Implicit, Intuitive, and Explicit Knowledge of Abstract Regularities in a Sound Sequence: An Event-related Brain Potential Study

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Abstract

■ Implicit knowledge has been proposed to be the substrate of intuition because intuitive judgments resemble implicit processes. We investigated whether the automatically elicited mismatch negativity (MMN) component of the auditory event-related potentials (ERPs) can reflect implicit knowledge and whether this knowledge can be utilized for intuitive sound discrimination. We also determined the sensitivity of the attention- and task-dependent P3 component to intuitive versus explicit knowledge. We recorded the ERPs elicited in an "abstract" oddball paradigm. Tone pairs roving over different frequencies but with a constant ascending inter-pair interval, were presented as frequent standard events. The standards were occasionally replaced by deviating, descending tone pairs. The ERPs were recorded under both ignore and attend conditions. Subjects were interviewed and classified on the basis of whether or not they could datect the deviants. The deviants elicited an MMN even in subjects who subsequent to the MMN recording did not express awareness of the deviants. This suggests that these subjects possessed implicit knowledge of the sound-sequence structure. Some of these subjects learned, in an associative training session, to detect the deviants intuitively, that is, they could detect the deviants but did not give a correct description of how the deviants differed from the standards. Intuitive deviant detection was not accompanied by P3 elicitation whereas subjects who developed explicit knowledge of the sound sequence during the training did show a P3 to the detected deviants. ■

INTRODUCTION

Cognitive psychology has a long history of interest in implicit cognitive processes such as implicit learning (Cleeremans, Destrebecqz, & Boyer, 1998; Knowlton & Squire, 1996; Seger, 1994; Reber, 1967, 1989) and implicit memory (Schacter, Dobbins, & Schnyer, 2004; Schacter, 1987). Implicit learning in the auditory domain has been demonstrated in sequence learning (Buchner & Steffens, 2001) and artificial grammar learning paradigms (Altmann, Dienes, & Goode, 1995; Howard & Ballas, 1980). These studies have indicated that listeners can learn sequential sound structures and sound regularities without being explicitly aware of the learned relationships. Implicit memory is typically studied in priming experiments. Auditory priming studies have shown that sound identification is facilitated by previous listening to the to-be-identified sounds although subjects cannot consciously recollect the previous learning episode (Chiu & Schacter, 1995; Church & Schacter, 1994; see, however, for a critical view, Butler & Berry, 2001; Shanks & St. John, 1994). A commonly used definition (Nisbett & DeCamp Wilson, 1977) states that implicit processes are automatic processes that take place without awareness and result in knowledge that is difficult to verbalize. Explicit processes do require effort and awareness, and the details of the information involved can be expressed verbally.

Implicit knowledge has been proposed to be the substrate of intuition (Lieberman, 2000; Reber, 1989) because intuitive judgments resemble implicit processes. It is difficult to verbalize the information involved in an intuitive decision, and one is not fully aware of all the processes contributing to it. To our knowledge, there is yet no empirical evidence for this notion. If it were the case that implicit knowledge is the substrate of intuition, it would mean that implicit knowledge could be used to make *correct* intuitive decisions. The aims of the present study were to use auditory event-related potentials (ERPs) to probe the presence of implicit knowledge, to investigate whether implicit knowledge can be utilized for correct intuitive sound discrimination, and to determine which ERP components reflect intuitive or explicit knowledge.

The mismatch negativity (MMN) is a negative component of the auditory ERPs, peaking between 150 and 300 msec poststimulus (Näätänen, Gaillard, & Mäntysalo, 1978; for reviews, see Picton, Alain, Otten, Ritter, &

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Achim, 2000; Ritter, Deacon, Gomes, Javitt, & Vaughan, 1995), reflecting a neural change-detection process. The MMN is typically elicited in an oddball paradigm by rare sounds (deviants) that differ in some aspect from frequently presented sounds (standards). The auditory system extracts the regularities from the auditory input and stores them in a sensory–memory template. When a sound is detected that does not match this memory representation, an MMN is elicited.

An interesting aspect of the MMN is that it is elicited at an involuntary processing stage. The underlying neural mechanisms are, to a large degree, automatic; attention to the auditory stimuli is not required (Alho, Woods, & Algazi, 1994; however, see also Alain & Woods, 1997; Woldorff & Hillyard, 1991). It could, therefore, be that the neural change detection mechanism underlying the MMN elicitation is implicit. It is, however, a well-established fact that MMN elicitation correlates with the perception of stimulus deviance. This has been shown in several studies testing discriminative abilities in a behavioral session subsequent to the unattended MMN recording (Novitski, Tervaniemi, Huotilainen, & Näätänen, 2004; Jaramillo, Paavilainen, & Näätänen, 2000; Tervaniemi, Ilvonen, et al., 2000; Tiitinen, May, Reinikainen, Näätänen, & Sams, 1994). Furthermore, a larger discrepancy between standards and deviants is reflected in larger MMN amplitudes as well as in higher hit rates, and when the difference between standards and deviants becomes too small to be perceived, the MMN disappears (Sams, Paavilainen, Alho, & Näätänen, 1985). From these studies, it became evident that although the MMN can be elicited when stimuli are unattended, the deviants are detected if subjects do subsequently attend to the sound material. Thus, when attended, the outcome of the auditory change-detection process reaches awareness.

Although the majority of studies find support for this view, some exceptions have been reported. A few studies found that not only detected deviants (hits) elicited an MMN but also deviants that are not detected (misses) (Neuloh & Curio, 2004; Alho & Sinervo, 1997). It has also been reported that MMN elicitation can precede the behavioral detection of deviants over the course of a difficult speech-contrast discrimination training (Tremblay, Kraus, & McGee, 1998).

In addition, preliminary evidence that the ''abstract'' MMN can reflect implicit knowledge was obtained by Paavilainen, Simola, Jaramillo, Näätänen, and Winkler (2001). In an abstract oddball paradigm, higher order relationships between physical sound features are manipulated (Paavilainen, Jaramillo, & Näätänen, 1998; Tervaniemi, Maury, & Näätänen, 1994; Saarinen, Paavilainen, Schröger, Tervaniemi, & Näätänen, 1992; for a review, see Näätänen, Tervaniemi, Sussman, Paavilainen, & Winkler, 2001). This results in a relatively complex auditory scene in which there is no physically identical repeating sound. For instance, the tonal interpair relationship of tone pairs constantly varying over a frequency range can be constant and serve as standard event (Saarinen et al., 1992). In the Paavilainen, Simola, et al. (2001) study, abstract feature conjunctions were manipulated. The standard stimuli varied randomly over a large range in both frequency and intensity, but followed the rule, ''the higher the frequency, the higher the intensity.'' Occasional deviant stimuli violated this rule and elicited an MMN, indicating that the auditory system had been able to encode the regular frequency–intensity relationship, as well as to detect the deviants. The ''knowledge'' of the auditory system was, however, not necessarily consciously available to all subjects. In an interview and detection task after the MMN measurement, not all subjects expressed knowledge of the relationship between frequency and intensity, nor were they able to detect the deviants. Based on this study it can, however, not yet be concluded that these three subjects possessed implicit knowledge because their ERPs were not analyzed separately. This leaves open the possibility that they did not have an MMN contributing to the group-averaged MMN. In the present study, we investigated this further by using an abstract roving tone-pair paradigm (Saarinen et al., 1992).

We also investigated whether the memory used for automatic change detection can be utilized for intuitive behavioral detection of the deviants. We engaged our subjects in an associative training in which the occurrence of the deviant coincided with a flash on a computer screen. The training was aimed at teaching subjects the sound quality of the deviants without telling them how the stimulus sequence was constructed, that is, without giving them explicit knowledge. This procedure might enable subjects to learn to detect the deviants intuitively.

Different auditory processing stages could be differentially affected by the knowledge that subjects have of the stimuli. An automatic processing stage might not be affected by whether subjects have intuitive or explicit knowledge of the stimuli, and the MMN amplitude should then not be affected either. On the other hand, subsequent attention-dependent and task-related processing stages could very well be affected by ''knowledge type.'' The P3 component of the ERPs (Herrmann & Knight, 2001; Picton, 1992; Sutton, Braren, Zubin, & John, 1965), a centrally positive multimodal deflection peaking around 300 msec poststimulus, is elicited by detected deviants. The P3 amplitude is affected by many parameters related to target detection and evaluation, such as task difficulty (Kok, 2001), stimulus expectancy (Squires, Wickens, Squires, & Donchin, 1976), and informational content (Johnson, 1986). It is therefore likely that the P3 amplitude is also sensitive to whether subjects use intuitive or explicit knowledge for the detection of deviants. An explicit decision might involve more stimulus evaluation processes than an intuitive decision, and the P3 amplitude might therefore be larger for an explicit decision. This is supported by visual sequence-learning studies that compare the effect of explicit versus implicit knowledge on the ERPs (Rüsseler, Henninghausen, Münte, & Rösler, 2003; Rüsseler & Rösler, 2000; Schlaghecken, Stürmer, & Eimer, 2000; Baldwin & Kutas, 1997). Subjects who had explicitly learned the sequence order showed larger P3 amplitudes to order violations than subjects with implicit knowledge.

We tested the following hypotheses. (1) The outcome of the auditory neural change-detection mechanism eliciting the MMN can be implicit. If this hypothesis holds, MMN should be elicited in subjects who, in an interview after the MMN recording, do not express awareness of the deviants. (2) Implicit knowledge can be the substrate of intuition. If so, subjects with implicit knowledge should be able to learn to detect the deviants intuitively with the help of the associative training task. (3) Knowledge type does not affect involuntary processes. The MMN amplitude should thus, under ignore conditions, not be affected by whether subjects have previously expressed intuitive or explicit knowledge. (4) Knowledge type does, on the other hand, affect later attention-related detection processes. The P3 should thus be larger for subjects using an explicit deviant-detection strategy than for those using an intuitive strategy.

METHODS

Subjects

Twenty-four subjects participated in the experiment. Subjects were selected to have a native language easily understood by the experimenters and were required to express themselves in their native language during the whole experiment. All subjects reported normal hearing and were paid for their participation. The data of one subject was discarded because of a lack of motivation to participate. The remaining 23 subjects (9 women) had a mean age of 26.5 years.

Stimuli

We used an abstract oddball paradigm with roving ascending tone pairs as standards and roving descending tone pairs as deviants. The stimuli were sinusoidal tones, delivered through headphones at an intensity of 40 dB above hearing threshold. The two types of tone pairs, standards ($p = .9$) and deviants ($p = .1$), were presented semirandomly (there was always a minimum of one standard between the deviants). The individual tone duration was 75 msec, the within-pair interval was 20 msec, and the interpair interval was 300 msec. Tones ranged from C4 to C5 on the musical scale in semitone steps (or from 261.6 to 523.3 Hz). The frequency step within the standard pairs was five semitones ascending, and the frequency change within the deviant pairs was five semitones descending.

In the ''ignore'' conditions, stimuli were presented in three blocks of 13 min, and in the ''attend'' condition, in four blocks of 10 min. In total, 5100 standards and 510 deviants were presented per subject for each condition. In the training session, subjects watched a black computer screen that flashed white during the presentation of the second tone of a deviant tone pair.

Procedure

After electrode montage, subjects were comfortably seated in an acoustically and electrically shielded room. First, an electroencephalogram (EEG) recording was conducted in which subjects watched a video (''Ignore I'' condition, see Table 1). The subjects watched a self-selected, subtitled silent movie and were instructed to disregard the sound stimulation delivered through the headphones. Subsequently, the subjects were interviewed (Interview I) to determine whether they possessed knowledge of sound structure. Now they had to listen to the stimulus material as long as they thought was needed to learn to describe the sound sequence as detailed as possible. After their description of the stimuli, they listened to the stimuli again, but now with the instruction to listen for something that was ''occasionally different'' or somehow ''stood out'' among the other sounds. They were asked to give an as detailed as possible description of what they had heard. If subjects noticed that something was occasionally different, we tested their ability to detect the deviants by requesting them to press a button when they heard a sound that stood out.

Subjects continued with an associative-training session. They watched a black screen that flashed white whenever a deviant was presented. The subjects were instructed to learn to discriminate the sounds (targets) that were associated with the flashes so that they could detect them later on without the help of the screen. They did not receive any information from the experimenters about the sound structure. Subjects were allowed to listen to the sounds and watch the screen as long as they wanted. When they indicated that they could detect the sounds coinciding with the flashes, they were tested with the screen switched off. After that, all subjects were given performance feedback (''you detected none/some/most of the target sounds'') and received a second screen training followed by a brief test. Subjects were interviewed again (Interview II) to determine whether they possessed no knowledge, intuitive knowledge, or explicit knowledge of the difference between the standards and deviants. They were asked the following question: ''Now that you press most of the time correctly to the target sounds, can you as precisely as possible describe in which way they are different from the other sounds?'' ERPs were not recorded during the training session.

Table 1. Experimental Phase, Subject Classification, and Terminology Used to Denote the Grand-averaged ERPs

Experimental Phase	*Subject Categorization*		*Names of Subject Groupings*		*Names of Subject Groupings, Post Hoc Comparison*
EEG recording—Ignore I		Figue 1	Ignore I explicit (4) Ignore I no knowledge (19)	Figue 5A–C	Will express explicit knowledge (5) Will express intuitive knowledge (12)
Interview I	4 subjects express explicit knowledge 19 subjects do not express knowledge				
Training					
Interview II	9 subjects express explicit knowledge 12 subjects express intuitive knowledge 2 subjects are not able to detect the deviants				
EEG recording—Attend		Figue 2	Attend explicit (9) Attend intuitive (12)		
Interview III	None of the subjects has changed knowledge type				
EEG recording—Ignore II		Figue 3	Ignore II explicit (9) Ignore II intuitive (12)	Figue 5D–F	Express explicit knowledge (5) Express intuitive knowledge (12)
		Figue 4	Ignore no knowledge (2)		

The chronology of the experiment is given in the first column. The second column shows the subject classification based on the verbal responses in Interviews I–III. The third column gives the terminology used to denote the grand-averaged ERPs. The fourth column gives the terminology used for the grand-averaged ERPs of the post hoc comparison. The number of subjects in each grand-averaged ERP is given in parentheses.

The experiment continued with the EEG recording for the attend condition. Subjects were instructed to press a button to the target sounds after which they were interviewed again (Interview III) to determine whether their knowledge of the stimuli had changed during the attend condition.

Subsequently to the attend condition, we recorded the EEG again in the Ignore II condition in which the subjects continued to watch a movie. After this condition, the electrodes were removed and we explained to the subjects the details of the experiment. This was the first time that the subjects who had expressed explicit knowledge during the experiment received a confirmation that they had given a correct description of the stimuli. Subjects who had not expressed explicit knowledge were given a detailed explicit description of the stimuli. We asked them whether they recognized the sounds they had listened to from our description and whether they had had, in any phase of the experiment, a similar idea in mind without expressing it to the experimenters. All verbal responses of the subjects were tape recorded for later reference.

Data Recording and Analysis

The EEG was recorded from 32 recording sites placed according to the 10-20 system by using an electrode cap. In addition, electrodes were placed at the left (Lm) and right (Rm) mastoids. The reference electrode was placed on the tip of the nose. The horizontal electrooculogram (EOG) was recorded by electrodes placed on the lateral canthi of the eyes, and the vertical EOG was measured with electrodes above and below the right eye. The EEG was digitized at a rate of 500 Hz (band pass 0.1–100 Hz). The signal was downsampled off-line to 250 Hz. Nine channels were selected for further analysis (Fz, Cz, Pz, F3, F4, C3, C4, left mastoid LM, and right mastoid Rm). The raw EEG was band-pass filtered (2–35 Hz) and divided into epochs from −100 to 600 msec, with the onset of the second tone of the stimulus pairs at 0 msec. Single epochs were baseline corrected from −100 to 0 msec after which all epochs containing signal exceeding ±60 μV were removed. ERPs were averaged separately for each condition, stimulus type, and subject group (see below). In the attend condition, ERPs were averaged separately for standard pairs, detected deviant pairs (hits), and nondetected deviant pairs (misses).

The MMN amplitudes were measured for each subject as the mean amplitude in a 64-msec window centered on the peak amplitude of the grand-average deviant-minus-standard difference wave. P3 amplitudes were determined in the same way from Pz. Dependent-sample two-tailed t tests were used to determine the presence of MMN and P3. Independent-sample t tests were used to test whether the MMN amplitudes or behavioral responses were different between different subject groups. Behavioral results from the attend condition were determined by calculating the hit rate, false alarm rate, and the reaction time (RT) to the hits. Responses were considered correct if they occurred between 200 and 3000 msec from the onset of the second tone of a deviating tone pair. This range was determined by inspecting the histogram of the RTs. In a post hoc comparison, a two-way ANOVA was used with the factor Group (will express explicit knowledge, will express intuitive knowledge) and the repeated measure Condition (Ignore I, Ignore II).

In two cases there were not enough subjects in the groups to perform regular group-level statistics. Instead, a randomization test (Ponton, Don, Eggermont, & Kwong, 1997) was performed. First the signal was filtered with a 2- to 10-Hz fourth-order Butterworth band-pass filter (attenuates 24 dB/octave) for the purpose of noise reduction (Tervaniemi, Lehtokoski, et al., 1999). The mean amplitude in a 64-msec window around the peak of the MMN was calculated for the group-averaged deviant and for all individual standard epochs. A total of 1500 subaverages of the standard-amplitude measure were calculated. Each subset was the average of randomly selected amplitude measures of a total equal to the number of epochs averaged in the deviant. The probability that the deviant response was drawn from the distribution of standard subaverages was calculated to determine the level of significance.

RESULTS

Verbal Reports and Subject Classifications

In Interview I (see Table 1), 4 of the 23 subjects were able to describe the stimuli exactly: They mentioned both the ascending frequency relationship in the standard tone pairs and the descending frequency relationship in the deviant tone pairs. The ERPs of the Ignore I condition of these 4 subjects were averaged (''Ignore I explicit'' group). The remaining 19 subjects did not describe the stimuli accurately, and although 4 of them mentioned that the tones were presented in pairs, they did not mention the particular within-pair frequency relationships. None of these 19 subjects (''Ignore I no knowledge'' group) noticed sounds being sometimes different or standing out among the others.

During the training session, all subjects except 2 indicated within 3 min that they thought they could detect the target sounds without the help of the visual cue on the screen. Of the 23 subjects, 21 learned to detect the deviants. Two subjects wanted to listen much longer to the training than the others but nevertheless did not learn to discriminate the deviants.

In Interview II, 9 subjects expressed explicit knowledge of the sound structure (4 subjects expressed explicit knowledge in Interview I and another 5 subjects developed explicit knowledge during the training). Twelve subjects did not express explicit knowledge, giving either a wrong (''I press when a sound is louder'' or ''I press when a sound comes quicker'') or a subjective explanation (''I press when I hear a bloop instead of a bleep'' or ''I press when it sounds darker''). After the training session there were in total 9 subjects with explicit knowledge (''attend explicit'' group), 12 with intuitive knowledge (''attend intuitive'' group), and 2 expressing no knowledge of the stimulus structure.

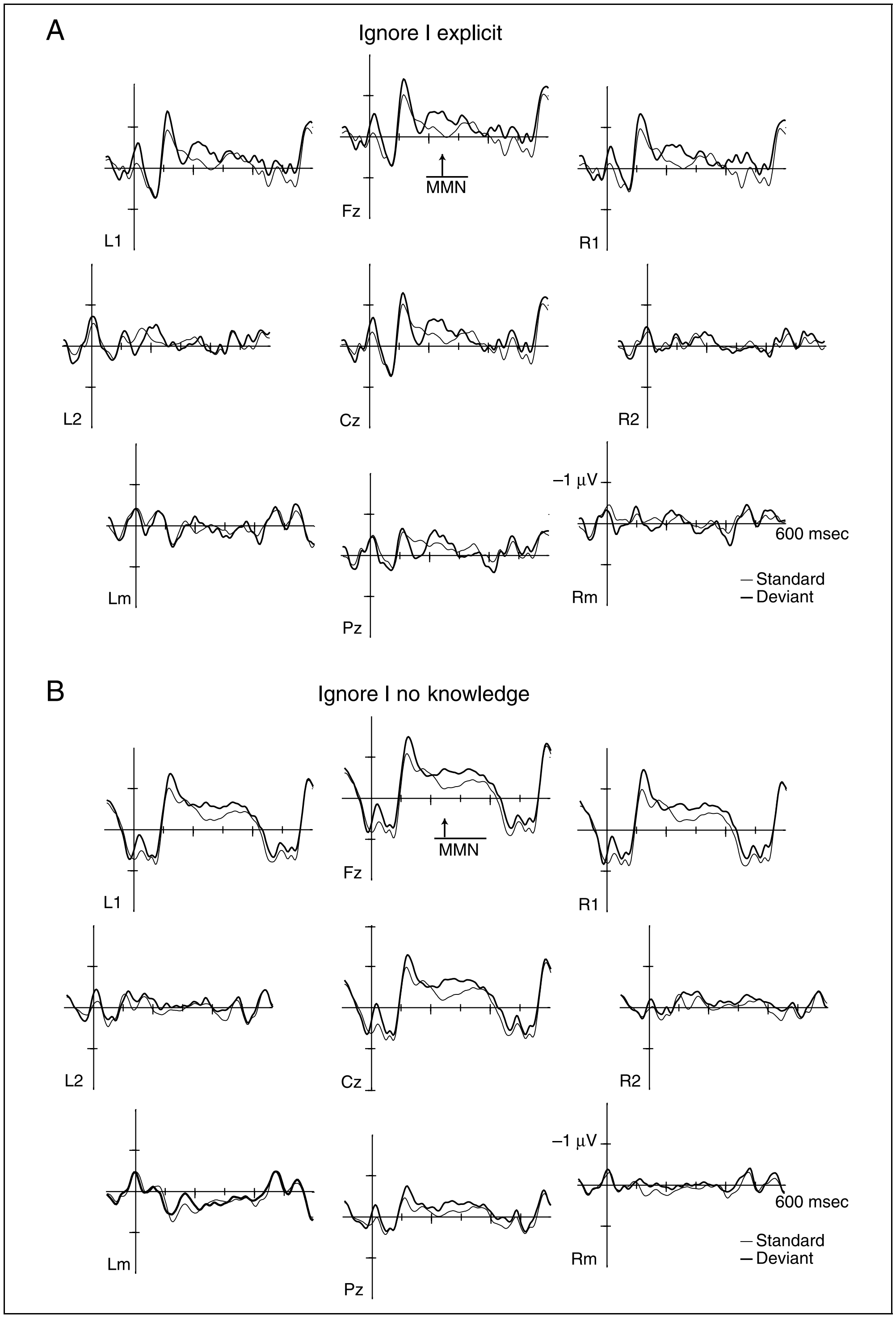
During Interview III (after the attend condition), no additional subjects expressed explicit knowledge, indicating that no further learning had occurred during the attend condition. ERPs from the Ignore II condition were averaged separately for the subjects with intuitive knowledge (''Ignore II intuitive'' group), for subjects with explicit knowledge (''Ignore II explicit'' group), and for the two subjects without knowledge (''Ignore no knowledge'' group).

After the experiment, subjects received a full explanation of the structure of the stimulus structure. None of the subjects of the intuitive or no knowledge group recognized from our explanation the stimuli they had listened to. Most subjects reacted with surprise to the way the stimulus sequence was constructed.

ERPs in the Ignore I Condition

Grand-average ERPs for the Ignore I explicit group are presented in Figure 1A. A randomization test (see Methods) indicated that an MMN, peaking at Fz at 239 msec,

Figure 1. ERPs elicited in the Ignore I condition for the subjects expressing explicit knowledge (A) and for the subjects expressing no awareness of deviants (B). Time zero corresponds to the onset of the second tone of a pair. The gray arrows indicate the duration, peak latency, and peak amplitude of the MMN.



was elicited ($p < .03$). Grand-average ERPs for the Ignore I no knowledge group are displayed in Figure 1B. The curves show an MMN peaking at Fz at 244 msec, $t(18) = 4.1, p < .0007$.

ERPs in the Attend Condition

Grand-average ERPs obtained for the attend explicit group are presented in Figure 2A. For the detected deviants (hits), a negative deflection with respect to the standard ERP is seen, peaking at Fz at 276 msec, $t(8) = 3.1, p < .02$. This is most likely an MMN with a partly overlapping N2b component. The N2b is also elicited by deviants in attended conditions, but the N2b scalp distribution is more central than that of the MMN (e.g., Novak, Ritter, Vaughan, & Wiznitzer, 1990). The hit ERP shows a negative deflection that is larger at Cz than at Fz, accompanied by a negative deflection at

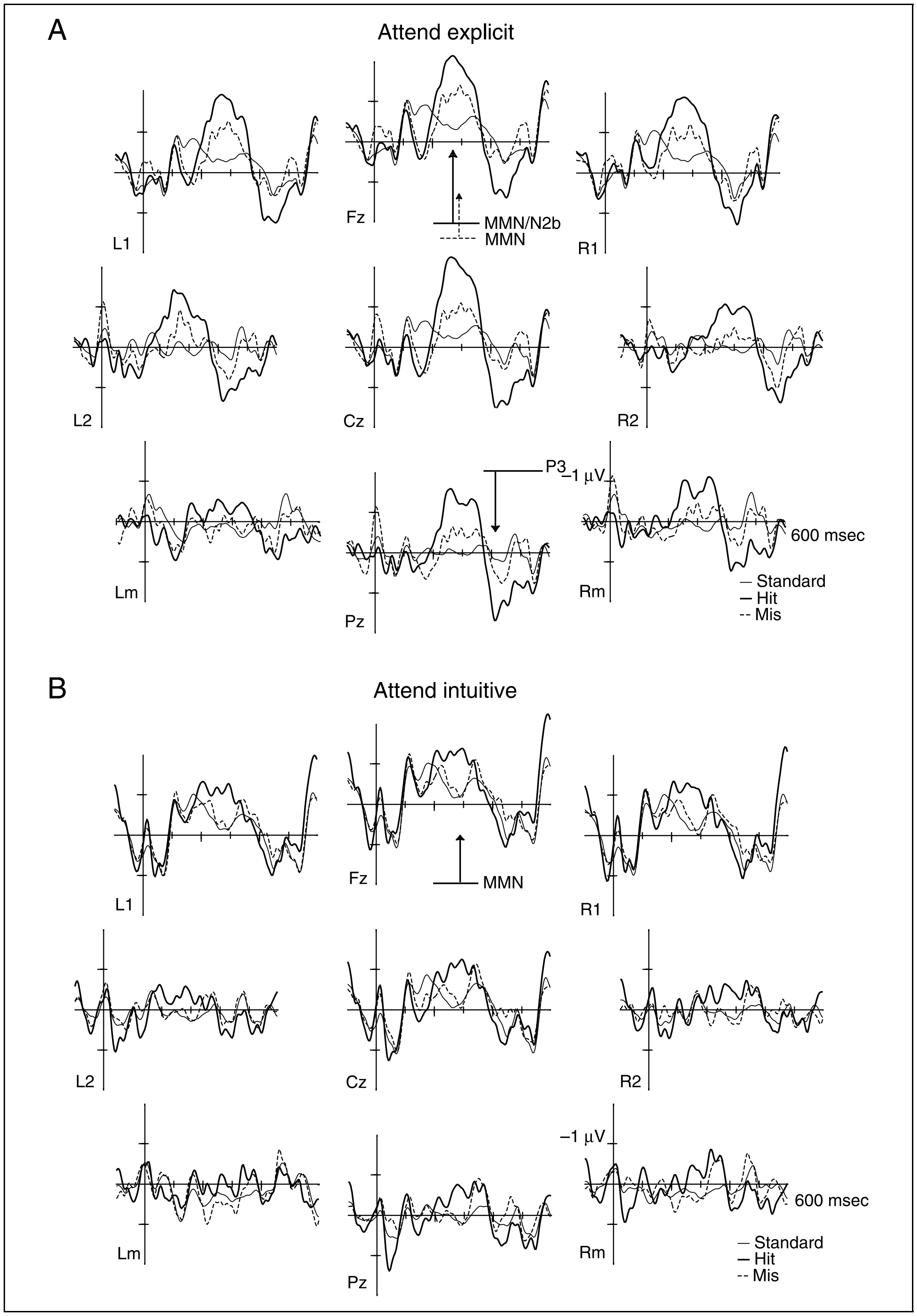


Figure 2. ERPs elicited in the Attend condition for the subjects expressing explicit knowledge (A) and for the subjects expressing intuitive knowledge (B). Time zero corresponds to the onset of the second tone of a pair. The gray arrows indicate the duration, peak latency, and peak amplitude of the MMN, MMN/N2b, and P3.

the mastoids, suggesting that in addition to an MMN, an N2b was elicited. The MMN/N2b was followed by a P3 peaking at 410 msec at Pz, $t(8) = -3.0$, $p < .02$). The deviants that were not detected (misses) also elicited an MMN peaking at 296 msec, $t(8) = 2.3$, $p < .05$, which was not followed by a P3 component.

Grand-averaged ERPs obtained for the attend intuitive group are presented in Figure 2B. An MMN was elicited by the hits, peaking at 288 msec, $t(11) = 3.1$, $p < .01$. In this group, the MMN was not followed by a P3 and there was no evidence for an MMN for the missed deviants.

In addition to the well-known ERP components, there is an unexpected positive deflection for the hits and misses (see Figure 2A and B) preceding the MMN peaking at around 170 msec at Fz. It is largest in the attend explicit group but also present in the attend intuitive group for both the hits and misses: attend explicit group hits: $t(8) = 5.2$, $p < .0008$; misses: $t(8) = 4.6$, $p < .002$; attend intuitive group hits: $t(11) = 5.2$,

$p < .0003$; misses: $t(8) = 7.0, p < .00002$. It seems to be an attention-related component because it is not elicited in the ignore conditions. Nevertheless, it does not reflect a target-related process because it is elicited for the misses and because it was elicited irrespective of whether there is an N2b/P3 complex. This component might be a P165, as described by Goodin, Squires, Henderson, and Starr (1978). The P165 in their study also reflected attended processing because it was obtained by subtracting the ignore-deviant ERP from the attended-deviant ERP. However, not enough is known about the functional characteristics of the P165 to draw a definite conclusion.

Behavioral Responses

The attend explicit group had a significantly shorter RT than the attend intuitive group, 553 versus 784 msec; $t(19) = -2.8, p < .01$. There was a trend toward a higher hit rate in the attend explicit group than in the attend intuitive group (53% vs. 38%; $t(19) = 1.9$, $p < .07$). There was no significant difference between the false alarm rates. They were low for both groups (0.4% for the attend explicit group vs. 1.4% for the attend intuitive group). Taken together, the detection performance of the attend explicit group was better that of the attend intuitive group. The two subjects who did not learn to detect the deviants in the training session had a mean hit rate of 3% and a mean false alarm rate of 0.2%.

ERPs in the Ignore II Condition

Grand-average ERPs for the Ignore II explicit group are presented in Figure 3A. An MMN was elicited, peaking at 242 msec, $t(8) = 4.2, p < .003$. The ERPs for the Ignore II intuitive group are presented in Figure 3B. A very small but nevertheless significant MMN was elicited, peaking at 236 msec, $t(11) = 2.7$, $p < .02$. The MMN amplitude in the explicit group was larger than in the intuitive group, $t(19) = -2.7, p < .01$.

To determine whether an MMN was elicited in the two subjects in the Ignore no knowledge group (who were not able to detect the deviants), their ERPs from the Ignore I and the Ignore II condition were averaged (Figure 4). A randomization test indicated that a statistically significant MMN was elicited ($p < .001$).

Post Hoc Comparison

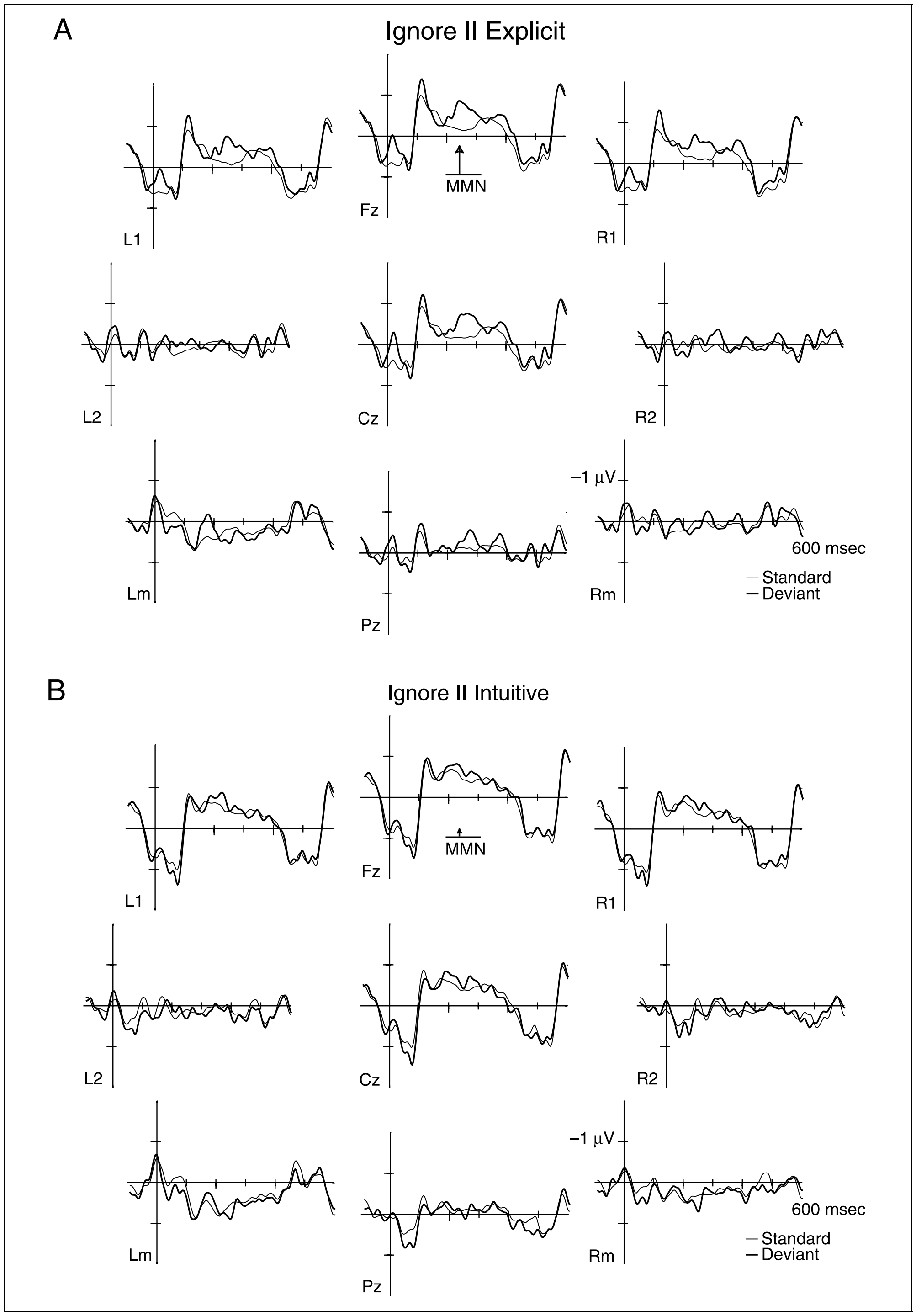
The Ignore I no knowledge group was divided into a group of five subjects who later developed explicit knowledge (‘‘will express explicit knowledge’’ group) and into a group of those 12 subjects who only learned to express intuitive knowledge (‘‘will express intuitive knowledge,’’ see Table 1). The grand-average ERPs obtained for the ‘‘will express explicit knowledge’’ group are displayed in Figure 5A, and those for the ‘‘will express intuitive knowledge’’ group in Figure 5B. We averaged the ERPs from the same two groups of subjects from the Ignore II condition. The ERPs of the five subjects in the ‘‘will express explicit knowledge’’ group after they shifted to explicit knowledge are shown in Figure 5C, and those of the 12 subjects in the ‘‘will express intuitive knowledge’’ after they have shifted to expressing intuitive knowledge are shown in Figure 5D. The MMN of the group that developed explicit knowledge was larger than the MMN of the group that did not develop explicit knowledge, Ignore I and II conditions pooled together: $F(1,15) = 6.0$, $p < .03$; Ignore II condition alone: $F(1,15) = 6.1, p < .03$.

DISCUSSION

An MMN was elicited in the majority of subjects in the first ignore condition, although they did not express awareness of the deviants in the interview after the MMN recording. Even in the two subjects who did not, at any point during the experiment, learn to detect the deviants, an MMN was elicited. These results indicate that the sensory auditory system could distinguish the deviant tone pairs from the standard tone pairs, although this information was not consciously available to all subjects. This suggests that the outcome of the automatic neural change detection mechanism giving rise to MMN elicitation can be implicit. In addition, during the associative training task, about half of the subjects did not learn to describe the stimulus structure, but nevertheless were able to detect the deviants (in the attend condition) by using their intuition. This result supports our hypothesis that implicit knowledge can be the substrate of correct intuitive decisions. Furthermore, we found, against our expectations, that the MMN amplitude in the second ignore condition was larger for the subjects who had expressed explicit knowledge than for the subjects who had expressed intuitive knowledge. We could therefore *not* confirm the hypothesis that knowledge type does not affect automatic involuntary processes. On the other hand, we found a P3 elicited by the hits in subjects expressing explicit knowledge but not for subjects expressing intuitive knowledge. This confirms our hypothesis that attentive processing related to target detection is affected by knowledge type. In addition, the behavioral detection performance was better (shorter RTs and higher hit rate) for the subjects expressing explicit knowledge than for the subjects expressing intuitive knowledge.

That the outcome of the neural change detection process eliciting the MMN can be implicit is in accordance with the automatic characteristics of the MMN. Although it is commonly reported that MMN elicitation correlates with perception, our result is in line with a study in which subjects were trained for several days to

Figure 3. ERPs elicited in the Ignore II condition for the subjects expressing explicit knowledge (A) and for the subjects expressing intuitive knowledge (B). Time zero corresponds to the onset of the second tone of a pair. The gray arrows indicate the duration, peak latency, and peak amplitude of the MMN.



discriminate a difficult novel speech contrast (Tremblay et al., 1998). The MMN as well as the ability to behaviorally discriminate the speech contrast were measured at various phases of the experiment. In about half of the subjects who learned to discriminate the speech contrast, the MMN appeared before the behavioral discrimination ability developed. This indicated that those subjects possessed implicit knowledge during the time between the neurophysiological and behavioral change. In addition, Allen, Kraus, and Bradlow (2000) showed that speech-sound differences too small to be consciously perceptible (subliminal) could elicit an MMN, and a few times it has been reported that missed deviants in a detection task can elicit an MMN (Neuloh & Curio, 2004; Alho & Sinervo, 1997). Taken together with our results, we can conclude that MMN elicitation does not necessarily always correspond with the ability to perceptually discriminate deviants from standards, which indicates that the sensory memory of acoustic regularities can be implicit.

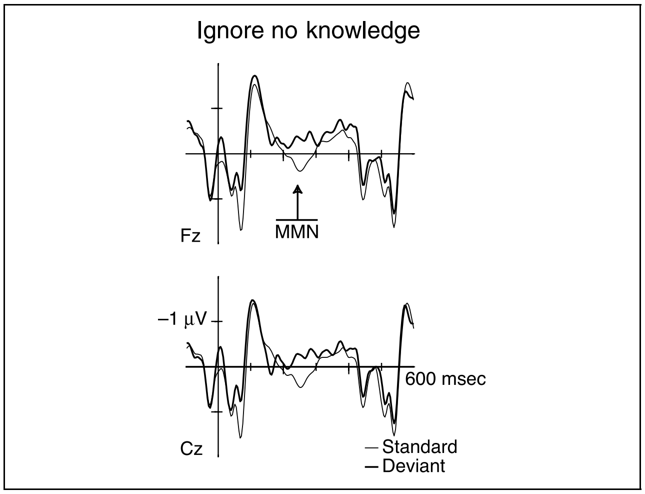
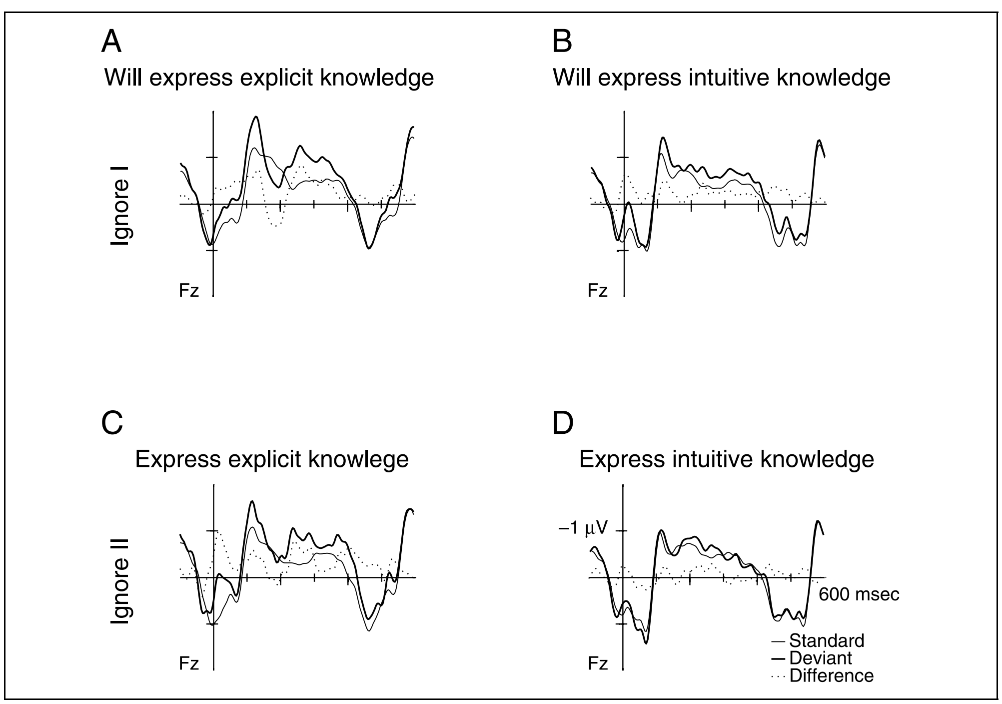


Figure 4. The ERPs of the two subjects who did not learn to detect the deviants at all. Their ERPs from the Ignore I and II conditions are averaged together. The zero line corresponds to the onset of the second tone of a pair. The gray arrows indicate the duration, peak latency, and peak amplitude of the MMN.

Part of the subjects with implicit knowledge could learn to detect deviants in an intuitive manner without expressing detailed knowledge of the stimulus structure. Subjects had thus learned, during the training, to partially access the information available in the sensory auditory system that they were initially unaware of. Subjects who learned to detect the deviants explicitly learned to access in detail the information needed for discriminating deviants from standards. This is a different form of learning than previously demonstrated in the MMN literature (Atienza, Cantero, & Stickgold, 2004; Atienza, Cantero, Dominguez-Marin, 2002; Tervaniemi, Rytkönen, Schröger, Ilmoniemi, & Näätänen, 2001; Näätänen, Schröger, Karakas, Tervaniemi, & Paavilainen, 1993). In these studies, both awareness of the deviants and the MMN were initially absent. Only after subjects had learned to discriminate the standard-deviant contrasts did an MMN appear. In the current study, subjects learned to access knowledge that was already represented in the auditory system.

Contrary to our expectations, we found that the MMN amplitude at the end of the experiment (Ignore II condition) was larger in subjects who had expressed explicit knowledge as compared to those who had expressed implicit knowledge. In order to explain this effect, we performed a post hoc analysis (see Figure 5) to investigate whether the MMN of subjects developing explicit knowledge in the training session became larger or whether subjects with an initially large MMN were more likely to develop explicit knowledge. We averaged separately the ERPs from Ignore I condition of those subjects who would develop explicit knowledge during the training session and of those subjects who would develop intuitive knowledge. We selected the ERPs of the same two subgroups at the end of the experiment (Ignore II) to make a within-subject comparison. The MMNs of the subjects who would develop explicit knowledge were already larger at the beginning of the experiment than the MMNs of the subjects who would develop intuitive knowledge, and the MMN amplitude stayed similar within each of the two subgroups during the experiment. This suggests that the MMN amplitude did not become larger when subjects gained more detailed knowledge about the stimulus structure. Rather,

Figure 5. ERPs of the Ignore I condition of the subjects who do not express explicit knowledge but who will develop it during the training phase of the experiment (A) and of the subjects who do not express awareness of the deviants and will only express intuitive knowledge after the training phase (B). The ERPs of the Ignore II condition of the same subjects as in (A) who now have expressed explicit knowledge (C) and of the same subjects as in (B) who now have expressed intuitive knowledge (D).



the initial MMN amplitude reflected the potential of subjects to develop explicit knowledge during the short training session.

Stimulus evaluation processes reflected by the P3 component were clearly affected by the type of knowledge that subjects possessed. P3 was elicited in subjects expressing explicit knowledge, whereas it was absent in subjects expressing intuitive knowledge. The same was possibly the case for the N2b component, which seemed to be elicited in subjects of the explicit knowledge group only. It was, however, difficult to distinguish the N2b from the MMN. The difference in N2b/P3 elicitation demonstrates that different neural processes underlie intuitive and explicit sound detection. In visual sequence-learning experiments, the N2 and the P3 component have also been shown to reflect explicit knowledge (Rüsseler et al., 2003; Rüsseler & Rösler, 2000; Schlaghecken et al., 2000; Baldwin & Kutas, 1997; Eimer, Goschke, Schlaghecken, & Stürmer, 1996). In these studies, subjects performed a stimulus–response matching task in which a particular stimulus corresponded to a particular type of response. Subjects were not informed that the stimulus presentation was sometimes ordered. In an ordered sequence, the RTs became shorter compared to the random sequences. This indicates that the order of the stimulus presentation had been learned. Those subjects who had explicit knowledge of the stimulus order show larger N2 and/or P3 than the subjects who where not aware of the stimulus order.

Our results show that the behavioral detection performance was better for subjects with explicit knowledge than for subjects with intuitive knowledge. An explanation for longer RTs in subjects with intuitive knowledge might be a lower degree of response confidence. The subjects with intuitive knowledge, unlike the subjects with explicit knowledge, often expressed doubt to the experimenters and sometimes, even disbelief about whether they were performing the task correctly. The longer RTs for subjects with intuitive knowledge are in contradiction with some theories on intuition. These theories would have predicted that because intuition lacks insight into the information and rules contributing to a decision, intuitive decisions are fast (Lieberman, 2000).

An interesting additional finding was observed in the attend condition. In the subjects with explicit knowledge, the missed deviants elicited an MMN. This suggests that the subjects with explicit knowledge, using an analytic deviant-detection strategy, did not classify the missed deviants into the category of descending tone pairs that they were trying to detect (this is also reflected in the absence of P3 to misses). Their auditory system did nevertheless detect even these deviants, as indicated by the MMN. These explicit-knowledge subjects apparently possessed partial implicit knowledge that they were not able to use for detecting the deviants. On the other hand, the intuitive-knowledge subjects, although they had an overall lower hit rate, optimally utilized the implicit knowledge available to them, as no MMN was observed for the misses.

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