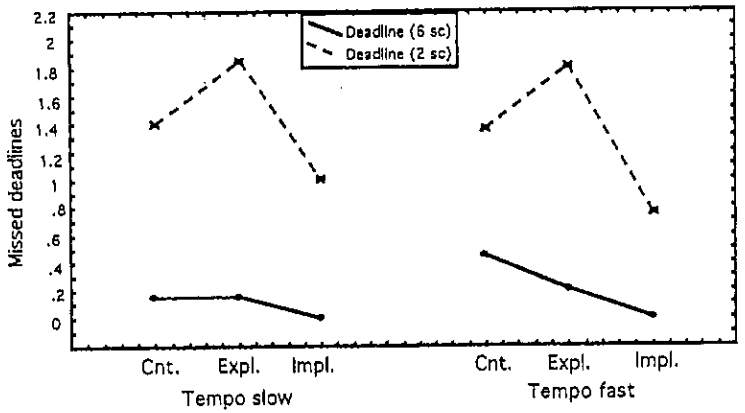

Figure 3. Number of timed-out responses observed in each group (CNT = control, EXPL = explicit learning, IMPL = implicit learning) as a function of the permitted response period (6 sec. vs. 2 sec.) when the sequences were played at a fast or slow tempo.

Discussion

The prior exposure of subjects to a relatively small number of sequences of timbres (21) governed by an artificial rule system was sufficient to enable them to determine which of a new series of sequences broke one or more of the rules. Performance tended to be better in the Implicit condition. The internalization of timbre grammars may therefore result from the simple exposure of subjects to sequences generated by the system without it being necessary for them to implement any explicit analysis processes. The fact that the observed performance was only slightly above the random response level (mean success of 54.5%) is not surprising, given the rapidity of the training phase and the small amount of difference in this study between the grammatical and agrammatical sequences (1.45 letters on average).

However, the results of this study do not permit us to differentiate clearly between implicit and explicit forms of learning: the number of correct responses observed in the Explicit and Implicit groups differed only marginally and the various factors manipulated affected performance in these experimental conditions in similar ways. In this respect, the present study does not replicate the initial results obtained by Turner and Fischler (1993). These authors observed significant (though moderate) interactions between the time limit and the learning situation. The only argument in favor of a dissociation between the two forms of learning appeared when the timed-out responses were analyzed. Although there are only a few such responses, their distribution indicates that the participants in the Explicit groups foud the short time limit more disruptive than the other participants. Overall, these results suggest that the time required to formulate a response was longer in the Explicit condition but that once a response had been decided on, it was more likely to be correct than in the Implicit condition.

The sequential presentation of events might explain the observed differences between these results and those obtained by Turner and Fischler (1993): in our study, information processing could start as soon as the first timbre was heard and this may have reduced the effect of the time limit. However, additional analyses which took into account the length of the sequences failed to distinguish between the two learning modes – even when the sequences were short, the participants in the Explicit groups produced a pattern of results similar to that of the Implicit groups. In contrast, these supplementary analyses revealed an important bias: whatever the experimental condition, the majority of the participants judged short sequences (3 timbres) to be agrammatical. No response bias was observed for longer sequences.

Although Experiment 1 reveals the acquisition of knowledge relating to the acquisition of an artificial timbre grammar, it did not allow us to reliably determine whether the processes involved were implicit or explicit in nature. The validity of such a distinction has been challenged by a number of authors. In particular, Perruchet and Pacteau (1990) showed that subjects can develop explicit knowledge of the associations between adjacent events and that these associations allow them to categorize sequences correctly during the test phase. This suggests that the

knowledge acquired is not necessarily implicit and is not related to the artificial rule system. This argument has been supported by a number of studies (Dulany et al., 1984; Dienes, Broadbent, & Berry, 1991), although not in all cases (Mathews, 1990 ; Gomez & Schvanenveldt, 1994).

The first aim of Experiment 2 was to determine the nature of the regularities internalized by subjects: are they surface regularities related to specific timbre transitions, as Perruchet and Pacteau (1990) suggest, or are we observing knowledge of the abstract rule system (Reber, 1967, 1969)? The most convincing research in favor of the second hypothesis tested learning in transfer situations. Mathew, Buss, Stanley, Bkanchard-Fields, Cho, and Druhan (1989) showed that changing the letters in the test phase while keeping the grammar intact barely affected subjects' performance. Altmann, Dienes, and Goode (1995) provided a more decisive demonstration: their subjects continued to differentiate between grammatical and agrammatical sequences when the sequences addressed a sensory modality other than that involved in the acquisition phase. Performance in transfer situations was only moderately good (mean value 55%) but nevertheless better than random responding. However, transfer from the visual modality (letter sequence) to the auditory modality (sequence of notes of differing pitch) appears to have been simpler than in the opposite direction (56% success vs. 54% success). The fact that knowledge of the grammar can be transferred from one modality to the other indicates that its content must go beyond simple surface regularities. One of the aims of Experiment 2 was to show that knowledge acquired during timbre sequence learning is sufficiently abstract to be transferable to letter sequences.

The second aim was to test the influence of the learning mode on the contents of that knowledge: implicit learning might favor the development of a sensitivity to surface regularities whereas explicit learning could favor the acquisition of knowledge of the abstract rule system. This question was not addressed by Altmann et al. (1995). In the initial phase, subjects had to analyze sequences (of letters or sounds) "in order later to answer questions about these sequences". Although this instruction does not explicitly encourage the subjects to search for the underlying rules, it might nevertheless be thought to lead them to search for regularities about which questions might subsequently be asked. The second aim of Experiment 2 was to establish a more decisive contrast between the two learning modes (implicit vs. explicit). Finally, the third

objective was to test for the possible effect of musical proficiency. Although implicit learning is largely insensitive to interindividual differences, it is conceivable that subjects who have received extensive musical training might fare better in extracting the rules underlying the sound sequences and in transferring that knowledge from the auditory modality to the visual modality.

EXPERIMENT 2

Method

Participants. Forty-eight students took part in the experiment, 32 of which were students at the Université de Bourgogne; they were assigned at random to the Explicit and Implicit learning conditions. The other 16 were advanced music students (music theory and instrumental training) at the Dijon Conservatory of Music; they were assigned to the Implicit condition.

Material. The grammatical and agrammatical sequences used in this experiment were identical to those employed by Dienes et al. (1994) and Dienes, Broadbent, and Berry (1991). Among the grammatical sequences used in the test phase, five were identical to those presented in the acquisition phase (Table 2 in Appendix). The 25 agrammatical sequences were comparable to the grammatical sequences in terms of length and the frequency of occurrence of the letters. The five timbres of the preceding experiment were re-used: the voice was associated with the letter X, the piano with the letter V, the gong with the letter T, the trumpet with the letter M, and the violin with the letter R. The duration of the timbres was 600 ms. During the transfer phase, the letter sequences were presented sequentially with each letter appearing on the computer screen for 600 ms.

Procedure. Twenty grammatical sequences of timbres were presented during the acquisition phase. In the implicit condition, each sequence was followed by a 5-second silence, and then by a white noise lasting 400 ms. Immediately after the white noise, a timbre was presented. The participants had to press a key on the keyboard to indicate whether or not this timbre belonged to the sequence. This task was intended to

force the participants to analyze and memorize the grammatical sequences without encouraging them in any way to search for rules. In the Explicit condition, the sequences were separated by 6 seconds of silence and the experimental task consisted of using this period of silence to discover the rules for the transition between timbres. We replicated the instructions given by Altmann et al. (1995) by telling all participants at the end of the acquisition phase that the sequences they had heard had been produced by a computer program and therefore possessed certain specific regularities. The task in the experimental phase was to differentiate between the sequences produced by the program and the random sequences. Participants had 3 seconds in which to respond. In the Test condition, new sequences of timbres were presented (25 grammatical, 25 agrammatical). In the Transfer condition, letter sequences were presented to the participants, who were then informed that the computer program was now going to generate different-length letter sequences in which each letter would correspond to one of the preceding timbres. No further information was given concerning this correspondence. All participants underwent the experimental phase under both conditions. The testing order was counterbalanced.

Results

We performed a 3 × 2 × 2 × 2 Anova with the first factor (Implicit musicians, Implicit nonmusicians, Explicit nonmusicians) as the between-subject factor and the other three (two conditions – Test vs. Transfer, two condition presentation orders, and two types of sequence – Grammatical vs. Agrammatical) as the within-subject factors. The Anova revealed no significant effects of these factors on the number of correct responses even though, as Figure 4 shows, overall performance was better in the Implicit and Test conditions. Only the (unforeseen) three-way interaction was marginally significant, $F(2, 42) = 3$, $p = .06$: the number of correct responses for the grammatical and agrammatical sequences did not change in the same way between the Test and Transfer conditions for the examined groups. The number of grammatical responses tended to increase in the Implicit group in the Transfer condition, but not for the other two groups. However, the number of correct responses differed significantly from the random response level in the implicit groups but only in the Test condition ($t = 2.49$, $p < .02$; $t = 1.99$, $p < .05$, for nonmusicians and musicians, respectively). At no point did the number of correct responses obtained from the Explicit group differ from the random response level. We also analyzed the timed-out responses. There were very few of these (less than 1 response out of 50 on average) and the Anova performed with this dependent variable did not reveal any significant effects due to the manipulated factors.

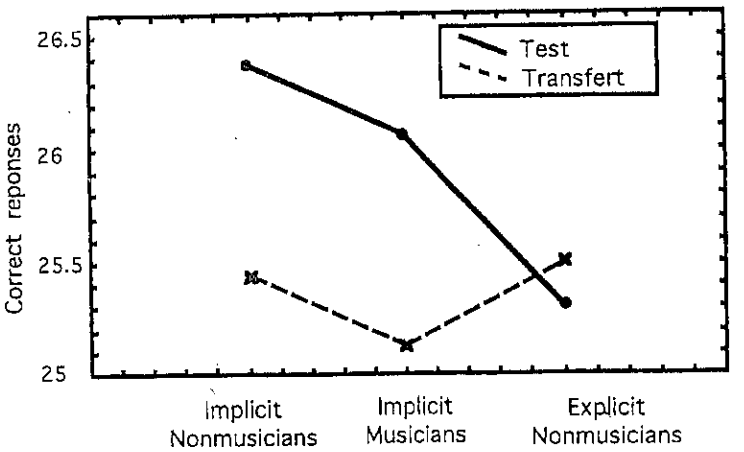

Figure 4. Number of correct responses observed in each group (IMPL = implicit learning, MUSI = musician subjects, EXPL = explicit learning) in the Test and Transfer situations (25 = random response level).

Discussion

This experiment had three aims. In the light of the results obtained by Altmann et al. (1995), we imagined that the knowledge acquired by participants when they listen to grammatical sequences of timbres could be transferred to letter sequences in the second phase of the experiment. This hypothesis is not validated here. The percentage of correct responses was considerably greater than the random response level in the Test condition (for both Implicit groups) but not in the Transfer condi-

tion. This result suggests that the knowledge internalized through simple exposure to grammatical sequences of timbres is primarily related to surface regularities and not to an abstract system of rules.

The second objective was to test for the possible influence of the learning mode on the contents of this knowledge. Since the participants in the Explicit group were informed of the presence of generative rules from the very start of the experiment, they should have experienced less difficulty in performing the task in the transfer condition. We were unable to answer this question on the basis of the results obtained here, since no learning appears to have taken place in the Explicit condition. The results simply confirm that in this type of situation, performance is slightly better in an implicit learning condition (Reber, 1967).

The final aim was to test the influence of the participants' musical training. Musician subjects who had been trained throughout their academic life to listen to complex systems of relations between sounds, to transfer these structures from one sensory modality to another in musical dictation exercises (auditory to visual) and singing exercises (visual to auditory) might have benefited from that training in this experiment. However, the results showed that familiarity with the material used and the type of exercise presented did not improve performance, either in the Test or in the Transfer condition.

To summarize, this experiment confirms that simple exposure to grammatical sequences of timbres left sufficient traces in memory to enable participants to evaluate the grammaticality of new sequences. Such judgements of grammaticality were primarily based on the development of a sensitivity to surface regularities. Far from improving performance, an explicit search for the rules underlying the sequences actually tended to lower it.

GENERAL DISCUSSION

Over the last 20 years, considerable research on the learning of artificial grammars has revealed the extraordinary capability of the cognitive system to tacitly internalize regularities present in structured sequences of events. Two questions have been the focus of considerable debate. One relates to the implicit or explicit nature of the acquired knowledge, and the other, to the content of that knowledge. The possible influence of the inherent properties of the material is never mentioned. The conclusions obtained using letter sequences are generally considered to be valid for all possible sequences of events. The main aim of the present study was to replicate the results of recent work using sequences of musical timbres. Experiment 1 used the same methodology as Turner and Fischler (1993) in order to distinguish between the implicit and explicit modes of learning. Experiment 2 returned to the principle of intermodal transfer to test the contents of the knowledge acquired in this type of experimental situation (Altman et al., 1995).

Firstly, the results obtained confirmed that the presentation of a small number of grammatical sequences of timbres is sufficient to generate a sensitivity to the underlying regularities of the sequences. Following a brief acquisition phase, the subjects succeeded in correctly identifying which sequences in a new set shared the same regularities. Despite this, the percentage of correct responses observed in these experiments remained small and lower than the values obtained using sequences of letters. The results obtained by Perruchet et al. (1997) in a serial reaction time task also testify to the greater difficulty associated with internalizing the statistical regularities of sequences of acoustic events. This difficulty emphasizes the importance of the structure of the material in learning. The sequential presentation of acoustic material might account for these differences. However, in the experiment conducted by Perruchet et al. (1997), performance levels remained higher for sequences of visual events, even when they were presented sequentially.

Another explanation may lie in the more fundamental psychophysical differences between visual and acoustic material. Sound objects (such as musical timbres) have extremely rich acoustic structures which result in strong interactions in the basilar membrane when they are played sequentially (for a review, see McAdams, 1994). The harmonic ranges of a violin and a voice do not create the same types of peripheral interference as those of a violin or a piano. Their similarities in attack and composition tend to link the first two timbres but to separate the other two. These interactions are the source of salient acoustic relations between the timbres. For this reason, sound sequences exhibit acoustic regularities which interfere with the statistical regularities induced by the rules of the artificial grammar. In cases where timbres are projected onto the grammar by means of a random operation (as is the case here), it is highly possible that these two types of regularity conflict to a greater or lesser extent, thus making learning more difficult. Learning would doubtlessly be easier if the rules of the grammar were derived

from potential acoustic relations inherent in the material used. Tonal music represents just such a case (Parncutt, 1989; Krumhansl, 1990; Bigand, Parncutt, & Lerdahl, 1996). The rules of this musical grammar partially coincide with the acoustic properties of harmonic sounds, a fact which no doubt facilitates acquisition. Unlike that of sound sequences, the internal structure of the visual material generally used in experiments (letter sequences), although far from impoverished, would appear to be more neutral and inert, thus facilitating the encoding of artificial regularities.

The same argument might account for the observed difficulty in replicating the learning transfer phenomena reported by Altmann et al. (1995). The results of Experiment 2 testify to the participants' difficulty in transferring knowledge acquired while listening to sequences of timbres, to letter sequences. This suggests, as concluded by Perruchet and Pacteau (1990), that the knowledge acquired during the initial phase of the experiment was primarily related to surface regularities. The influence of this type of regularity may increase with the structural complexity of the material: the richer the material, the more salient the surface relations between the events within a sequence. Surface regularities are probably more important for subjects when musical timbres are used instead of letters or sinusoidal sounds. Indeed, it is understandable that it should be more difficult (or even impossible) to transfer knowledge when sequences exhibiting different degrees of surface complexity are used (such as timbres and letters). The former might lead subjects to focus on the salient surface dimensions of the sequences, whereas the latter, due to their greater surface simplicity, might encourage the encoding of more abstract rules. It would be more difficult to transfer the acquired knowledge since the different types of knowledge involved might require a different type of encoding.

Seen from this perspective, the difficulties exhibited by participants during the second experiment are revealing. In general, participants were surprised at having to assess the grammaticality of new sequences of timbres at the end of the acquisition phase. They all experienced considerable difficulty in understanding the rationale behind the experiment when they were asked to judge the grammaticality of sequences of letters following training on sequences of timbres. The difficulty of this task appeared to be all the greater when the participants started with the transfer condition and worked in the implicit condition. All of the musician subjects seemed to find it absolutely impossible to compare letter

sequences with timbre sequences due to the great difference between these two types of events.

This type of reaction, which Altman et al. (1995) do not seem to have encountered, also poses a methodological and theoretical problem. The majority of the participants in the implicit condition found it impossible to make an explicit judgement about the grammaticality of sequences of timbres or letters, even though there was nothing to draw their attention to this aspect during the acquisition phase. This raises a legitimate question: if the knowledge acquired during the initial phase of the experiment were implicit in nature, that is to say, if it could not be verbally articulated, subjects would experience substantial difficulty in accessing it intentionally in order to judge the grammaticality of new sequences. Indeed, such a task would appear to be inappropriate for an investigation of the content of this type of knowledge, thus explaining the difficulty encountered in distinguishing between the implicit and explicit modes of learning. According to Vokey and Brooks (1992), one of the ways of performing a judgement of grammaticality task would require the subjects in the implicit condition to perform a mental reanalysis of the sequences they had already seen or heard in order to search explicitly for the rules that underlie them. This analysis might be more difficult in the auditory than in the visual modality. Using implicit rather explicit tests would thus be more appropriate for comparing implicit learning in the visual and auditory modalities.

CONCLUSION

This study shows that simple exposure to grammatical sequences of timbres suffices for enabling subjects to assess the grammaticality of new sequences. To a certain extent, each experiment represents a "miniature" reproduction of the acculturation to musical material discussed by Francès (1958), Bharucha (1987), and Krumhansl (1990) in connection with tonal music. The fact that the sequences used here varied only in timbre, and in accordance with totally artificial rules, suggests that new musical grammars defined for aesthetic reasons and bearing on this parameter might be integrated in a similar way, even by subjects with no particular musical expertise. However, the success rates observed in these experiments were low when compared with the results obtained for comparable sequences of letters. This suggests that acoustic material

may well impose specific constraints on the learning of artificial grammars. The analysis of these constraints might lead us to reconsider the importance of low-level processes in current research on implicit learning.

RÉSUMÉ

Cette étude porte sur l'apprentissage de grammaires artificielles de timbres. Dans l'expérience 1, les sujets écoutaient des séquences de timbres produites par une grammaire artificielle, puis ils devaient différencier les séquences présentant ou non une violation de la grammaire. Les sujets de la condition explicite étaient informés de l'existence de règles sous-tendant ces séquences ; ceux de la condition implicite ne l'étaient pas (Reber, 1967). L'expérience 2 porte sur l'influence du mode d'apprentissage sur le contenu des connaissances acquises. Après la phase d'apprentissage, les sujets devaient effectuer un jugement de grammaticalité sur de nouvelles séquences de timbres (condition de test) ou de lettres (condition de transfert). Les résultats confirment l'avantage de la condition implicite sur la condition explicite mais suggèrent que les connaissances acquises portent plus sur des régularités de surface que sur des règles abstraites. Ces résultats sont discutés dans le cadre des recherches actuelles sur l'apprentissage implicite et sur la cognition musicale.

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APPENDIX

Table A1
Grammatical and agrammatical sequences used in Experiment 1 (from Turner & Fischler, 1993)

Acquisition	Test	
Grammatical	Grammatical	Agrammatical
TSXS	TXS	PXS
TSSXS	TSSSSXS	TSSSKK
TSSSXS	TSXXKK	TKXXKK
TXXKK	TSSSXXKK	TSSSXXPP
TSSXXKK	TSXXTKK	KSXXTKK
TXXTKK	TSSXXTKK	TSSXXTSK
TXXTTKK	TXXKPXKK	TPPKPXKK
TSXXTTKK	TXXKPS	TXXKSS
TSSXXTKK	TSXXKPS	SSXXKPS
TSSXXKPS	TXXTKPS	TXXTSPK
TXXTTKPS	PKK	PTT
TSXXTKPS	PTKK	TTKK
PTTKK	PKPXKK	PKPXTK
PTTTKK	PTTKPXKK	KKTKPXKK
PTTTTKK	PKPXTTKK	PKPXTT
PTKPXKK	PTKPXTKK	STKPXTKK
PKPXTKK	PTKPS	PTKXX
PTKPXTKK	PTTTKPS	TTTKPS
PTTKPS	PKPXKPS	PKPXKPK
PTTTTKPS	PTKPXTKPS	XXPXTKPS
PTKPXKPS		

Table A2
Grammatical and agrammatical sequences used in Experiment 2 (from Altman, Dienes, & Goode, 1995)

Acquisition	Test	
Grammatical	Grammatical	Agrammatical
MTTTTV	VXTTTV	VXRRT
MTTVT	MTTTV	VXX
MTV	MTTVRX	VXRVM
MTVRX	MVRXVT	XVRVM
MTVRXM	MTVRXV	XTTTTV
MVRX	MTVRXR	MTVV
MVRXRR	MVRXM	MMVRX
MVRXTV	VXVRXR	MVRTR
MVRXV	MTTTVT	MTRVRX
MVRXVT	VXRM	TTVT
VXM	MVT	MTTVTR
VXRR	MTVT	TVTTXV
VXRRM	MTTV	RVT
VXRRRR	MVRXR	MXVT
VXTTVT	VXRRR	VRRRM
VXTVRX	VXTV	XRVXV
VXTVT	VXR	VVXRM
VXVRX	VXVT	VXRT
VXVRXV	MTV	MTRV
VXVT	VXRRRM	VXMRXV
	VXTTV	MTM
	VXV	TXRRM
	VXVRX	MXVRXM
	VXVRXV	MTVRTR
	MVRXRM	RRRXV

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To what extent does pause location predict pause duration in adults' and children's writing?

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Abstract

The present study examines the relationships between pause duration and pause location in adults' and children's writing. Ten adults, ten third graders and ten second graders were individually videotaped and timed while writing a report about a personal tour. Pauses were coded in relation to their location in the grammatical units of the text. Pause durations were input into analyses of variance and multiple linear regression analyses. First, the results revealed a strong similarity between adults and children both in the temporal structure and, by inference, in the cognitive organization of their writing. Second, pause location was found to be a relatively weak predictor of pause duration variations. Lastly, differences in pause duration were observed between adults and children and between second and third graders. These results are discussed in terms of cognitive load, in the framework of the cognitive management of writing.

Key words: adults' writing, children's writing, pause duration, pause location.

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