An Investigation of the Implicit Learning of
Metrical and Non-metrical Temporal Patterns

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Declaration

I hereby declare that this submission is my own work and, to the best of my knowledge, that it contains no material that has been previously published or written by another person, nor material that has been accepted for the award of any other degree or diploma at the University of Western Sydney or the University of Lyon 2. Material that has been published or submitted for publication in peer-reviewed journals is explicitly acknowledged in the thesis.

The thesis is to be submitted to the University of Western Sydney and the University of Lyon 2 in accordance with the Cotutelle agreement between the University of Western Sydney and the University of Lyon 2.

I also declare that the intellectual content of this thesis is the product of my own work, except to the extent that assistance from others in the project’s design and conception is acknowledged.

____________________________________________
Benjamin G. Schultz
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Abstract

Implicit learning (IL) occurs unintentionally and without awareness. The majority of the literature on IL relates to the investigation of ordinal patterns, that is, patterns where the properties of stimuli systematically vary along one or more categorical dimensions (e.g. a repeating sequence of spatial locations). The IL of temporal patterns, that is, patterns where the temporal intervals between consecutive stimuli vary systematically, has received considerably less attention. Moreover, results of previous studies are mixed regarding whether temporal patterns can be learned independently of an ordinal pattern, or when an ordinal sequence is unpredictable. To examine the IL of temporal patterns, five experiments and a model–based analysis are presented in this thesis.

The present program of research investigated the IL of temporal patterns and examined the conditions under which the IL of temporal patterns is observed. Based on suggestions that learning of temporal patterns is underestimated in the serial reaction-time task when the upcoming stimulus is unpredictable (Ullén & Bengtsson, 2003), Experiment Sets 2 and 3 investigated the conditions under which temporal learning is observed. According to probabilistic uncertainty, a response cannot be prepared to an unknown stimulus even if the timing of the upcoming stimulus is predictable. Thus, it is hypothesized that temporal learning is observed in a single response serial reaction-time task and an immediate recall task, but that learning is underestimated in a multiple response serial reaction-time task when stimulus identities are unpredictable. Generation and recognition tasks based on the process dissociation procedure (Jacoby, 1991) were used to assess the degree to which learning was implicit. Furthermore, a model for
separating conscious and unconscious processes, which is based on a model proposed by Buchner, Steffens, Erdfelder, and Rothkegel (1997), was used to analyze recognition data.

Hypotheses regarding how temporal patterns are learned were derived from theories of rhythm and time perception. Rhythm is the systematic sequencing of events in relation to timing, accent, and grouping (Patel, 2008). Metrical patterns are patterns from which an underlying isochronous (evenly spaced) pulse can be abstracted and where event-onsets periodically occur according to equal groupings of pulses. Non-metrical patterns are patterns that cannot be conceived in terms of an isochronous pulse, or equal grouping of pulses (Essens & Povel, 1985). The dynamic attending theory and metric binding hypothesis (Jones, 2009) posit that attentional oscillators guide attention to periodic points in time at one or more periodicities. Based on the dynamic attending theory and the metric binding hypothesis, it was hypothesized that metrical and non-metrical patterns can be implicitly learned and that metrical patterns are learned more readily than non-metrical patterns.

The results of Experiment Sets 2 and 3 can be summarized as follows. First, temporal pattern learning is underestimated in the multiple response serial reaction-time task when the ordinal sequence is unpredictable (Experiments 2a and 3b). In contrast, the single response serial reaction-time task (Experiment 2a) and the immediate recall task (Experiment 3b) capture temporal learning, even when the ordinal sequence is unpredictable. These results are interpreted through probabilistic uncertainty; when the
identity of an upcoming stimulus cannot be predicted, a response to the upcoming stimulus cannot be prepared, even if the timing of the stimulus is predictable. In turn, it is more difficult to provide evidence for temporal learning when the ordinal sequence is random, even if the timing of the stimulus is predictable. Second, metrical and non-metrical patterns can be implicitly learned. There was evidence that the metrical framework was abstracted in Experiment Sets 2 and 3: disruptions to performance were greater for patterns that violated metrical expectancies (i.e. with a weaker meter) than for patterns with the same metrical strength as the learned temporal pattern. However, metrical patterns were only learned more readily than non-metrical patterns under particular conditions, specifically, in the immediate recall task, for implicit learners, and when the ordinal pattern was predictable. These results suggest that, while a metrical framework can be learned and utilized, the presence of meter, relative to no meter, may not necessarily improve the rate of learning for temporal patterns. Differences between the metrical and non-metrical patterns are discussed in the framework of the dynamic attending theory and the metric binding hypothesis.

Third, there was a discrepancy between the data of the generation task and the recognition task (and model analysis) concerning IL in Experiment Set 2: while the generation task indicated that learning was implicit in Experiments 2a and 2b, the model analysis of the recognition data indicated that learning was unconscious in Experiment 2a but indicated equal contributions of conscious and unconscious processes to recognition judgments in Experiment 2b. These results suggest that there may be differences in the processes captured by generation and recognition tasks. Specifically, it
is suggested that there may be differences in the way IL is reflected in generation and recognition tasks, and that familiarity-based processing (i.e. in the recognition task) might be experienced consciously (as suggested by Shanks & Johnston, 1999).

Based on the overall findings of experiments reported in this thesis, it is concluded that auditory temporal patterns that are characteristic of metrical and non-metrical rhythms can be implicitly learned. To further understand the role of meter for learning complex sequences of patterns and movements, experiments that investigate the implicit and explicit learning of metrical and non-metrical patterns, in both the presence and absence of ordinal patterns, are proposed for future research.
Preface

Humans have the ability to anticipate events as they sequentially occur in time. We learn to anticipate these events in a variety of settings including spoken communication, sport, music, and dance. Such activities are temporally structured with beginnings, patterned timings, varying rates, and endings (Jones & Boltz, 1989). Some have suggested that temporal patterns can be learned implicitly (e.g. Bergeson & Trehub, 2006; Patel, Iverson, & Rosenberg, 2006; Trehub & Hannon, 2005). Implicit learning (IL) occurs unconsciously, unintentionally, and without the ability to explicitly demonstrate what has been learned (Perruchet & Pacton, 2006; Shanks, 2005). While there is some evidence that the IL of temporal patterns can occur in infancy (Bergeson & Trehub, 2006; Trehub & Hannon, 2005), results are mixed regarding whether IL of temporal patterns can occur in adulthood (Brandon, Terry, Stevens, & Tillmann, 2012; Buchner & Steffens, 2001; Karabanov & Ullén, 2008; O’Reilly, McCarthy, Capizzi, & Nobre, 2008; Shin & Ivry, 2002; Ullén & Bengtsson, 2003). Set against this background, the aims of the thesis are: 1) to investigate the conditions that give rise to the IL of auditory temporal patterns, 2) to examine how musical properties of auditory temporal patterns (e.g. rhythm and meter) might affect the IL of auditory temporal patterns, and 3) to examine whether extant mixed results of research into temporal pattern learning for adults can be explained by methodological differences.
Overview of the Thesis

Chapter 1 contains a review of the literature concerning the IL of temporal patterns and suggests possible explanations for why some studies have not found temporal pattern learning. Specifically, three explanations are proposed. First, temporal pattern learning may be better elicited in the auditory modality than the visual modality. Second, temporal learning manifests when temporal intervals do not vary as a function of reaction time. Third, temporal learning may be underestimated when responses are dependent on the correct identification of stimuli. Methods for examining the IL of temporal patterns, such as the serial reaction-time task (SRT) and immediate recall task (IRT) are discussed. In Chapter 2, the concepts of rhythm and meter are discussed in regards to how properties of musical rhythm influence the way temporal expectancies are acquired. A distinction is drawn between metrical and non-metrical rhythms, and predictions are derived from theories of temporal perception, namely, the dynamic attending theory (Jones & Boltz, 1989) and the metric binding hypothesis (Jones, 2009). A summary of hypotheses is provided at the end of Chapter 2.

In the thesis, five experiments and a model-based analysis are reported. Chapter 3 summarizes Experiment 1, entitled the syllable identification task. The syllable identification task, based on the SRT, was used to examine the IL of temporal patterns. Temporal pattern learning was not evident in the syllable identification task. Explanations for why temporal pattern learning was not evident are discussed, and it is suggested that the task, that required the identification of spoken syllables, may have reduced learning effects. Furthermore, it is suggested that the multiple response SRT,
where the primary task is stimulus identification, underestimates temporal pattern learning when the upcoming stimuli are unpredictable. Chapter 3 then details the stimuli and temporal patterns that were used in Experiment Set 2 (Chapter 4; Experiments 2a and 2b) and Set 3 (Chapter 6; Experiments 3a and 3b) and reports three pilot experiments with the goal to select and refine stimuli. In Experiment Sets 2 and 3, auditory stimuli were tones that could emanate from the left headphone, the right headphone, or binaurally and participants were to identify the tone location. Chapter 3 reports Pilot Experiment 1: The Binaural Summation Experiment (Marks, 1978) that was conducted to ensure that the perceived loudness of the monaural and binaural stimuli presentations was matched. Chapter 3 also reports a music notation experiment (Pilot Experiment 2) and a beat tapping experiment (Pilot Experiment 3) that were both conducted to ensure that metrical and non-metrical temporal patterns are perceived as metrical and non-metrical, respectively. Furthermore, a more engaging task in the form of a “computer game for the blind” is introduced.

Chapter 4 reports two experiments in the form of a journal manuscript. Chapter 4 is currently in press for The Quarterly Journal of Experimental Psychology (Schultz, Stevens, Keller, & Tillmann, 2012). Supervisors of the research are co-authors on this journal manuscript as well as the two journal manuscripts presented in Chapters 5 (submitted) and 6 (in preparation). The work is predominantly that of the PhD candidate (Benjamin Schultz), with conceptual, design, and analysis guidance provided by supervisors Catherine Stevens, Barbara Tillmann, and Peter Keller. The supervisors are also holders of an associated Australian Research Council Discovery Project.
Chapter 4 investigated the IL of temporal patterns in two experiments (Experiments 2a and 2b). To examine if the single response SRT is a more sensitive measure of temporal pattern learning than the multiple response SRT, Experiment 2a compared a multiple response SRT with a single response SRT. Results suggested that the single response SRT was more sensitive to temporal learning than the multiple response SRT. Experiment 2b used a single response SRT to compare the IL of metrical and non-metrical patterns. Based on the dynamic attending theory (Jones & Boltz, 1989) and the metric binding hypothesis (Jones, 2009), it was hypothesized that metrical patterns are learned more readily than non-metrical patterns. Results suggested that metrical and non-metrical patterns can be implicitly learned, but that the metrical pattern was not learned more readily than the non-metrical pattern. However, there was evidence that the metrical framework was abstracted in the metrical condition. Previous experiments that have demonstrated differences between metrical and non-metrical patterns have used reproduction tasks (e.g. Essens & Povel, 1985; Grahn & Brett, 2007). Thus, it is possible that differences between metrical and non-metrical patterns are more pronounced when a task involves both encoding and retrieval (e.g. an IRT) compared with online responses (e.g. in the SRT). A comparison of the SRT and IRT is made in subsequent experiments (Experiments 3a and 3b) that are reported in Chapter 6.
Chapter 5 presents a model-based analysis of conscious and unconscious pattern identification using recognition data obtained in Experiments 2a and 2b. The model-based analysis has been submitted to the journal *PLoS One* (Schultz\(^b\), Stevens, Keller, & Tillmann, 2012). The model was used to disentangle conscious and unconscious processes under the assumption that perceptual fluency is related to unconscious processes. Perceptual fluency is a sense of familiarity of a previously encountered stimulus in the absence of true recognition of the stimulus (Curran, 2001). Results of the model suggested that unconscious processes contributed more to recognition judgments than conscious processes in Experiment 2a (i.e. the metrical patterns in single response SRT). Conversely, conscious and unconscious processes reflected in the model contributed similarly to recognition judgments in Experiment 2b (i.e. in metrical and non-metrical conditions using a single response SRT). Explanations for the differences between the results of the model for Experiments 2a and 2b are discussed. Specifically, it is suggested that 1) perceptual fluency may be a distinct process from implicit learning (as suggested by Shanks & Johnstone, 1999), and 2) perceptual fluency and motor fluency reflect different processes, and motor fluency more closely relates to implicit learning.

Chapter 6 reports Experiments 3a and 3b that examined the IL of metrical and non-metrical patterns, and compared how temporal learning is captured by the multiple response SRT and the IRT. Experiments 3a and 3b form the basis of two manuscripts that are in preparation, and will be submitted to *The Journal of Experimental Psychology: Learning, Memory, and Cognition* (Schultz\(^c\), Stevens, Keller, & Tillmann,
in preparation; Schultz\textsuperscript{4}, Stevens, Keller, & Tillmann, in preparation). Experiment 3a examined the IL of metrical and non-metrical patterns in the presence of a predictable ordinal pattern. Based on the dynamic attending theory (Jones & Boltz, 1989) and the metric binding hypothesis (Jones, 2009), it was hypothesized that metrical patterns are learned more readily than non-metrical patterns. While both ordinal and temporal patterns were learned in the multiple response SRT and IRT in this experiment, only the temporal pattern was learned implicitly. In the IRT, there was evidence that the metrical pattern was learned more readily than the non-metrical pattern, as overall improvement in the training blocks was greater for the metrical condition compared to the non-metrical condition. Experiment 3b examined the IL of metrical and non-metrical patterns when the ordinal sequence was unpredictable and randomised from trial to trial. Based on probabilistic uncertainty, it was hypothesized that temporal learning is underestimated in the multiple response SRT as no online preparation could be made for responses to the unpredictable ordinal sequence. As hypothesized, learning of the temporal pattern was indicated in the IRT but not the multiple response SRT. Results of the IRT implied that metrical patterns were not learned more readily than non-metrical patterns, but there was evidence that the metrical framework was abstracted in the metrical condition. The latter finding suggests that the benefits of meter might be less evident when the ordinal pattern is uncertain (as per probabilistic uncertainty).

Chapter 7 presents a general discussion of the experiments and results, and considers implications of the research for the IL of auditory temporal patterns. Specifically, issues regarding the methods for assessing the IL of temporal patterns are discussed, and it is
suggested that the multiple response SRT underestimates temporal learning. Thus, the multiple response SRT is likely a less appropriate measure for the IL of temporal patterns. Differences in learning metrical and non-metrical patterns are also discussed through the lens of theories of temporal expectancy, such as the dynamic attending theory and the metric binding hypothesis (Jones, 2009). Broadly, the set of results indicate that metrical patterns are not learned more readily than non-metrical patterns 1) when non-metrical timing deviations are predictable in an online task (i.e. the SRT), and 2) when an ordinal sequence is unpredictable in a reproduction task (i.e. the IRT).
Chapter 1

The Implicit Learning of

Temporal Patterns
1.1 What is Implicit Learning?

Implicit learning (IL) occurs when new information is acquired without awareness, and without the intention to learn (Berry & Dienes, 1993; Shanks, 2005). The broad hypothesis is that people are able to acquire new information and statistical regularities from exposure to their environment and culture. For example, some have suggested that language acquisition occurs through IL, that is, it occurs through exposure to the language and does not require explicit knowledge of the grammar (e.g. Christiansen, Allen, & Seidenberg, 1998; Saffran, Newport, Aslin, Tunick, & Barrueco, 1997). However, IL remains controversial: what constitutes IL has varied between studies (see Frensch, 1998, for a review), and assessing whether learning is implicit is methodologically challenging (see Cleeremans, Destrebecqz, & Boyer, 1998, for a review). These controversies are discussed in the following sections.

1.1.1 Definitions of Implicit Learning

As noted by Frensch (1998), IL is defined differently throughout the IL literature. There are at least five components that have been used to characterize IL and different studies have adopted various combinations of these components. IL has been characterized as 1) learning that is automatic, incidental, and unconscious (e.g. Cleeremans & Jiménez, 1996; Mathews et al., 1989), 2) the acquisition of knowledge of a structure or rule-based system, such as a grammar (e.g. Buchner & Wippich, 1998; Perruchet & Vinter, 1998; Reber, 1993), 3) acquiring knowledge without the ability to articulate what has been learned (e.g. Lewicki, Czyzewska, & Hoffman, 1987), 4) learning that occurs without awareness that one has learned anything (e.g. Lewicki, Czyzewska, & Hoffman, 1987),
and 5) learning without an intention to learn the materials or structure (e.g. Perruchet & Vinter, 1998; Stadler & Frensch, 1994). The present thesis adopted a common and less contentious definition of IL (suggested by Berry & Dienes, 1993): the unintentional acquisition of new information that is difficult to express or articulate.

1.1.2 Paradigms for Assessing Implicit Learning

It is possible that variation in the definition of IL stems from the different methods used to assess IL. Two paradigms that have predominantly been employed to examine IL: sequence learning paradigms (e.g. Destrebecqz & Cleeremans, 2001; 2003) and artificial grammar learning paradigms (e.g. Reber, 1967; 1989). In sequence learning paradigms, participants are exposed to a sequence of events and, unknown to participants, the sequence follows a repeating pattern or structure. If performance in the task improves over trials containing the repeating pattern, then learning is said to have occurred. Furthermore, if participants cannot verbalize knowledge of the pattern, then learning is implicit. Sequence learning paradigms have been implemented in the form of serial reaction-time tasks (see section 1.2.1) and immediate recall tasks (see section 1.2.2).

In artificial grammar learning paradigms (Reber, 1967; 1989), participants are instructed to memorize strings or sequences of events and, unknown to participants, the sequences follow the rules of a grammar. After memorizing sequences, participants are informed that the sequences were governed by a grammar and are asked to classify new sequences as grammatical or ungrammatical. If participants can classify new sequences above chance level, then learning of the grammar is said to have occurred. Furthermore,
learning is implicit if participants cannot describe the rules of the grammar or articulate why certain features make a sequence grammatical or ungrammatical (Dienes, Altmann, Kwan, & Goode, 1995). Previous studies on the IL of temporal patterns have used sequence learning paradigms. Thus, the present study used sequence learning paradigms to examine the IL of temporal patterns, specifically, the serial reaction-time task and the immediate recall task.

1.1.3 Definitions of Temporal and Ordinal Patterns

A great deal of the IL literature has focused on the learning of ordinal patterns (see Cleeremans, Destrebecqz, & Boyer, 1998, for a review). In contrast, the IL of temporal patterns has received considerably less attention (Brandon, Terry, Stevens, & Tillmann, 2012; Buchner & Steffens, 2001; Karabanov & Ullén, 2008; O’Reilly, McCarthy, Capizzi, & Nobre, 2008; Salidis, 2001; Shin & Ivry, 2002; Ullén & Bengtsson, 2003). Furthermore, of the studies that have investigated the IL of temporal patterns, many have examined temporal learning in the presence of a concurrent ordinal pattern or random ordinal sequence (Brandon et al., 2012; Buchner & Steffens, 2001; Karabanov & Ullén, 2008; O’Reilly et al., 2008; Shin & Ivry, 2002; Ullén & Bengtsson, 2003). A temporal pattern is a chain of events in which the temporal intervals between event onsets systematically vary (Povel & Essens, 1985). In this way, events not only unfold over time, but a pattern is formed by the series of temporal intervals. For example, the Morse code signal for “SOS”, (· · · — — — · · ·) where intervals between the onsets of short (·) events are half as long as intervals between the onsets of long (—) events, is a temporal pattern that consists of the relative intervals 1-1-1-2-2-2-1-1-1. An ordinal
pattern is a chain of events in which a property of the stimulus varies systematically along one or more dimensions. For example, the ordinal patterns used in some of the experiments of the present thesis are series of tones where the tone can emanate from the left headphone, the right headphone, or both headphones. If the order of tone locations occurred in a repeating pattern, it might be possible to learn the ordinal pattern. If there is simultaneously an ordinal pattern and a temporal pattern, then an ordinal and temporal pattern are presented *concurrently*.

### 1.1.4 Independent Learning of Temporal Patterns from Ordinal Patterns

Previous experiments examining the independent learning of temporal patterns from ordinal patterns have reached different conclusions regarding whether temporal patterns can be learned independently of concurrently presented ordinal patterns or sequences (Brandon et al., 2012; Buchner & Steffens, 2001; Karabanov & Ullén, 2008; O’Reilly et al., 2008; Shin & Ivry, 2002; Ullén & Bengtsson, 2003). For example, Shin and Ivry (2002) found that learning of temporal patterns did not occur when the temporal pattern was not correlated with the ordinal pattern. Similarly, O’Reilly et al. (2008) did not find learning of temporal patterns when the ordinal sequence was random and uncorrelated with the temporal pattern. These studies (O’Reilly et al., 2008; Shin & Ivry, 2002) suggest that temporal patterns cannot be learned independently of an ordinal pattern or sequence. In other words, they indicate that the temporal pattern is not learned when the ordinal pattern is not predictable. In contrast, studies by Karabanov and Ullén (2008) and Ullén and Bengtsson (2003) have shown learning of temporal patterns when the ordinal sequence was randomized in each trial. As the ordinal sequence was
unpredictable and ever-changing, no relationship could be formed between the temporal pattern and the ordinal sequence. Thus, these studies (Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003) indicate that temporal patterns can be learned independently of an ordinal sequence. Similarly, Salidis (2001) found evidence for temporal learning when the ordinal stimulus was constant, indicating that temporal patterns can be learned without a concurrently presented ordinal pattern. The next section critically assesses previous studies on the IL of temporal patterns, to consider possible explanations for mixed results regarding whether temporal patterns can be learned in the absence of a concurrent ordinal pattern.

1.2 Previous Studies on the Implicit Learning of Temporal Patterns

Evidence for the independent learning of temporal patterns is inconclusive. However, there are some notable differences between the studies that have shown evidence of IL of temporal patterns and those that have not. Here, the experiments that have investigated the IL of temporal patterns are discussed, followed by a critique of the methods and stimuli used in previous experiments. The aim of this review is to bring to light possible explanations for mixed results, and to determine the best paradigm for ascertaining the IL of temporal patterns. Particular attention is paid to the paradigm used, the modality of the stimuli, and the type of temporal interval used to create temporal patterns.
1.2.1 The Implicit Learning of Temporal Patterns in a Serial Reaction-time Task

The predominant paradigm for examining the IL of temporal and ordinal patterns is the serial reaction-time task (SRT). The SRT was initially used in an influential study of pattern learning by Nissen and Bullemer (1987), and has since been frequently employed to test IL (see Cleeremans, Destrebecqz, & Boyer, 1998, for a review). In the SRT, participants are presented with sequential stimuli and are to identify each stimulus as it occurs. Generally, the paradigm is a multiple-alternative forced-choice task (but see Salidis, 2001) where the ordinal stimuli vary along a dimension (e.g. spatial locations or pitch). The multiple-alternative forced-choice SRT is henceforth called the multiple response SRT. In the multiple response SRT, the participant is not informed that the stimuli follow a repeating temporal and/or ordinal pattern. Learning is characterized by decreases in reaction time (RT) over training blocks that contain a repeating temporal and/or ordinal pattern. To ensure that decreases in RT in training blocks do not simply reflect task learning, test blocks containing novel or random sequences are introduced after training blocks. The rationale is that because the task remains the same, if RT increases are observed in test blocks, then this must be attributed to learning of the pattern structure and not task learning. Lastly, when the original pattern is reintroduced after the test block, RT should return to similar latencies as those prior to the test block. An example of results indicating learning in an SRT is shown in Figure 1.1 (taken from Destrebecqz & Cleeremans, 2001).
Figure 1.1. Example of results indicating learning in a serial reaction-time task (from Destrebecqz & Cleeremans, 2001). Reaction time (RT) declines over training blocks 1 to 12 where the ordinal pattern (consisting of spatial items) is maintained, and increases when a novel pattern of spatial items is introduced in block 13. When the original pattern is reintroduced in blocks 14 and 15, RT returns to similar latencies to those prior to the introduction of the test block.

The SRT has been used to investigate the IL of temporal patterns in several studies (see Table 1.1). These studies have examined how temporal patterns are learned when the ordinal sequence is patterned (Buchner & Steffens, 2001; O’Reilly, et al., 2008; Shin & Ivry, 2002), when the ordinal sequence is random (Brandon, et al., submitted; O’Reilly, et al., 2008), or when the stimulus is constant (Salidis, 2001). Studies using the SRT have been unable to demonstrate learning of the temporal pattern that is independent of an ordinal pattern.
Buchner and Steffens (2001) examined the IL of temporal patterns in the presence of a correlated ordinal pattern of pitches. In two conditions, the ordinal pattern correlated perfectly with the temporal pattern where the each of four different pitches occurred exclusively with one of four temporal intervals that preceded or followed the stimulus. For example, pitch 1 would only occur with interval 1, pitch 2 with interval 2, pitch 3 with interval 3, and pitch 4 with interval 4. In a third condition, the ordinal and temporal patterns were correlated but the relations between the temporal intervals and pitches were not exclusive, that is, an “ambiguous” condition. For example, interval 1 could occur before pitches 1 or 3, interval 2 could occur before pitch 4, interval 3 could occur before pitches 1 or 3, and interval 4 could before with pitches 2 or 3. Thus, pitches and temporal intervals did not stand in one-to-one relations with each other. In training blocks, the temporal and ordinal sequences followed a repeating pattern. In the test blocks, the ordinal pattern continued as in training blocks but the temporal sequence was random. Although RT decreased over training blocks for all three conditions, RT only increased in test blocks for the two conditions where the ordinal and temporal patterns were perfectly correlated, but not for the condition where ordinal and temporal patterns were “ambiguous”. As temporal patterns were only learned when they correlated perfectly with the ordinal pattern, this was viewed as evidence that temporal patterns cannot be learned independently of ordinal patterns.
Table 1.1.

*Methods and stimuli in experiments that have investigated the implicit learning of temporal patterns.*

<table>
<thead>
<tr>
<th>Task</th>
<th>Modality</th>
<th>Interval</th>
<th>Author</th>
<th>Year</th>
<th>Concurrent Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serial reaction-time task</td>
<td>Visual</td>
<td>*RSI</td>
<td>Shin &amp; Ivry (Expt. 1)</td>
<td>2002</td>
<td>Spatial</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Shin</td>
<td>2008</td>
<td>Spatial</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*IOI</td>
<td>Shin &amp; Ivry (Expt. 2)</td>
<td>2002</td>
<td>Spatial</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>O’Reilly et al.</td>
<td>2008</td>
<td>Patterned and Random</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Immediate recall task</td>
<td>Auditory</td>
<td>RSI</td>
<td>Buchner &amp; Steffens</td>
<td>2001</td>
<td>Pitch</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Salidis</strong></td>
<td></td>
<td>2001</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>IOI</td>
<td>Brandon et al.</td>
<td>Submitted</td>
<td></td>
<td>Syllables: Random</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Intervals refer to response-stimulus intervals (RSI) and inter-onset intervals (IOI).*

**Salidis (2001) used a stimulus detection task that differed from the traditional stimulus identification serial reaction-time task.

Like Buchner and Steffens (2001), Shin and Ivry (2002) found evidence that temporal patterns cannot be learned independently of an uncorrelated ordinal pattern of visual spatial locations. In two experiments, Shin and Ivry examined the learning of temporal patterns.
patterns in the presence of an ordinal pattern that was either correlated or uncorrelated with the temporal pattern. The correlated condition in Shin and Ivry (2002) was similar to the “ambiguous” condition used by Buchner and Steffens (2001) in that temporal intervals and ordinal items did not have exclusive one-to-one relations. In the correlated condition, the ordinal and temporal patterns were the same length. Thus, the relationship between the ordinal and temporal patterns did not change over training blocks. In the uncorrelated condition, the temporal pattern contained one less item than the ordinal pattern. Thus, in the uncorrelated condition, the relationship between the ordinal and temporal patterns shifted for each presentation of the patterns. For example, consider the temporal patterns A-C-B-C-A-B-C (correlated) and A-C-B-C-A-B-C (uncorrelated), and the ordinal pattern 1-4-2-1-3-2-4-3 shown in Example 1. In the correlated condition, the relationship between the temporal and ordinal patterns is the same for each presentation, that is, the relationship is always 1A-4C-2B-1C-3A-2B-4C-3B. In the uncorrelated condition, the relationship shifts for each presentation, that is, the first sequence relationship would be 1A-4C-2B-1C-3A-2B-4C; the second would be 3A-1C-4B-2C-1A-3B-2C, and so on.

Learning of the temporal and ordinal patterns was assessed by comparing RT increases in various test blocks where the ordinal and/or temporal sequences were random, or where the relationship between the ordinal and temporal pattern was adjusted (i.e. a phase shift was introduced). The results of Shin and Ivry (2002) suggested that temporal patterns were only learned when the temporal pattern correlated with the ordinal pattern, but not when the temporal pattern was uncorrelated with the ordinal pattern. This was
viewed as evidence that temporal patterns cannot be learned independently of an ordinal pattern.

Example 1.

*Ordinal and Temporal patterns in correlated and uncorrelated conditions from Shin and Ivry (2002)*

<table>
<thead>
<tr>
<th>Temporal Correlated</th>
<th>A</th>
<th>C</th>
<th>B</th>
<th>C</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>B</th>
<th>A</th>
<th>C</th>
<th>B</th>
<th>C</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ordinal</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Temporal Uncorrelated</td>
<td>A</td>
<td>C</td>
<td>B</td>
<td>C</td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>A</td>
<td>C</td>
<td>B</td>
<td>C</td>
<td>A</td>
<td>B</td>
</tr>
</tbody>
</table>

O’Reilly and colleagues (2008) found evidence that temporal patterns cannot be learned independently of an ordinal pattern of visual spatial locations, or a random ordinal sequence. In the ordinal condition, the ordinal sequence was patterned (i.e. followed a predictable and repeating sequence) but the temporal sequence was random. In the temporal condition, the temporal sequence was patterned, but the ordinal sequence was random. In the combined condition, both the ordinal and temporal sequences were patterned and the patterns were correlated. In three test blocks, the ordinal sequence was randomized, the temporal sequence was randomized, or both the ordinal and temporal sequences were randomized. In training blocks, RT decreases only occurred for the ordinal condition and the combined condition, but not the temporal condition. In other words, RTs only decreased over training blocks when the ordinal sequence was patterned. In test blocks, RT increases occurred for the ordinal condition when the
ordinal sequence was random and for the combined condition when the ordinal and temporal sequences were random, but did not increase for the temporal condition when the temporal sequence was random. As RT increases in response to randomization of the temporal sequence only occurred for the combined condition, this was viewed as evidence that temporal patterns can only be learned in the presence of a correlated ordinal pattern. Thus, O’Reilly et al. (2008) indicated that temporal patterns cannot be learned independently of an ordinal pattern and temporal patterns cannot be learned when the ordinal sequence is random.

Brandon et al. (submitted) provided evidence that temporal patterns can be learned when the ordinal sequence is a random sequence of spoken syllables. The temporal patterns used were characteristic of musical rhythm, that is, the temporal intervals between consecutive event-onsets occurred in a repeating pattern. Participants were presented with a temporal pattern in training blocks, and were presented with a novel rhythm in a test block. In Experiment 1, RT decreased over training blocks and increased in the test block indicating that temporal patterns were learned. In Experiment 2, there was evidence that the groups of temporally proximal events were learned (i.e. the shortest interval), but not the timing of longer temporal intervals. For the groups of temporally proximal events, RT decreased over training blocks and increased in the test block when a new temporal pattern was introduced. For the longer temporal intervals, RT decreased over training blocks, but did not increase in test blocks. This was viewed as evidence that the short temporal intervals were learned, but that expectancies for longer temporal intervals may not have been acquired (but see Chapter 2 for alternative explanations).
Brandon et al. (submitted) concluded that temporal patterns can be learned when the ordinal sequence is random.

Salidis (2001) demonstrated that temporal patterns can be implicitly learned in an SRT where participants did not have to identify the stimulus. In two experiments, Salidis used a single auditory tone and participants had to press a key in response to the tone onset. In Experiment 1, training blocks contained a repeating temporal pattern, and a random temporal sequence was introduced in the test block. Results indicated that only the shorter temporal intervals were learned, but not the longer temporal intervals; RT for the smallest interval decreased over training blocks and increased in the test block; RT for the medium and long intervals did not decrease over training blocks or increase in test blocks. In Experiment 2 (Salidis, 2001), training blocks contained the repeating temporal pattern and a novel temporal pattern was introduced in the test block (for reasons discussed in Section 1.2.1.1). Although RT decreases in training blocks were not reported, RT increases were evident for short, medium, and long intervals, indicating that the temporal pattern may have been learned. However, learning in Experiment 2 cannot be concluded unless RT decreased in training blocks, a result that was not reported in Salidis (2001).

From this review of SRT studies on the IL of temporal patterns, it is evident that results are inconclusive. Some SRT studies suggest that temporal patterns can only be learned when they are learned in the presence of a correlated ordinal pattern (Buchner & Steffens, 2001; O’Reilly et al., 2008; Shin & Ivry, 2002). When the ordinal sequence is
random, there is some evidence that temporal patterns can be learned (Brandon et al., 2012), but also some evidence that temporal patterns were not learned (O’Reilly et al., 2008). Lastly, the learning of temporal patterns has been demonstrated when there is no ordinal sequence, that is, the stimulus is constant (Salidis, 2001). In the following section, two criticisms of the SRT are discussed.

1.2.1.1 The Use of Random Test Sequences

One criticism of the SRT in the context of learning correlated or independent structures is that test blocks often use random test sequences and that, subsequently, RT increases in test blocks may not reflect learning of the pattern (Reed & Johnson, 1994). The rationale is as follows. A large proportion of SRT experiments create patterns based on second order conditional probabilities (see Cleeremans, Destrebecqz, & Boyer, 1998, for a review). Patterns based on second order conditional probabilities are constructed in such a way that each item of the pattern can be determined and predicted by the two items that precede it. For example, consider the pattern [1-3-2-3-1-2] (from Cohen, Ivry, & Keele, 1990) where numbers (1, 2, and 3) refer to items of a sequence (e.g. three temporal intervals, of three spatial locations). Each pair of items is called a transition, and each transition is followed exclusively by one item: The transition 1-3 is always followed by 2, the transition 3-2 is followed by 3, and the transition 2-3 is followed by 1, and so on. In this way the transitions provide cues that can be used to predict the next item, and provide a statistical structure to the pattern that can be learned. Previous SRT experiments on the IL of temporal patterns have used temporal patterns where the order of temporal intervals is governed by second order conditional probability (Buchner &
Steffens, 2001; O’Reilly et al., 2008; Salidis, 2001; Shin & Ivry, 2002; see also Brandon et al., 2012). Furthermore, these studies (with the exception of Brandon et al., 2012; Salidis, 2001) have used test blocks that contain random sequences to ascertain that the pattern and its structure has been learned. However, a study by Reed and Johnson (1994) indicated that RT increases in test blocks containing a random sequence may occur as a result of changes to surface statistical features, and may not, in fact, indicate learning.

Reed and Johnson (1994) identified five surface statistical features, referred to as simple frequency information, that should be controlled to ensure that RT increases in test blocks reflect pattern learning: 1) item frequency, the number of times each item occurs in the pattern; 2) transition frequency, the number of times each transition (i.e. pair of items) occurs in the pattern; 3) rate of reversal, the number of times that the first and last item, of a group three items, is identical (e.g. 3-2-3); 4) rate of full coverage, the average number of items that need to be presented for each unique item to have occurred; and 5) rate of complete transition usage, the average number of transitions that must be viewed for each unique transition to have occurred. If a test block contains a pattern or a pseudo-random sequence that matches the simple frequency information of the pattern in training blocks, then RT increases in the test block can be attributed to learning of the pattern and the pattern structure. However, if a test block contains a random pattern with different simple frequency information to that of the training pattern, then RT increases in the test block could be attributed to sensitivity changes in simple frequency information.
Two studies (Brandon et al., 2012; Salidis, 2001) investigating the IL of temporal patterns have demonstrated temporal learning when some of the simple frequency information is controlled (as per Reed & Johnson, 1994). In Salidis (2001), training and test patterns were identical in regards to simple frequency information. In Brandon et al. (submitted) Experiment 1, item frequency was matched between training and test patterns, but all other simple frequency information varied (i.e. transition frequency, rate of reversal, rate of full coverage, and rate of full transition usage). In Brandon et al. Experiment 2, item frequency and transition frequency were matched between the training pattern and the test pattern, but the other simple frequency information varied (i.e. rate of reversal, rate of full coverage, and rate of full transition usage). In the present experiments, to ensure that RT increases in test blocks can be attributed to learning of the temporal pattern and the temporal structure: 1) temporal intervals in temporal patterns were governed by second order conditional probabilities, and 2) temporal patterns in test blocks matched the simple frequency information of the temporal pattern in the training blocks.

1.2.1.2 Probabilistic Uncertainty of the Stimulus Identity

As described above, many of the previous SRT experiments have examined the learning of temporal patterns in the presence of ordinal patterns or random ordinal sequences (Brandon et al., 2012; Buchner & Steffens, 2001; O’Reilly et al., 2008; Shin & Ivry, 2002; but not Salidis 2001). When examining RT increases in test blocks, some studies have obtained larger performance decrements (i.e. increases in RT) when the ordinal sequence is random compared to when the temporal sequence is random (O’Reilly et al.,
O’Reilly et al. (2008) and Shin and Ivry (2002) concluded that temporal patterns cannot be learned in the absence of an ordinal pattern. However, in the SRT, when the ordinal sequence is random, participants are unable to prepare for the next response because the identity of the stimulus is unpredictable, even if they have knowledge of the temporal pattern. Thus, it is possible that the multiple response SRT paradigm underestimates temporal pattern learning due to probabilistic uncertainty of the identity of the next stimulus (Ullén & Bengtsson, 2003). In other words, based on probabilistic uncertainty, in circumstances when the ordinal sequence is random, the exhibition of knowledge of the temporal structure could be underestimated or masked by uncertainty of the identity of the upcoming stimulus. Furthermore, test blocks where the ordinal sequence is unpredictable would elicit larger RT increases than test blocks where the temporal sequence is unpredictable.

A task that does not require stimulus identification, such as a stimulus-detection task, might be a more sensitive test of temporal pattern learning. For example, the stimulus-detection task used in Salidis (2001) does not require stimulus identification, and Salidis demonstrated the IL of temporal patterns. Similarly, reproduction and recall tasks (Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003) do not require online
identification of stimuli. That is, the recall of an ordinal and/or temporal sequence does not require in-the-moment responses. Instead, recall of the ordinal and/or temporal sequences occurs after the sequence has been presented. The use of immediate recall paradigms for investigating the IL of temporal patterns is now discussed.

1.2.2 The Implicit Learning of Temporal Patterns in an Immediate Recall Task

The immediate recall task (IRT) has been suggested as an alternative method of examining the IL of temporal and ordinal patterns where the preparation of responses is not reliant on knowledge of the upcoming stimulus identity (Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003). In each trial of the IRT, participants are presented with a sequence and are asked to reproduce the sequence as accurately as possible. Unbeknownst to participants, the temporal and/or ordinal pattern (e.g. visual shapes corresponding to arrow keys on the keyboard) is the same in every trial. At the end of the trial, feedback is provided regarding the number of errors made. Error for the reproduction of stimulus identities, that is, ordinal error, is calculated as the number of incorrect responses and the number of responses given in the wrong order. Temporal error is calculated as the degree to which the produced intervals differ from the pattern intervals of the training pattern. Learning of the ordinal pattern and the temporal pattern is demonstrated by decreases in ordinal error and temporal error over trials, respectively. Furthermore, test blocks containing random sequences are used before and after the training phase to ensure that learning effects cannot be attributed to overall task or perceptual-motor improvement.
The IRT has been used to demonstrate independent processing of ordinal and temporal patterns using auditory-visual patterns (Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003). Ullén and Bengtsson (2003) examined ordinal and temporal pattern learning in two experiments using visual ordinal patterns comprised of shapes that corresponded to arrow keys on the keyboard. In Experiment 1, the onset of each visual stimulus was accompanied by a drum sound that did not change. There were three types of patterns: 1) an ordinal pattern with a constant temporal interval, 2) a temporal pattern with a constant stimulus, and 3) a combined ordinal and temporal pattern. Participants were either: a) first trained on the combined pattern and then trained separately on the ordinal and temporal patterns, or b) first trained separately on the temporal and ordinal patterns and then trained on the combined pattern. For both groups, learning of the temporal and ordinal patterns occurred: ordinal error decreased over blocks containing the ordinal pattern, temporal error decreased over blocks containing the temporal pattern, and both ordinal and temporal error decreased over blocks containing the combined pattern. Furthermore, fewer trials were required to accurately reproduce the ordinal and temporal patterns after previous exposure to the patterns. This pattern of results occurred regardless of whether participants were originally trained on the ordinal and temporal patterns separately, or trained on the combined ordinal and temporal pattern. These results were viewed as evidence that ordinal and temporal patterns were learned, and that separate knowledge of ordinal and temporal patterns can be demonstrated after learning a combined ordinal-temporal pattern.
In Experiment 2 of Ullén and Bengtsson (2003), visual stimuli were shapes that corresponded to arrows on the keyboard. Auditory stimuli were tones of varying pitch, and each pitch corresponded with a different visual shape. There were three conditions: 1) a temporal condition where the temporal pattern repeated and the ordinal sequence was random in each trial, 2) an ordinal condition where the ordinal pattern repeated and the temporal pattern was random in each trial, and 3) a random condition where both the ordinal and temporal sequences were random in each trial. In the temporal condition, temporal accuracy increased over trials, but no systematic changes in ordinal accuracy were evident, indicating that the temporal pattern was learned. In the ordinal condition, ordinal accuracy increased over trials, but no systematic changes in temporal accuracy were evident, indicating that the ordinal pattern was learned. In the random condition, neither temporal accuracy nor ordinal accuracy increased over training blocks, indicating that task performance did not improve over trials when there were no patterns to learn. These results indicate that temporal patterns can be learned independently of a random sequence of ordinal stimuli.

Karabanov and Ullén (2008) examined temporal pattern learning in an IRT when the ordinal sequence was random in each trial, akin to the temporal condition of Ullén and Bengtsson (2003, Experiment 2). In one condition, participants were only instructed to reproduce the ordinal sequence and in another condition participants were instructed to reproduce both the ordinal sequence and the temporal pattern. The rationale was that participants who were only instructed to reproduce the ordinal sequence may incidentally learn, and thus reproduce, the temporal pattern. In other words, participants
who were only instructed to reproduce the ordinal sequence may implicitly learn the
temporal pattern. Results showed that temporal error decreased over training blocks
when participants were instructed to reproduce only the ordinal sequence, but not when
instructed to reproduce the ordinal sequence and the temporal pattern. These results were
viewed as evidence that temporal patterns were implicitly learned. Furthermore,
temporal patterns were learned independently of the ordinal sequence, as the ordinal
sequence was random in each trial.

The two studies using an IRT have demonstrated the independent learning of temporal
patterns (Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003). These studies using the
IRT (and some using the SRT) have differed from previous studies in at least three
notable ways: 1) they used auditory (Brandon et al., 2012; Salidis, 2001) or auditory-
visual stimuli (Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003), 2) they used
temporal patterns consisting of inter-onset intervals (Brandon et al., 2012; Karabanov &
Ullén, 2008; Ullén & Bengtsson, 2003), or 3) because the measure of temporal pattern
learning (via the IRT) was less affected by probabilistic uncertainty of upcoming
stimulus identities (Karabanov & Ullén, 2008; Salidis, 2001; Ullén & Bengtsson, 2003).
Thus, it is possible that the mixed results regarding the IL of temporal patterns could be
explained by differences in the stimuli used. Probabilistic uncertainty has been
previously discussed (Section 1.2.1.2). The following section discusses why the use of
auditory stimuli and inter-onset intervals may elicit the learning of
temporal patterns.
1.2.2.1 Modality and the Learning of Temporal Patterns

Stimulus modality has differed between experiments that have used the SRT and IRT to examine the IL of temporal patterns. Many of the SRT studies that have examined the learning of ordinal and/or temporal patterns have used visual stimuli (Lee, 2000; Miyawaki, 2006; O’Reilly et al., 2008; Shin, 2008; Shin & Ivry, 2002). However, none of the studies that have only used visual patterns to investigate temporal pattern learning have demonstrated learning of the temporal pattern, or learning of the temporal pattern that is independent of the ordinal pattern (but see Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003 who used auditory-visual stimuli in an IRT). Of the three SRT experiments on the IL of temporal patterns that use auditory stimuli, two have indicated temporal pattern learning (i.e. Brandon et al., 2012; Salidis, 2001; but not Buchner & Steffens, 2001). Evidence from sensorimotor synchronization experiments suggests that auditory stimuli elicit more precise synchronization to temporal patterns than discrete visual stimuli (Chen, Repp, & Patel, 2002; Kolers & Brewster 1985; Patel, Iverson, Chen, & Repp, 2005; Repp & Penel, 2002; 2004; Semjen & Ivry 2001)\(^1\). Similarly, temporal patterns presented in the auditory modality are better discriminated and reproduced than temporal patterns presented in the visual modality (Glenberg & Jona 1991; Handel & Buffardi, 1969; Patel et al., 2005). For example, Repp and Penel (2004) revealed that auditory perception is dominant when performing synchronization tasks where there is interference with visual and auditory sequences by auditory and visual distracters, respectively. This suggests that there is greater sensitivity for the perception of temporal sequences with sequences of auditory stimuli than those using visual stimuli.

\(^1\) Studies using dynamic visual stimuli (i.e. moving visual displays) have shown synchronization that is comparable for visual and auditory stimuli (Hove, Spivey, & Krumhansl, 2010).
The present thesis does not test hypotheses related to a comparison of auditory and visual modalities, but rather uses auditory stimuli to examine the IL of temporal patterns.

1.2.2.2 Types of Temporal Intervals

Previous SRT experiments on the IL of temporal patterns have used two different types of temporal intervals: response-stimulus intervals and inter-onset intervals (IOI; also called stimulus-onset asynchronies). The majority of SRT experiments have used response-stimulus intervals (Buchner & Steffens, 2001; Lee, 2000; Miyawaki, 2006; Salidis, 2001; Shin, 2008; Shin & Ivry, 2002: Experiment 1). Response-stimulus intervals are temporal intervals between the participant’s response to the previous stimulus and the onset of the next stimulus. However, the use of response-stimulus intervals in an SRT results in temporal intervals between stimulus-onsets that are the sum of the RT to the previous stimulus and the response-stimulus interval. While response-stimulus intervals are controlled by the experimental design, participants’ RT to events can vary as a result of a range of perceptual, cognitive, and motor processes, not to mention the length of the response-stimulus interval itself. Thus, the intervals between subsequent events would vary as a function of RT. Such variability might negatively affect the formation of temporal expectancies for the timing of events in temporal patterns consisting of response-stimulus intervals. Thus, previous SRT studies may have been unable to ascertain temporal pattern learning due to the use of response-stimulus intervals (Buchner & Steffens, 2001; Shin & Ivry, 2002: Experiment 1; but see Salidis, 2001).
In contrast, IOIs are temporal intervals between the onsets of successive stimuli that are controlled and unaffected by RT variations. As IOIs do not vary as a function of RT, it should be easier to develop temporal expectancies for the timing of events in temporal patterns using IOIs. Furthermore, temporal sequences constructed from IOIs are characteristic of musical rhythm (to be discussed in Chapter 2). The use of IOIs in studies on the IL of temporal patterns have produced mixed results: while some studies have demonstrated the IL of temporal patterns using IOIs (e.g. Brandon et al., 2012; Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003), others have not shown (independent) IL of temporal patterns (O’Reilly et al., 2008; Shin & Ivry, 2002, Experiment 2). Music cognition research has demonstrated that certain temporal patterns constructed from IOIs can be learned explicitly (see Chapter 2: The Learning of Rhythm and Meter; also Essens & Povel, 1985; Povel & Essens, 1985; Tillmann, Stevens, & Keller, 2011), indicating that the IL of temporal patterns that are rhythmic should be possible. The present thesis uses temporal patterns constructed from series of IOIs.

1.3 Interim Summary

The review of the literature on the IL of temporal patterns has shown that the IL of temporal patterns occurs when: 1) responses are not subject to probabilistic uncertainty, that is, in a stimulus-detection task (Salidis, 2001) or an IRT (Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003), 2) when auditory stimuli are used (Brandon et al., 2012; Karabanov & Ullén, 2008; Salidis, 2001; Ullén & Bengtsson, 2003; but not Buchner & Steffens, 2001), and 3) when temporal patterns consist of patterned IOIs (Brandon et al., 2012; Karabanov & Ullén, 2008; Salidis, 2001; Ullén & Bengtsson, 2003). Thus, the IL
of temporal patterns should occur when these conditions are met. However, there are some concerns regarding whether temporal pattern learning is, in fact, implicit in tasks such as the IRT and SRT. Furthermore, the best way to ascertain the degree to which learning is implicit warrants some consideration. In the following section, the methods of assessing IL that have been used in experiments on the IL of temporal patterns are discussed (Shanks, 2005; Shanks & St. John, 1994)

1.4 Using the Process Dissociation Procedure to Assess Implicit Learning.

There is an ongoing debate (see Cleeremans, Destrebecqz, & Boyer, 1998; Perruchet, 2008; Shanks, 2005 for reviews) regarding how best to detect IL and distinguish IL from explicit learning, and a number of methods have been proposed such as verbal reports, generation tasks, and recognition tasks. Some earlier studies on the IL of temporal patterns have used verbal reports as an index of awareness (i.e. explicit knowledge; e.g. Brandon et al., 2012; Karabanov & Ullén, 2008; Salidis, 2001; Shin & Ivry, 2002; Ullén & Bengtsson, 2003). Although some of these studies have used verbal reports in tandem with other measures of IL (Brandon et al., 2012; Karabanov & Ullén, 2008; Salidis, 2001), others have used verbal reports as the sole measure of IL (Shin & Ivry, 2002; Ullén & Bengtsson, 2003). However, there are some concerns regarding whether verbal reports are sensitive enough to detect awareness of a learned pattern (Shanks & St. John, 1994). Furthermore, it has been argued that a lack of awareness of the presence of a pattern may not be enough to infer IL (Shanks & St. John, 1994; Stadler & Roediger, 1998). The following section discusses some alternative methods for assessing IL, with a particular focus on the process dissociation procedure (Jacoby, 1991).
More sensitive tests of IL have been derived from theories of dissociable systems that aim to disentangle conscious and unconscious processes (e.g. Bamber, 1979; Dunn & Kirsner, 1988; Shanks & St. John, 1994). However, there is some controversy regarding methods of dissociating cognitive processes. The controversy appears to stem from the assumption of *process purity*, that is, the assumption that performance in a task reflects a single process when it is likely that a number of interrelated processes (e.g. conscious and unconscious processes) are engaged (Curran, 2001). A number of different theories and methods for dissociating two cognitive processes have been proposed, many of which pertain primarily to memory (e.g. Bamber, 1979; Dunn & Kirsner, 1988). The *process dissociation procedure* (Jacoby, 1991) has been used to separate the influences of implicit and explicit learning of sequences while aiming to avoid the assumption of process purity (Destrebecqz & Cleeremans, 2001; 2003; Karabanov & Ullén, 2008).

In the *process dissociation procedure*, each participant is required to perform a task under two different types of instruction - inclusion and exclusion. The inclusion instruction requires that participants demonstrate declarative knowledge of what has been learned. The exclusion instruction requires that participants suppress knowledge about what has been learned. For example, in Jacoby, Toth, and Yonelinas (1993), the inclusion instruction asked participants to complete word stems with words that were previously learned in a study phase; the exclusion instruction asked participants to complete word stems with different words than those learned in a study phase. While performance under the inclusion instruction is facilitated by both conscious and
automatic processes, performance under the exclusion instruction is facilitated by conscious processes but interfered with by automatic processes. Thus, differences between performances under the two instructions can provide insights into the contribution of conscious and unconscious influences. The process dissociation procedure has been used to investigate the IL of temporal patterns in two different paradigms: the recognition task (Buchner & Steffens, 2001) and the generation task (Karabanov & Ullén, 2008).

1.4.1 The Recognition Task

Recognition tasks based on the process dissociation procedure have been used to examine whether participants can recognize learned sequences and discriminate them from foil or distracter sequences (Buchner & Steffens, 2001; Destrebecqz & Cleeremans, 2001; 2003; Jacoby, 1991). In recognition tasks, participants are presented with a number of sequences or sequence fragments, some of which are from the original pattern (i.e. the training pattern) and some of which are distracter sequences. Participants are asked to indicate whether they recognize the sequences (or sequence fragments) from the training block (or exposure phase). If participants are able to identify the original sequence and reject the distracter sequence above levels that would be predicted by chance, then they are said to have explicit knowledge of the sequence.

Recognition tasks using the process dissociation procedure have been criticized on the basis that recognition and familiarity are positively correlated and that the process dissociation procedure is not sensitive to this relationship (Bower & Schacter, 1990;
Graf & Komatsu, 1994; Schacter & Graf, 1986). The relationship between recognition and familiarity is a concern for recognition tasks based on the *process dissociation procedure* because responses that may imply recognition may actually be attributable to familiarity of sequence features as opposed to true recognition of the learned sequence. For example, consider the nursery rhymes “Twinkle twinkle, little star” and the “Alphabet song” that have the same melody. If someone who had never heard either nursery rhyme were taught “Twinkle twinkle, little star”, then presented with the “Alphabet song” in a recognition task, they might recognize the melody feature but not truly recognize the “Alphabet song” that differs in regards to the lyrics. Thus, they might make a recognition judgment based on features of the melody. Similarly, they could make a correct recognition judgment of “Twinkle twinkle, little star” solely based on the melody, without any knowledge of the lyrics, and this recognition judgment would be indistinguishable from true recognition. A true recognition of the original nursery rhyme would consist of recognition of the lyrics and the melody.

The *sequence identification measurement model* (SIMM; Buchner & Steffens, 2001; Buchner, Steffens, Erdfelder, & Rothkegel, 1997; Buchner, Steffens, & Rothkegel, 1998) has been proposed as a method for disentangling the familiarity of sequence features (e.g. statistical regularities) from conscious recognition and unconscious recognition. The SIMM examines IL under the assumption that perceptual fluency and IL are equivalent (a full description of the SIMM and an implementation of the SIMM using recognition data from Experiment Set 2 are given in Chapter 5). Perceptual fluency is defined as the ease with which information is processed (Jacoby, 1991).
Correct recognition judgments that are based on familiarity instead of true recognition are thought to be associated with perceptual fluency (Buchner et al., 1997; Buchner et al., 1991). For this reason, perceptual fluency is sometimes conceptualized as a sense of familiarity or recognition without the ability to make accurate judgments regarding why the object is familiar, that is, correct recognition judgments in the absence of true recognition (Jacoby & Dallas, 1981). For example, amnesic patients have great difficulty when attempting to explicitly remember previously encountered people, places, and events. Yet, amnesic patients still experience a sense of familiarity when presented with these previously encountered items or situations (Verfaellie & Cermak, 1999). In related studies on the remember-know distinction (e.g. Gardiner, Gregg, & Karayianni, 2006), the remember aspect reflects the conscious memory (i.e. true recognition), and the know aspect reflects familiarity in the absence of true recognition, that is, perceptual fluency.

Some have suggested that perceptual fluency is equivalent or related to IL and unconscious processes (Buchner et al., 1997; 1998; Jacoby, 1991). However, Shanks and Johnstone (1999) have argued that perceptual fluency is not equivalent to IL because fluency and familiarity may be experienced consciously. Alternatively, it has been suggested that perceptual fluency may reflect a reduced level of conscious control one has over implicitly learned information (Fu, Dienes, & Fu, 2010). For example, some experiments (Dienes et al., 1995; Wan, Dienes, & Fu, 2008) have demonstrated that participants can correctly choose which of two artificial grammars to use in a given situation, despite reporting that they are guessing. This indicates that, although an individual may be able to recognize and use learned information via perceptual fluency,
they may not be able to identify how or why they are able to do so. In other words, although learning is implicit according to definitions of IL stating that knowledge cannot be articulated, conscious control and recognition of the implicitly learned information may still be possible. The present thesis used the recognition task and SIMM to assess implicit and explicit learning of the temporal patterns. In addition and because of criticisms of the recognition task and uncertainty regarding whether perceptual fluency reflects IL, a generation task was also employed to assess IL.

1.4.2 The Generation Task

The generation task has been used in a number of studies (Destrebecqz & Cleeremans, 2001; 2003; Nissen & Bullemer, 1987; Salidis, 2001) and has been shown to be a sensitive test of implicit and explicit sequence knowledge (Perruchet & Amorim, 1992). The generation task outlined here is based on the process dissociation procedure (Jacoby, 1991) and has previously been used to assess the IL of temporal patterns in a study by Karabanov and Ullén (2008). Participants perform the generation task under both the inclusion instruction and the exclusion instruction. In the inclusion instruction, participants are instructed to reproduce the original temporal patterns that were presented in the earlier task (e.g. the IRT or the SRT). The exclusion instruction asks participants to produce new temporal patterns that are different from the original temporal pattern. Patterns produced in the inclusion and exclusion conditions are then compared to the training pattern, and given a similarity score based on how much they resemble the training pattern. If similarity in the inclusion instruction is less than or equal to similarity in the exclusion instruction, then declarative knowledge of the
training pattern has not been shown and learning is regarded as implicit. By contrast, higher similarity scores for the inclusion instruction than for the exclusion instruction indicate that learning is explicit.

While responses in the recognition task can be based on true recognition or familiarity with features of the sequence, generation tasks are unaffected by familiarity-based processes, because cues or features of the learned sequence are not provided; participants are not given a stimulus and, subsequently, cannot use features of a stimulus to make recognition judgments. Hence, the generation task does not rely on familiarity or perceptual fluency to assess IL. Instead, the generation task examines how well people are able to demonstrate explicit knowledge of the sequence, and whether people unintentionally reproduce the sequence when the task requires suppression of learned knowledge. Experiments in the present thesis used the generation task to detect explicit and implicit learning, as this method does not rely on familiarity or perceptual fluency. The present thesis assessed IL using verbal reports in tandem with the generation task (as in Karabanov & Ullén, 2008) and recognition task (as in Buchner & Steffens, 2001) based on the process dissociation procedure.

1.5 Summary of the Methods of Assessing Implicit Learning

The review of the literature suggests that the IL of temporal patterns occurs when: 1) the temporal pattern is presented in the auditory modality (as in Brandon et al., 2012; Karabanov & Ullén, 2008; Salidis, 2001; Ullén & Bengtsson, 2003; but not Buchner & Steffens, 2001), and 2) when temporal patterns consist of a sequence of IOIs (as in
Brandon et al., 2012; Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003; but not O’Reilly et al., 2008; Shin & Ivry, 2002, Experiment 2). Thus, experiments in the present thesis used temporal patterns of sequenced IOIs presented in the auditory modality.

It is also possible that mixed results could be explained by differences in the task; the multiple response SRT may underestimate learning in circumstances where the ordinal sequence is unpredictable or random due to probabilistic uncertainty (Ullén & Bengtsson, 2003). In contrast, the single response SRT (Salidis, 2001) and IRT (Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003) are less affected by probabilistic uncertainty, and have demonstrated the IL of temporal patterns when the ordinal sequence is unpredictable. The present thesis explores and compares different methods for assessing the IL of temporal patterns. In Experiment 1 (Chapter 3), the multiple response SRT was used to examine the IL of temporal patterns when the ordinal sequence was unpredictable. In Experiment 2a (Chapter 5), the multiple response SRT was compared with the single response SRT to test whether temporal learning is underestimated or obscured in the multiple response SRT when the ordinal sequence is unpredictable. In Experiment 2b (Chapter 5), the single response SRT was used to compare the IL of metrical and non-metrical patterns (see Chapter 2 for definitions). In Experiment 3a (Chapter 7), the multiple response SRT was compared with the IRT under circumstances where the ordinal pattern was predictable. In Experiment 3b (Chapter 7), the multiple response SRT was compared with the IRT under circumstances where the ordinal pattern was unpredictable. The aim of the suite of experiments in the
The present thesis is to examine the circumstances under which the IL of temporal patterns occurs, and to bring to light explanations for why experiments on the IL of temporal patterns have obtained mixed results.

Lastly, to assess the degree to which learning was implicit, two tasks adapted from the process dissociation procedure were administered: the generation task (Karabanov & Ullén, 2003) and the recognition task (Buchner & Steffens, 2001; Buchner et al., 1997; 1998). The recognition task was used in Experiments 2a and 2b to demonstrate the contribution of conscious and unconscious processes to recognition judgments and to examine the relationship between perceptual fluency and IL (see Chapter 5). The generation task was used in Experiments 1, 2a, 2b, 3a, and 3b to test for explicit and implicit knowledge of the sequence in the absence of perceptual fluency and familiarity-based processing. For Experiments 2a and 2b (Chapter 5), differences between the generation task and the recognition task were examined, in regards to how IL may be reflected in motor fluency in the generation task, and perceptual fluency in the recognition task and a model based analysis (i.e. the SIMM; Buchner & Steffens, 2001; Buchner et al., 1997; Buchner et al., 1998).

In the following chapter, musical rhythm is discussed with a focus on how properties of rhythm may influence the learning of temporal patterns. As mentioned earlier, the temporal patterns used in the present thesis consist of patterned IOIs. The patterning of IOIs results in temporal patterns that are characteristic of musical rhythm. Previous experiments from the music cognition literature have indicated that metrical and non-
metrical musical rhythms can be explicitly learned (e.g. Essens & Povel, 1985; Grahn & Brett, 2007; Keller & Burnham, 2005; Povel & Essens, 1985). Thus, the IL of musical rhythms might also be possible. Chapter 2 describes musical rhythm, and how properties of musical rhythm may influence how temporal expectancies are acquired. Chapter 2 also revisits a number of the experiments described in Chapter 1, to interpret some of the mixed results of previous studies (Brandon et al., 2012; Karabanov & Ullén, 2008; O’Reilly et al., 2008; Shin & Ivry, 2002; Ullén & Bengtsson, 2003) but from a music cognition perspective.
Chapter 2

The Learning and Perception of

Rhythm and Meter
Music cognition research (e.g. Järvinen & Toiviainen, 2000; Palmer & Krumhansl, 1990) suggests that musical rhythm has properties, such as meter, that aid in the acquisition of temporal expectancies. Rhythm is the “systematic patterning of sound in terms of timing, accent, and grouping” (Patel, 2008, pp. 96). Rhythms can be broadly defined as metrical and non-metrical. A metrical rhythm is a temporal pattern from which an underlying isochronous, that is, even-spaced, pulse can be cognitively abstracted (London, 2004). The pulse is commonly referred to as the beat, and is most commonly perceived as occurring at isochronous intervals between 400ms and 900ms (Fraisse, 1982; Parncutt, 1994). Moreover, the perceived beat can be cognitively arranged into groups of equal size called measures, where the first beat of a measure is perceived as accented (Lerdahl & Jackendoff, 1981), even in the absence of other physical accents (e.g. pitch change, increased intensity, or increased duration). The first beat of a measure is often referred to as the strong beat, and other beats of a measure are called weak beats (Palmer & Krumhansl, 1990). A non-metrical rhythm is a temporal pattern from which it is more difficult to both abstract a consistent beat and to group beats into equal measures (Essens & Povel, 1985).

2.1 Metrical Frameworks and Metrical Strength

A metrical framework is a cognitive abstraction of rhythm that is used to hierarchically organize the perception of time and guide attention to periodic moments in time (Jones & Boltz, 1989; Snyder, Hannon, Large, & Christiansen, 2006). Furthermore, the metrical strength of a rhythm corresponds with how well a pattern can be reproduced (Essens & Povel, 1985; Grahn & Brett, 2007; Povel & Essens, 1985) and how well one
can synchronize to the beat from a rhythm (Patel, Iverson, Chen, & Repp, 2005). A metrical rhythm where all strong beats contain an event is called a strongly metrical (SM) rhythm. A metrical rhythm where event onsets align with the pulse, but not all strong beats contain an event, is called a weakly metrical (WM) rhythm. A non-metrical rhythm is a rhythm where the timing of event onsets regularly deviates from a metrical framework (Essens & Povel, 1985). Examples of SM, WM, and non-metrical patterns are shown in Figure 2.1.

Figure 2.1. Beats (short vertical lines), strong beats (long vertical lines), and events (crosses) of the strongly metrical, weakly metrical, and non-metrical rhythms. The beats and strong beats here are not part of the rhythm itself. Instead, the beats and strong beats are a cognitive abstraction of the rhythm that may be perceived by the listener.
As shown in Figure 2.1, strong beats for the SM rhythm are always supported by the occurrence of events, and every event occurs on the beat. For the WM rhythm, strong beats do not always contain an event but all events occur on the beat. For the non-metrical rhythm, events rarely align with beats or strong beats. Thus, it is more difficult to impose a metrical framework onto non-metrical rhythms and the perception of meter may only arise locally, where consecutive IOIs are perceived as equal or have a simple integer ratio relationship.

The assignment of strong beats and weak beats depends on the meter that is abstracted and how often events correspond with each location. Furthermore, the strength of a beat location corresponds to the number of different metric levels that align with the beat location (Lerdahl & Jackendoff, 1981). For example, the SM rhythm in Figure 2.2 contains an event on every strong beat (i.e. the 2000ms pulse), that is, an event occurs every four beats. The WM rhythm does not have events that always occur every four beats, but all events conform to the underlying beat structure. Generally, events in metrical (specifically, SM) patterns should often align with strong beats and weak beats and rarely occur off the beat. Non-metrical patterns do not elicit a strong perception of periodic strong or weak beats so it is difficult to associate such patterns with metrical frameworks. That is, even if a beat is abstracted locally in a non-metrical rhythm, events in non-metrical rhythms will mostly be perceived as deviating from the beat and the metrical framework. However, it is possible that certain events in non-metrical patterns can be perceived as accented according to other rhythmic accenting rules (e.g. Bolton, 1894; Garner, 1974; Povel & Essens, 1985; Povel & Okkerman, 1981).
Figure 2.2. Metrical hierarchy for a strongly metrical rhythm. Hierarchical nestings represent grouping of beats at multiple levels. Crosses represent events in the rhythm. Pulses (500ms, 1000ms, and 2000ms) represent theorized strong and weak beats. According to Lerdahl and Jackendoff (1981), the metrical interpretation depends on how often events align with pulses at multiple levels. In the SM rhythm here, the 2000ms pulse always aligns with an event.

2.2 Rhythmic Accents and Metrical Accents

Rhythmic accents are perceptual accents that are elicited by the figural grouping of events. Figural grouping is the cognitive grouping of events that occur in close temporal proximity to one another (Bamberger, 1978; Handel, 1998; Povel & Essens, 1985). Rhythms are perceptually (and somewhat unconsciously) organized into figural groups of events that follow one another in close proximity, but the encoding of intervals between figural groups requires more effort (Keller & Burnham, 2005).
Povel and Okkerman (1981) showed that rhythmic accents can be perceived in temporal patterns in the absence of phenomenal accents, that is, in the absence of changes in intensity, pitch, or stimulus duration (Lerdahl & Jackendoff, 1983). Rhythmic accents are also referred to as subjective accents (Povel & Essens, 1985). In Povel and Okkerman, (1981), participants were presented with short rhythms consisting of two intervals of varying length and were asked whether they perceived an accent on the first tone or the second tone. When the two intervals differed by 50-110ms, the accent was perceived as occurring on the first tone. When the two intervals differed between 140-290ms, the accent was perceived on the second of the two tones. Povel and Okkerman concluded that the first of a group of three tones is perceived as accented and that a tone preceding a long interval is perceived as accented. With respect to the accent that is considered to be perceived before a long interval, this accent was only perceived when the shorter interval was less than 250ms and the difference between the two intervals must be larger than about 110ms. Such accents are called rhythmic accents.

Povel and Essens (1985) presented a clock model where metrical strength was defined by how often rhythmic accents, as defined by Povel and Okkerman (1981), corresponded with metrical strong beats. Rhythmic accents were defined as perceptual accents that occur on i) isolated events, ii) on the second event of a group of two events, and iii) on the first and last event of a group of three or more (Povel & Essens, 1985). The clock model measured metrical strength with a counter-evidence score (c-score) where a lower score represented greater metrical strength and the best metrical interpretation. If a rhythmic accent occurs on a strong beat, then this is considered to be
positive evidence. If a rhythmic accent occurs on a weak beat or occurs off the beat, then this is considered negative evidence. The measures of metrical strength provided by the clock model corresponded with ratings of rhythmic complexity, and the ability to reproduce the rhythm; rhythms with higher c-scores were rated as more complex and were reproduced with less accuracy than rhythms with lower c-scores (Povel & Essens, 1985). These results suggest that metrical accents and rhythmic accents interact to elicit a metrical interpretation, and affect the perceived strength of a metrical framework.

Although the original clock model was based on negative evidence (Povel & Essens, 1985), adaptations of the model have since been developed that focus on positive evidence (p-scores) and hybrid models (h-scores) that weight both positive and negative evidence equally (McAuley & Semple, 1999). These adaptations have revealed that musicians and non-musicians may weight positive and negative evidence differently in a beat tapping task; beats tapped by non-musicians generally corresponded with negative evidence (c-scores); beats tapped by musicians more often corresponded with the hybrid model at moderate tempi (i.e. smallest interval = 200-300ms) and the hybrid or positive evidence model at the slowest tempo (smallest interval = 400ms; McAuley & Semple, 1999). These results indicate that the type of evidence used when perceiving the beat or meter may depend on musical experience and on the tempo of the temporal pattern. Thus, clock models are useful for measuring the metrical strength and the metrical interpretation of a rhythm. However, clock models have difficulty interpreting rhythms with frequent timing deviations such as non-metrical rhythms. Specifically, clock models cannot adequately capture human perception of temporal patterns when
small timing deviations are introduced, or when changes in phase or tempo occur (Large & Jones, 1999), and cannot be used to derive hypotheses regarding how metrical and non-metrical patterns are learned. The dynamic attending theory has been proposed as a model for temporal perception for metrical rhythms and rhythms that contain non-metrical timing deviations (Jones & Boltz, 1989; Large & Jones, 1999).

2.3 Dynamic Attending Theory and the Metric Binding Hypothesis

The dynamic attending theory (Jones, 2009; Jones & Boltz, 1989) relates to how temporal expectancies are formed. The dynamic attending theory supposes that attention oscillates over time and that attending oscillations adaptively synchronize to regularities (e.g. metrical frameworks) in the timing of external events. This process is called entrainment. The periodic occurrence of events within a metrical framework can induce entrainment, thus strengthening expectancies (and quicken responses) for event onsets that conform to the metrical framework.

The metric binding hypothesis (Jones, 2009) is an extension of the dynamic attending theory that relates to how meter is learned through exposure to rhythm. While the dynamic attending theory relates to “in-the-moment’ expectancies” (Jones, 2009, pp. 83), the metric binding hypothesis posits that when two or more oscillations are concurrently established, the levels of entrainment will eventually bind and form a “metric cluster” (Jones, 2009, pp. 84). Metric clusters consist of multiple concurrent oscillations with continuing associations at various time levels based on bindings. Metric clusters strengthen expectancies to various metrical levels; in other words, expectancies
are strengthened in pulse locations, the first pulse of groups, and coincidences of the two. With repeated exposure to an external rhythm, internal entrainment to the rhythm and formation of a metrical framework may occur (Large & Jones, 1999). In this way, temporal regularities activate oscillators that guide attention to metrical points in time when a metrical framework is available, and can be momentarily perturbed if an event does not align with the metrical framework.

Based on the dynamic attending theory and the metric binding hypothesis, it was hypothesized that metrical patterns can be learned more readily than non-metrical patterns (Jones, 2009). It was also hypothesized that, when trained on SM patterns, greater performance decrements occur when a new rhythm with a weaker metrical framework is introduced (WM patterns) than when the new rhythm maintains the original metrical framework (a novel SM pattern). Such differences are not expected for non-metrical patterns as metric binding cannot occur during training.

2.4 Music Cognition Research on the Perception and Production of Rhythm and Meter

Although the IL of metrical and non-metrical patterns has not yet been systematically examined, an extensive body of knowledge on how people perceive, reproduce, and synchronize to rhythmic patterns already exists. Evidence from sensorimotor synchronization tasks (e.g. Patel et al., 2005) and reproduction tasks (e.g. Essens & Povel, 1985; Grahn & Brett, 2007; Keller & Burnham, 2005; Povel & Essens, 1985), suggests that people have greater difficulty developing temporal expectancies in
response to WM and non-metrical patterns compared to SM patterns. Research on the perception and production of rhythmic patterns is now discussed.

2.4.1 Sensorimotor Synchronization Tasks

In sensorimotor synchronization tasks, participants are presented with a rhythm and are asked to tap the beat or pulse (see Repp, 2005 for a review). Lower asynchronies between the taps and the theoretical beats indicate better synchronization with the beat. Similarly, lower variability of the inter-tap intervals indicates better synchronization to the beat. Patel et al. (2005) used a sensorimotor synchronization task to compare how people synchronize to the beat of SM and WM patterns (based on those of Povel & Essens, 1985) for visual and auditory modalities. As discussed previously (see section 1.2.2.1), participants were generally unable to synchronize to the beat of visual patterns. For auditory patterns, asynchronies were lower for SM patterns than for WM patterns indicating that it was easier to abstract and respond to the beat and metrical framework for SM patterns compared to WM patterns. Such results are in line with the dynamic attending theory and the metric binding hypothesis (Jones, 2009); for SM patterns, entrainment to the strong metrical framework occurred and guided attention to periodic events; for WM patterns, the metrical framework was weaker and periodic expectancies were sometimes violated which, in turn, prevented or reduced the formation of metric clusters via metric binding. Therefore, if one were trained on an SM pattern, then presented a novel SM pattern, responses should be perturbed less than if a

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2 Sensorimotor synchronization tasks differ from the implicit learning tasks in the present experiments in that the SRT and the IRT require responses to the events themselves, instead of responses to the beat. However, the beat tapping task in Pilot Experiment 3 is a sensorimotor synchronization task.
novel WM pattern was introduced due to the change in periodic structure. Thus, in the present thesis it is hypothesized that, when trained on an SM pattern, reaction time increases are greater for test blocks containing a novel WM pattern compared to test blocks containing a novel SM pattern.

2.4.2 Reproduction Tasks

Studies on the reproduction of rhythmic patterns have demonstrated better reproduction accuracy for SM patterns compared to WM patterns (Povel & Essens, 1985), and for metrical patterns compared to non-metrical patterns (Essens & Povel, 1985; Grahn & Brett, 2007). Furthermore, reproduction tasks provide insights into how metrical and non-metrical patterns might be learned. In Povel and Essens (1985), participants were presented with SM and WM patterns and were asked to listen until they felt that they could reproduce the pattern. Then participants were to reproduce the temporal pattern via key presses. Listening times and quality of reproductions (i.e. timing deviation of produced temporal intervals from the pattern intervals) were recorded. Results demonstrated longer listening times for WM patterns compared to SM patterns. Similarly, timing deviations increased as metrical strength decreased (as measured by the clock model). Taken together, the pattern of listening times and timing deviations indicate that 1) SM patterns are processed more easily than WM patterns, 2) SM patterns are reproduced more accurately than WM patterns, and 3) SM patterns are learned more readily than WM patterns, as there was no performance trade-off between listening times and reproduction accuracy. Thus, it is likely that metrical patterns (specifically, SM patterns) are also learned more readily than non-metrical patterns.
There is some evidence that metrical patterns may be learned more readily than non-metrical patterns (Essens & Povel, 1985; Grahn & Brett, 2007). In Essens and Povel (1985) Experiment 2, participants were presented with metrical and non-metrical patterns with different integer ratio relationships: metrical patterns with simple integer ratios of 2:1, 3:1 and 4:1, and non-metrical patterns with complex integer ratios of 1.5:1, 2.5:1, and 3.5:1. Only the inter-group interval was varied, and the within-group interval was constant (i.e. 250ms). Participants could listen and synchronize with the temporal pattern until they were comfortable that they could reproduce the pattern. Results indicated that between-group intervals could be reproduced accurately for metrical and non-metrical patterns except for the non-metrical pattern with an integer ratio of 1.5:1. These results were interpreted as evidence that short and long intervals that have a complex integer ratio relationship can be encoded and reproduced. This could also be interpreted as evidence that metrical and non-metrical patterns can be learned.

In Essens and Povel (1985) Experiment 3, complex temporal patterns were constructed with interval ratios of 2:1 and 3:1. In the metrical condition, temporal patterns were presented against a metrical framework, that is, a low-pitch isochronous sequence with an IOI of 800ms (the smallest IOI in the pattern was 200ms). In the non-metrical condition, temporal patterns were presented without a metrical framework and patterns could not easily be interpreted in regards to a metrical framework. For temporal patterns with an interval ratio of 2:1, metrical and non-metrical patterns were reproduced with similar accuracy. Conversely, for temporal patterns with an interval ratio of 3:1, metrical
patterns were reproduced more accurately than non-metrical patterns. Essens and Povel concluded that temporal patterns with an interval ratio of 2:1 are a special case and can be reproduced in the presence or absence of meter. However, temporal patterns with larger interval ratios are reproduced more accurately when interpreted through a metrical framework than when the pattern is non-metrical. Based on these results, the present thesis used temporal intervals with interval ratios larger than 2:1 to examine whether abstraction of a metrical framework facilitates the learning of temporal patterns. Unfortunately, listening times were not reported in Essens and Povel (1985) so no conclusions can be made regarding whether metrical patterns were learned more readily than non-metrical patterns in their Experiments 2 and 3.

In the reproduction experiment of Grahn and Brett (2007), participants were presented with strongly metrical patterns (called “metric simple” patterns), weakly metrical patterns (called “metric complex” patterns), or non-metrical patterns (called “nonmetric” patterns). Strongly and weakly metrical patterns were constructed from intervals that had a simple interval ratio relationship, that is, interval ratios of 2:1, 3:1, and 4:1. Non-metrical patterns were constructed from intervals that had a complex interval ratio relationship, that is, 1.4:1, 3.5:1, and 4.5:1. Participants were presented each temporal pattern three times and were then asked to reproduce the pattern. Results indicated that strongly metrical patterns were reproduced more accurately than weakly metrical and non-metrical patterns. However, there were no significant differences for reproduction accuracy between weakly metrical and non-metrical patterns. These results could also suggest that strongly metrical patterns are learned more readily than weakly metrical and
non-metrical patterns. Thus, we hypothesize that strongly metrical patterns are learned more readily than non-metrical patterns. Overall, music cognition research can offer insight into how temporal patterns are perceived and reproduced and provides a foundation for the hypotheses regarding the implicit learning of metrical and non-metrical patterns.

2.5 The Implicit Learning of Musical Rhythm

A small number of the previous studies on the implicit learning of temporal patterns have used temporal patterns that are characteristic of musical rhythm, that is, patterned IOIs (Brandon et al., 2012; Karabanov & Ullén, 2008; O’Reilly et al., 2008; Shin & Ivry, 2002, Experiment 2; Ullén & Bengtsson, 2003; but not Buchner & Steffens, 2001; Salidis, 2001 who used response-stimulus intervals\(^3\)). However, the properties of rhythm such as meter and metrical strength have not often been considered or systematically manipulated (but see the discussion below on Brandon et al., 2012). In O’Reilly et al. (2008), temporal patterns were non-metrical patterns as the IOIs (500ms, 750ms, 1125ms and 1687ms) did not stand in a simple integer ratio relationship. O’Reilly et al. only demonstrated temporal learning when the ordinal sequence was predictable. However, temporal pattern learning may have been weaker in this experiment due to the use of non-metrical patterns, a possibility that was conceded by the author.

Shin and Ivry (2002, Experiment 2) found evidence that temporal patterns can only be learned when the ordinal pattern is predictable and correlated with the temporal pattern.

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\(^3\) As noted by Salidis (2001), response-stimulus intervals are inherently non-metrical due to the fact that the onsets between consecutive events vary as a function of RT.
Temporal patterns were metrical because the IOIs (550ms, 1100ms, and 1650ms) had a simple integer ratio relationship. However, the metrical strength and metrical interpretation would have been different for each participant because the positions of IOIs in the sequences were counterbalanced across participants. For example, consider the interval pattern A-C-B-C-A-B-C-B: for one participant A = 550ms, B = 1100ms, and C = 1650ms, so the temporal pattern would be 550-1650-1100-1650-550-1100-1650-1100 (temporal pattern 1); for another participant A = 1650ms, B = 550ms, and C = 1100ms, so the temporal pattern would be 1650-1100-550-1100-1650-550-1100-550 (temporal pattern 2). The metrical interpretation and metrical strength varies between these two temporal patterns. Temporal pattern 1 would likely be interpreted as more weakly metrical for metrical interpretations. Temporal pattern 2 is likely to be interpreted as more strongly metrical with an event occurring nearly every three beats. Furthermore, the durations of the temporal pattern differs between temporal pattern 1 (duration 9350ms) and temporal pattern 2 (duration 8250ms). Such differences in duration would also affect the metrical interpretation because the number of beats per sequence presentation would differ. For example, temporal pattern 1 might be perceived as having 17 beats and temporal pattern 2 might be perceived as having 15 beats. As 17 is a prime number, the formation of equal grouping of beats into a metrical structure would be difficult for temporal pattern 1. Conversely, beats could more easily be grouped into groups of three or five for temporal pattern 2. It is possible, therefore, that some patterns in Shin and Ivry (2002) were learned better than others, but because the data were pooled it is difficult to ascertain how properties of musical rhythm may have affected temporal pattern learning. Furthermore, test blocks contained random temporal
sequences so it is difficult to ascertain the metical interpretation in the test block, although, due to the nature of random sequences, it was most likely weakly metical. Shin and Ivry (2002) acknowledge that temporal learning may be enhanced when musical rhythms, or metrical rhythms, are used. However, they did not identify that their own temporal patterns may be interpreted as strongly or weakly metrical.

Ullén and Bengtsson (2003) used temporal patterns that were metrical, as the IOIs (375ms, 750ms, and 1125ms) had a simple integer ratio relationship. Furthermore, temporal patterns could be interpreted as strongly metrical patterns with an event occurring every three beats in training blocks (c-score = 0), and an event occurring every four beats in the control block (c-score = 2). Although the results of Ullén and Bengtsson (2003) indicated that metrical patterns can be implicitly learned, no conclusions were drawn regarding the metrical strength of the rhythms. Similarly, Karabanov and Ullén (2008) used metrical patterns, where IOIs (375ms and 750ms) had a simple integer ratio relationship. The metrical patterns may have been interpreted as strongly metrical with an event occurring every four beats (c-score = 2). Karabanov and Ullén (2008) demonstrated that metrical patterns can be implicitly learned, and suggested that the metrical structure and isochronous beat may have been learned as a property of the temporal pattern. However, systematic manipulations of the rhythmic and metrical structure were not conducted.

Brandon et al. (submitted) examined the implicit learning of metrical patterns and systematically manipulated patterns based on the likely metrical interpretation. Metrical
patterns were constructed from IOIs (700ms, 1400ms, and 2100ms) that had a simple integer relationship. In Experiment 1, training blocks contained either 1) a metrical pattern that suggested a strong beat every four beats (i.e. SM with a duple meter interpretation, c-score = 1), or 2) a metrical pattern that suggested a strong beat every three beats (i.e. SM with a triple meter interpretation, c-score = 2). The test block contained a metrical pattern that suggested a strong beat every four beats (i.e. SM with a duple meter interpretation, c-score = 2), for both groups. Experiment 1 demonstrated the IL of metrical patterns with duple and triple metrical interpretations. Furthermore, although the authors do not state this, patterns were all SM with their respective duple and triple meter interpretations.

In Experiment 2 (Brandon et al., 2012), the duple meter pattern from Experiment 1 was used in training blocks, and another duple meter pattern (also SM) was introduced in the test block (c-score = 2). The aim of Experiment 2 was to replicate the results of Experiment 1, with a test pattern that did not contain any new transitions (as discussed in Section 1.2.1.1 of Chapter 1). Results of Experiment 2 demonstrated that RT decreased over training blocks. However, RT only increased in test blocks for responses to short intervals (i.e. 700ms IOI), but not for responses to longer intervals (i.e. 1400ms and 2100ms). Brandon et al. suggested that the metrical framework may have aided participants’ responses to events that occur after longer intervals, and that the metrical framework helps listeners in predicting the next beat of an auditory pattern. As the metrical framework was consistent between the training blocks and the test block, participants could utilize the metrical framework and the beat and, in turn, RT did not
increase in test blocks for longer intervals. Overall, Experiment 2 demonstrated the IL of metrical patterns.

There is, however, another interpretation for the pattern of results for short and long intervals in Experiment 2 relating to figural grouping (Bamberger, 1980). In Experiment 2, Brandon et al. (submitted) controlled for the frequency of interval usage between the training pattern and the test pattern, and did not introduce new transitions in the test pattern. However, the test pattern featured a change in the size and arrangement of figural groupings. Specifically, the training pattern contained one run of four short intervals (i.e. a group of five events) and one run of one short interval (i.e. a group of two events), whereas the test pattern contained one run of three short intervals (i.e. a group of four events) and one run of two short intervals (i.e. a group of three events). Changes in figural groupings may have influenced observed RT changes for short intervals in test blocks due to differences in motor demands for responding to figural groupings of different sizes; participants may have been sensitive to such changes in the sizes of figural groupings. Furthermore, the rhythmic accenting of events changes with the size of figural groupings: only one event is rhythmically accented in a group of two events, whereas two events are rhythmically accented for groups of three or more (Povel & Essens, 1985). In turn, this affects the interaction of rhythmic accents with metrical accents (as per the results of Garner, 1974; Povel & Essens, 1985; Povel & Okkerman, 1981; as discussed in section 2.2). In the case of the training pattern, rhythmic accents generally supported the duple meter (c-score = 1); in the case of the test pattern,
rhythmic accents less often corresponded with metrical accents of a duple meter (c-score = 2).

Experiments in the present thesis maintained the size of figural groups and ensured that rhythmic accents (as outlined by Povel & Essens, 1985) correspond with intended metrical accents. However, the accent rule where the accent is perceived on the second event of a group of two has only been demonstrated for within-group intervals less than 300ms (Povel & Okkerman, 1981). Since the smallest IOI in patterns in the present thesis is 500ms, subjective rhythmic accents are assumed to occur on the first of a group of two. Experiments in the present thesis primarily investigated the IL of an SM pattern (c-score = 1; Experiments 1, 2a, 2b, 3a, and 3b) and compared the effects of introducing SM (c-score = 1) and WM (c-score = 4) test patterns (Experiments 2a, 2b, 3a and 3b). The c-score was maintained between SM training and SM test patterns. Furthermore, Experiment Sets 2 and 3 compare IL of an SM rhythm with IL of a non-metrical rhythm.

2.6 Summary and General Hypotheses
The aims of the present thesis are to investigate the conditions under which the IL of temporal patterns occurs and to compare the learning of metrical and non-metrical patterns. Furthermore, the thesis examines whether previous mixed results for temporal pattern learning can be explained by differences in methods for ascertaining temporal learning. From the review of the literature, a number of hypotheses can be made. Firstly, based on previous experiments on temporal pattern learning, it was hypothesized that metrical (Brandon et al., 2012; Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003) and
non-metrical patterns (Salidis, 2001) can be implicitly learned. In the SRT, learning is indicated by RT decreases in training blocks, and RT increases in test blocks. In the IRT, temporal learning is indicated by decreases in temporal error over training blocks and temporal error increases in test blocks. Ordinal learning is indicated by decreases in ordinal error over training blocks, and increases in ordinal error in test blocks. Based on the dynamic attending theory and the metric binding hypothesis (Jones, 2009), it was also hypothesized that metrical patterns are learned more readily than non-metrical patterns. If RT decreases in the SRT, or temporal error decreases in the IRT, are greater for metrical patterns than for non-metrical patterns, then metrical patterns are learned more readily than non-metrical patterns.

Based on the metric binding hypothesis, it was hypothesized that, when trained on SM patterns (i.e. in the metrical condition), greater performance decrements (i.e. RT increases in the SRT, temporal error increases in the IRT) occur when a new rhythm with a weaker metrical framework is introduced in test blocks than when the new rhythm maintains the original metrical strength (Experiments 2a, 2b, 3a and 3b). If RT increases (and temporal error increases) are greater for test blocks containing a novel WM pattern, compared to test blocks containing a novel SM pattern, then metric binding has occurred. Procedurally, following the SRT (Experiments 1, 2a, 2b, 3a, and 3b) and IRT (Experiments 3a and 3b), the generation (Experiments 1, 2a, 2b, 3a, and 3b) and recognition (Experiments 1, 2a, and 2b) tasks based on the process dissociation procedure were used to ascertain the degree to which learning was implicit.
Regarding methodological differences between previous experiments on the IL of temporal patterns, it was hypothesized that IL of metrical and non-metrical patterns can occur in the presence (Experiment 3a) and absence (Experiments 1, 2a, 2b, and 3b) of a concurrent ordinal pattern. However, based on probabilistic uncertainty, temporal learning may not be evident in the SRT when an ordinal sequence is unpredictable (Experiments 1, 2a, 3a, and 3b). If learning is not indicated in the multiple response SRT compared to the single response SRT (Experiment 2a) or IRT (Experiments 3a and 3b) when the ordinal sequence is random, then it is likely that the multiple response SRT underestimates temporal learning.
Chapter 3

Stimulus, Pattern, and Paradigm Selection
This chapter summarizes a preliminary experiment (Experiment 1) that used the multiple response SRT to compare the learning of metrical and non-metrical patterns. Experiment 1 produced non-significant results and indicated that metrical and non-metrical patterns were not learned. Three method-related explanations were proffered for why learning was not observed in Experiment 1: i) ordinal stimuli may have been difficult to differentiate, ii) the task may not have been engaging enough to motivate participants to perform the task to the best of their abilities, and iii) temporal patterns may not have been perceived as rhythmic. Following Experiment 1, three pilot experiments are reported that aimed to: 1) select a suitable set of ordinal stimuli, 2) determine an engaging paradigm for testing the IL of metrical and non-metrical patterns, and 3) establish suitable metrical and non-metrical patterns. More specifically, a stimuli test examining binaural summation was conducted to develop a suitable set of ordinal stimuli (Pilot Experiment 1), and music notation (Pilot Experiment 2) and beat tapping (Pilot Experiment 3) experiments were conducted to ensure that metrical and non-metrical patterns were perceived as metrical and non-metrical, respectively.

3.1 Experiment 1: Syllable Identification Task

3.1.1. Aim, Design, and Hypotheses

The aim of Experiment 1 was to investigate the IL of metrical and non-metrical patterns in a syllable identification task using the multiple response SRT (see Appendix A for full details). In the SRT, the temporal dimension was predictable and the sequence of ordinal stimuli was random. Dependent variables were accuracy and RT. Independent variables were Block (1-6; within-subjects), Syllable (/KA/, /PA/, /TA/; within-subjects),
and Metricality (metrical, non-metrical; *between-subjects*). Based on previous experiments that have demonstrated the IL of metrical patterns (Brandon et al., 2012; Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003) and non-metrical patterns (Salidis, 2001), it was hypothesized that metrical and non-metrical patterns can be implicitly learned. With respect to the dependent variable RT, learning of metrical and non-metrical patterns is demonstrated if RT decreases over training blocks that contain a repeating pattern, and increases in test blocks that contain a novel pattern. Based on the dynamic attending theory and the metric binding hypothesis, it was hypothesized that metrical patterns are learned more readily than non-metrical patterns. Specifically, if RT decreases over training blocks are larger for metrical patterns than for non-metrical patterns, then metrical patterns are learned more readily than non-metrical rhythms.

### 3.1.2 Method

#### 3.1.2.1 Participants

Participants (*N* = 48) were first year psychology students from the University of Western Sydney who participated for course credit (mean age = 21.1 years, *SD* = 5.5 years, range = 18-43 years, 34 female). Informed consent was obtained (HREC07/006).

#### 3.1.2.2 Materials and Stimuli

The stimuli and procedure was based on that of Brandon et al. (submitted) who found the IL of metrical patterns in an SRT in the presence of a random ordinal sequence of syllables. The cover story of a syllable identification task was implemented to promote IL and reduce awareness of the temporal pattern (as in Brandon et al., 2012). Auditory
stimuli consisted of the syllables /KA/, /PA/, and /TA/, that were designed using MBROLA text to sound speech synthesizer software so that syllable duration (218ms) and fundamental frequency (120Hz) were maintained (see Appendix R). Metrical and non-metrical patterns were constructed that matched in regards to second order conditional probabilities. Metrical and non-metrical test blocks were constructed that matched the training patterns in regards to simple frequency information (as outlined by Reed & Johnson, 1994). In the metrical condition, the training pattern was strongly metrical and the test pattern was weakly metrical.

3.1.2.3 Procedure
Full details of the procedure in Experiment 1 are provided in Appendix A. Participants were presented with a sequence of syllables and were asked to identify syllables as quickly and accurately as possible. Participants were not informed that the timing of stimuli occurred according to repeating a metrical or non-metrical temporal pattern. Blocks 1 to 4 contained the training pattern, block 5 contained the test pattern, and the training pattern was reintroduced in block 6. Generation and recognition tasks based on the process dissociation procedure were conducted after the SRT to examine the degree to which learning of the temporal pattern was implicit.

3.1.3 Results
A response was considered accurate if the syllable was identified correctly, and if the response was made between 100-850ms after the stimulus onset. Only RT to correct responses were submitted to analyses. In the SRT, no significant changes in RT were
observed over blocks for metrical or non-metrical patterns \[F(5, 225) = .71, p = .61, \eta_p^2 = .02\]. As shown in Table 3.1, RT did not decrease over training blocks and did not increase in test blocks. Thus, Experiment 1 did not demonstrate the learning of metrical and non-metrical patterns. Regarding the syllable stimuli, there were significant differences between the syllables \[F(2, 90) = 3.53, p = .03, \eta_p^2 = .07\], where RT for /PA/ \((M = 591.06, SEM = 7.01)\) were significantly greater than RT for /KA/ \((M = 578.76, SEM = 8.10)\) \((p = .006)\) and near-significantly greater than RT for /TA/ \((M = 580.06, SEM = 8.39)\) \((p = .06)\), but RT for /KA/ and /TA/ did not differ \((p = .75)\).

As shown in Table 3.1, accuracy in the SRT significantly decreased over blocks \[F(5, 230) = 3.05, p = .01, \eta_p^2 = .06\], indicating that participants may have become fatigued or disinterested with the task over the course of the experiment. In the generation task, similarity scores were calculated as the similarity between the training pattern, and the sequences produced by participants under inclusion and exclusion instructions (see Appendix A and Appendix L). Results of the generation task indicated that participants were able to reproduce aspects of the temporal patterns above chance levels \((ps < .05)\). There was a slight trend for similarity scores to be greater in the exclusion instruction than in the inclusion instruction \[F(1, 46) = 3.57, p = .07, \eta_p^2 = .07\] suggesting that, if learning had occurred, then learning was implicit. Results of the recognition task indicated that participants were unable to recognize the learned patterns, or recognize features of the learned pattern above chance levels \((ps > .10)\)\(^4\).

\(^4\) The \(p\) value for the recognition of the learned temporal pattern was significantly less than chance in the inclusion instruction \([t(41) = -2.54, p = .02]\).
Table 3.1

*Means and standard error of the mean (in parentheses) for accuracy (%) and RT (ms) to correct responses in metrical and non-metrical conditions over Blocks 1 to 6 in Experiment 1.*

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Metricity</th>
<th>Block 1</th>
<th>Block 2</th>
<th>Block 3</th>
<th>Block 4</th>
<th>Block 5</th>
<th>Block 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>Metrical</td>
<td>69.2</td>
<td>65.0</td>
<td>66.7</td>
<td>66.2</td>
<td>66.4</td>
<td>65.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.8)</td>
<td>(3.3)</td>
<td>(3.2)</td>
<td>(3.0)</td>
<td>(3.1)</td>
<td>(2.9)</td>
</tr>
<tr>
<td></td>
<td>Non-metrical</td>
<td>65.5</td>
<td>63.9</td>
<td>60.9</td>
<td>58.9</td>
<td>57.7</td>
<td>57.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.9)</td>
<td>(3.5)</td>
<td>(3.4)</td>
<td>(3.2)</td>
<td>(3.2)</td>
<td>(3.5)</td>
</tr>
<tr>
<td>RT</td>
<td>Metrical</td>
<td>571.3</td>
<td>572.5</td>
<td>569.6</td>
<td>570.8</td>
<td>574.9</td>
<td>578.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(9.5)</td>
<td>(10.6)</td>
<td>(10.6)</td>
<td>(11.2)</td>
<td>(10.7)</td>
<td>(12.8)</td>
</tr>
<tr>
<td></td>
<td>Non-metrical</td>
<td>593.5</td>
<td>595.8</td>
<td>591.0</td>
<td>597.1</td>
<td>600.2</td>
<td>594.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(9.7)</td>
<td>(10.8)</td>
<td>(10.8)</td>
<td>(11.5)</td>
<td>(11.0)</td>
<td>(13.1)</td>
</tr>
</tbody>
</table>

3.1.4 Discussion

In Experiment 1, results of the multiple response SRT did not support the hypothesis that metrical and non-metrical patterns can be learned. However, results of the generation task indicate that at least some aspect of the temporal patterns were learned, as similarity scores were above chance for sequences produced in the inclusion and exclusion instructions. Four explanations for why temporal patterns were not learned are now discussed.

Differences in RT between the syllables indicated that there may be differences in the processing speeds for syllable stimuli. Specifically, the syllable /PA/ may have been
processed and identified more slowly than syllables /KA/ and /TA/. Differences elicited by the set of stimuli may have also interfered with RT. Consequently, RT did not only reflect learning processes but also other processes relating to the differentiation of stimuli. Thus, it is possible that processes relating to identification of stimuli interfered with the learning of temporal patterns.

Secondly, the pattern for accuracy to decrease over blocks indicated that participants may have become disinterested with the experiment or fatigued, and may not have found the task engaging. It is possible that temporal pattern learning was not observed due to disinterest in the task and that learning might be exhibited if participants were more motivated to engage in the task. For this reason, a more motivating cover story of a computer game for the blind was designed in order to encourage participants to engage in the SRT.

It is also possible that IOIs in the temporal pattern were too long to be perceived as rhythmic or metrical, that is, IOIs were longer than those used in previous experiments of rhythm perception (e.g. Essens & Povel, 1985; Fraisse, 1982; Friberg & Sundberg, 1995; Povel & Essens, 1985). If patterns were not perceived as rhythmic, then it is possible that it was too difficult to form temporal expectancies and that learning could not occur. If patterns were used that were more similar to those of Povel and Essens (1985), or those used by Brandon et al. (submitted), with regard to figural groupings and the sizes of IOI then temporal patterns might be learned. For this reason, new temporal patterns were constructed for the other experiments in the present thesis, as discussed in
the following sections. The new temporal patterns used similar IOIs and figural grouping structures to those used in previous studies (Brandon et al., 2012; Povel & Essens, 1985), but still respected simple frequency information (Reed & Johnson, 1994) and matched in regards to figural groupings (Bamberger, 1980).

Lastly, in the SRT the ordinal sequence, that is, the order of syllable stimuli, was random. It is possible that learning was not observed in the SRT based on probabilistic uncertainty; participants may have been unable to prepare for upcoming responses to the unpredictable ordinal sequence, and were therefore unable to demonstrate learning of the temporal pattern. If participants are able to respond directly to the timing of stimuli in a task such as a reproduction task or a stimulus-detection task, then learning could be observed. Thus, Experiment 2a compared a stimulus detection task (i.e. a single response SRT) with a multiple-alternative forced-choice task (i.e. a multiple response SRT)

3.1.5 Conclusion

The lack of temporal pattern learning in Experiment 1 could be explained by difficulties in identifying stimuli, fatigue or a lack of motivation, the size of figural groups and IOIs, or probabilistic uncertainty. To combat these issues, three modifications were instigated relating to the stimuli and temporal patterns (probabilistic uncertainty was investigated in Experiment 2a). Firstly, due to differences in RT for the three syllables, the type of stimulus was changed. Secondly, to reduce effects of fatigue and boredom, a more engaging cover story was used in the form of a computer game. Thirdly, to ensure the
temporal patterns were correctly perceived as metrical and non-metrical, the temporal patterns were changed and tested. The following section discusses these changes and presents three experiments that were conducted to ensure that stimuli were well controlled and that metrical and non-metrical pattern are perceived as metrical and non-metrical, respectively.

3.2 Developing Controlled Stimuli

As there were RT differences between the syllable stimuli in Experiment 1, it was important to ensure that the stimuli do not differ in regards to how difficult they are to perceive and identify. Furthermore, it was important that the stimuli themselves do not affect the metrical interpretation of a temporal pattern, that is, that the stimuli do not differ along the dimensions of pitch, intensity, or duration (properties that were controlled for syllables in Brandon et al. submitted). If a stimulus within a set were to elicit accents differently than other stimuli within the set, then the accent could detract from the intended metrical accents of the temporal pattern. Accents that are elicited by properties of the stimulus itself are called phenomenal accents (Lerdahl & Jackendoff, 1983). Phenomenal accents can be elicited by changes in pitch (i.e. melodic accents), increases in perceived loudness (i.e. intensity accents), or changes in stimulus duration (i.e. duration accents). Thus, it is important to ensure that these stimulus properties are controlled, that a stimulus can be identified and differentiated from other stimuli, while at the same time not differing in regards to processing speeds.
To ensure that the properties of the stimulus were controlled, auditory spatial locations were used, that is, the properties of the stimulus was kept constant, but the presentation of the stimulus was changed. Specifically, a tone was presented from the left headphone, the right headphone, or both headphones (i.e. binaurally). Keeping the stimulus properties constant and changing the spatial location resulted in control over most aspects of the stimulus, as the stimulus properties were identical. Parmentier, Mayberry, Huitson, and Jones (2008) demonstrated that patterns of auditory spatial locations can be explicitly learned when non-word auditory stimuli are used. Auditory stimuli were presented at sequentially from one of seven angles ranging from -90 degrees to +90 degrees, in steps of 30 degrees. Results of Parmentier et al. (2008) indicate that auditory spatial locations can be differentiated and identified accurately if they differ by, at least, 30 degrees. Presenting tones from the left headphone, both headphones, and the right headphone is likely to be perceived analogously to the spatial positions of -90 degrees, 0 degrees, and +90 degrees, respectively. Thus, the presentations of a tone from the left headphone, right headphone, or both headphones should be able to be differentiated.

The advantage of using auditory spatial locations was that the stimulus set is homogenous, as the properties of the stimulus do not change. Thus, accents arising from differences in the properties of the stimulus cannot occur. However, it is possible that the presentation of the stimulus in both headphones may be perceived as louder than the presentation to the left or right headphones alone due to binaural summation. Before auditory spatial locations could be implemented as stimuli, it is necessary to account for the possible effects of binaural summation and adjust stimuli accordingly.
3.2.1 Pilot Experiment 1: Binaural Summation Experiment

Binaural summation is when a stimulus that is presented binaurally, that is, to both the left and right ears simultaneously, is perceived to be louder than when the same stimulus is presented monaurally, that is, to only the left or right ear (Marks, 1978; Porsolt & Irwin, 1967). Previous studies have demonstrated that a binaural stimulus is generally perceived as 3-6dB SPL louder than the same stimulus presented monaurally (Dillon, 2001; Marks, 1978). However, some studies have shown binaural stimuli to be perceived up to 10dB louder for frequencies of approximately 2000Hz (Porsolt & Irwin, 1967). Marks (1978) demonstrated that binaurally presented pure tones of the same frequency (approximately 500Hz) are perceived as up to 5dB louder than the same stimulus presented monaurally. Thus, Pilot Experiment 1 was conducted to reduce the perceived difference in loudness between the binaural and monaural presentations of the 394Hz triangle waveform stimulus to be used here (following Salidis, 2001).

3.2.2 Design

Within each trial, a pair of stimuli was present consecutively: a monaural stimulus (left or right) was presented before or after a binaural stimulus of varying intensity level relative to the monaural stimulus. The design was a 4 (Level of intensity difference between the monaural and binaural stimulus; 0dB, -2dB, -4dB, and -6dB) x 2 (Side of monaural stimulus; left and right) within-subjects design. Both orders (binaural to monaural, monaural to binaural) were presented, and trials were presented in a random
order. The dependent variable was the proportion of “different” judgements of loudness (compared to “same” judgements).

3.2.3 Hypothesis

Based on previous research on binaural loudness and summation (Dillon, 2001; Marks, 1978) it is hypothesized that a binaurally presented stimulus is perceived as 4 to 6 dB louder than the same stimulus presented monaurally. Second, it is hypothesized that when the intensity of a binaural presentation is reduced by 4-6dB, it is judged as being of similar loudness to the monaural presentations. Third, it is hypothesized that judgements do not differ between left and right monaural presentations.

3.2.4 Method

3.2.4.1 Participants

Participants (N = 12) were adult volunteers from the University of Western Sydney. The sample had a mean age of 25.4 years (SD = 4.6, range = 20-39), and six were female. All participants reported that they had normal hearing.

3.2.4.2 Stimulus and Materials

The stimulus was a triangle wave of 394Hz, 200ms duration and with rise and fall times of 10ms (as in Salidis, 2001). A waveform of the stimulus is shown in Figure 3.1. Each pair of stimuli consisted of a stimulus presented through either the left or right headphone, and a stimulus presented binaurally (see Appendix R for stimuli). The intensity of left and right presentations was kept constant at 94.5dB sound pressure level
The intensity of the binaural presentation either matched the intensity of the monaural stimulus (0dB difference), or deviated from the monaural presentations by -2dB (92.5dB SPL), -4dB (90.5dB SPL), or -6dB (88.5dB SPL). Measurements of intensity were obtained using a Brüel and Kjær artificial ear with a 1” microphone of type 4144 (see Appendix D). Pairs of stimuli were presented with an inter-onset interval (IOI) of 500ms, as this was the shortest interval used in Experiment 1. Stimuli and instructions were presented on a MacBook Pro using PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993). Auditory stimuli were presented through Sennheiser headphones (HD 650) using a Roland Edirol UA-25EX sound driver.

Figure 3.1. Waveform of 394Hz triangle wave used in the binaural summation test, and Experiments 2a, 2b, 3a, and 3b.
3.2.4.3 Procedure

Participants were informed that they would be performing an experiment where they would be judging whether the loudness of two sounds was the same or different and informed consent was obtained (H7764; see Appendix E). Participants listened to sounds presented from either the left headphone, right headphone, or both headphones, and were asked to judge whether the two sounds were the same or different in terms of loudness. Sounds were presented in pairs and, following each pair, participants were to respond “Same” or “Different” as quickly as possible. Participants responded “Same” by pressing the “1” key with their index finger, and responded “Different” by pressing the “3” key with their middle finger. Pairs always consisted of one monaural presentation (left or right) and one binaural presentation (0dB, -2dB, -4dB, or -6dB). Participants were given up to 2,000ms to respond, and any missed trial was repeated. Participants participated in four repetitions of each trial condition, that is, binaural dB Level (4) x monaural Side (2) x binaural/monaural Order (2) resulting in a total of 64 trials. No experimental session exceeded 15 minutes.

3.2.5 Results and Discussion

Data were coded so that a “same” response was 0 and a “difference” response was 1. The mean of the four repetitions was extracted for each cell (4 dB Levels x 2 Sides x 2 Orders). In this way, same/different scores close to 0 represent similarity judgements and those close to 1 represent dissimilarity judgements. Scores that are less than 0.5 can be interpreted as closer to the point of subjective equality (PSE).
To test the hypothesis that a binaural stimulus is perceived as louder than a monaural stimulus, a 4 (Binaural dB Level) x 2 (Side) repeated measures ANOVA on mean same/different responses was conducted. There was a significant main effect for Binaural Intensity \( F (3, 33) = 47.23, p < .001, \eta_p^2 = .81 \), but no significant main effect for Side \( F (1, 11) = 3.11, p = .11, \eta_p^2 = .22 \) or interaction for Level x Side \( F (3, 33) = .41, p = .75, \eta_p^2 = .04 \). As shown in Figure 3.2, fewer “Different” judgements were made as the binaural stimulus decreased in intensity, relative to the monaural stimulus. Planned comparisons using the Bonferroni adjustment revealed a significant difference between the 0dB binaural level and -2dB \( F (1, 11) = 18.28, p = .001, \eta_p^2 = .62 \), -4dB \( F (1, 11) = 64.38, p < .001, \eta_p^2 = .85 \), and -6dB \( F (1, 11) = 79.60, p < .001, \eta_p^2 = .88 \). This supports the hypothesis that a binaurally presented stimulus is perceived as louder than the same stimulus (at the same physical intensity) presented monaurally.
Figure 3.2. Judgments (“Same” or “Different”) for the binaural intensity level differences (0, -2dB, -4dB and -6dB) for left and right monaural stimulus presentations. Scores close to 0 represent more “Same” judgments and those close to 1 represent more “Different” judgments. The dashed line represents chance levels for detecting a difference between binaural and monaural stimuli. Error bars represent standard error of the mean.

To examine whether there were differences in judgements between binaural intensity levels that differed from the intensity of the monaural stimulus, a series of planned comparisons were conducted between relative binaural intensity levels other than 0dB. Planned comparisons using the Bonferroni adjustment were significant between the 2dB and 4dB \( [F (1, 11) = 31.22, p < .001, \eta_p^2 = .74] \) levels, the 2dB and 6dB levels \( [F (1, 11) = 53.14, p < .001, \eta_p^2 = .83] \), but not the 4dB and 6dB levels \( [F (1, 11) = 5.16, p = .27, \eta_p^2 = .32] \). The lack of a significant difference between the 4dB and 6dB levels indicates
that the binaural stimulus is perceived as similar to the monaural stimulus when the binaural stimulus is between 4-6dB less intense than the monaural stimulus. One-sample $t$-tests demonstrated that both the 4dB [$t (11) = -2.00, p = .035$] and 6dB [$t (11) = -3.91, p = .002$] level differences were significantly less than chance levels (0.5), indicating that binaural and monaural stimuli were perceived as being similar above chance levels. This finding is in line with previous findings on binaural summation (Dillon, 2001; Marks, 1978). Thus, the best candidates for the binaural stimulus are the 4dB and 6dB intensity reductions, relative to the monaural stimulus.

To ensure that that the 4dB and 6dB level differences did not differ between in relation to side, pair-wise comparisons were conducted for Side for the 4dB and 6dB levels. There was no significant difference between sides for the 4dB level [$F (1, 11) = 1.65, p = .23, \eta_p^2 = .13$]. There was a significant difference between sides for the 6dB level [$F (1, 11) = 5.53, p = .04, \eta_p^2 = .33$]. As shown in Figure 3.2, the significant difference between sides for the 6dB level indicates that the left monaural stimulus was perceived as more similar to the binaural stimulus than the right monaural stimulus. The 4dB level difference was perceived similarly regardless of side. Thus, implementing an intensity reduction of 4dB for the binaural stimulus, relative to the monaural stimulus, should reduce the effects of binaural summation.

**3.2.6 Conclusion**

Pilot Experiment 1 indicated that the intensity of monaural stimulus presentations relative to binaural stimulus presentations is perceived as similar when the binaural
stimulus was reduced by 4dB to 6dB. Furthermore, left and right monaural presentations were judged similarly for the 4dB level, but not the 6dB level. Based on these results, Experiment Sets 2 and 3 used the auditory spatial locations of left, both, and right as the to-be-identified stimulus with a binaural stimulus that was 4dB less intense than the monaural stimulus presentations.

### 3.2.7 A More Engaging Cover Story

Due to the change in stimuli, the syllable identification task cover story used to promote IL also had to be changed. Moreover, the cover story had to be engaging as the results of Experiment 1 indicated that participants may have become disinterested in the task. For these reasons, the cover story was changed from the syllable identification task to a computer game for the blind (see Appendix F), where participants would hear tones emanating from the left headphone, the right headphone, or both headphones. In the game, participants assume the role of a driver of a vehicle and have to use a special sonar system to avoid obstacles that instructs the driver to steer left (left headphone), right (right headphone), or jump (both headphones). The computer game for the blind cover story was used for Experiment Sets 2 and 3. The next section discusses the metrical and non-metrical temporal patterns used in Experiment Sets 2 and 3, and presents two experiments that were conducted to ensure that patterns were perceived as metrical and non-metrical.
3.3 Constructing Metrical and Non-metrical Patterns

One of the possible explanations for why temporal learning was not evident in Experiment 1 is that the length of the patterns (16s) and intervals (up to 3s) may have made it too difficult to form temporal expectancies. Similarly, it is possible that the beat and meter were not abstracted in the metrical condition. For these reasons, temporal patterns were constructed that were similar to those used by Povel and Essens (1985) and Brandon et al. (submitted). Povel and Essens used temporal patterns consisting of nine events with IOIs that ranged between 200ms to 800ms, with an overall duration of 3200ms. Brandon et al. used temporal patterns consisting of eight events with IOIs that ranged from 700ms to 2100ms, and an overall duration of 8400ms. To ensure that participants were still able to identify stimuli, temporal patterns were constructed with IOIs that ranged from 500ms to 2000ms, with an overall duration of 8000ms. Pattern construction was based on the patterns of Povel and Essens (1985) who demonstrated that metrical patterns can be reproduced in a reproduction task under explicit instruction.

Metrical and non-metrical patterns are presented in Figure 3.3. Metrical patterns were constructed from three IOIs of 500ms, three IOIs of 1000ms, one IOI of 1500ms, and one IOI of 2000ms. As such, all IOIs in the metrical patterns had a simple integer ratio relationship with the smallest IOI (500ms), that is, 2:1 (1000ms), 3:1 (1500ms), and 4:1 (2000ms). Non-metrical patterns followed the same pattern structures as the metrical patterns, but replaced: 1) the 1000ms IOIs with 1100ms IOIs, 2) the 1500ms IOI with a 1350ms IOI, and 3) the 2000ms IOI with a 1850ms IOI. Non-metrical patterns had a complex integer ratio relationship with the smallest IOI (i.e. 500ms), with non-metrical...
timing deviations that were larger than the just noticeable difference of the perceived beat (i.e. 2.5% of 500ms, as per Friberg & Sundberg, 1995). Thus, hypothetically non-metrical patterns were unable to be interpreted in terms of a metrical framework (Essens & Povel, 1985).

Figure 3.3. Metrical and non-metrical patterns used in Experiments 2a, 2b, 3a and 3b. For Experiments 2a and 2b, the base time unit represents 500ms (i.e. IOIs are divided by 500ms to ascertain the base unit). For Experiments 3a and 3b, the base time unit represents 400ms (i.e. IOIs are divided by 400ms to ascertain the base unit). Dashed lines represent the assumed strong beats, short vertical lines represent the assumed beat, and crosses represent events.

Metrical and non-metrical patterns differed from the temporal patterns of Povel and Essens (1985), in that the present temporal patterns were governed by second order conditional probabilities. This was done to remain consistent with previous experiments on the IL of temporal patterns (Brandon et al., 2012; Buchner & Steffens, 2001; O’Reilly et al., 2008; Salidis, 2001; Shin & Ivry, 2002), and provides a statistical
structure that can be used to learn the pattern of IOIs. Specifically, temporal patterns were matched in regards to: 1) item frequency (the number of times each IOI occurs in a pattern), 2) transition frequency (the number of times each pair of IOIs occur in the same order), 3) the rate of full coverage (the average number of items necessary to view each unique IOI in the pattern at least once), and 4) the rate of full transition usage (the average number of items necessary to view each IOI pairing at least once). These statistical features were constant between all patterns with the exception of one of the strongly metrical patterns (and its non-metrical counterpart), which differed only in regards to the rate of full coverage. The rate of full coverage was not matched in order to uphold another constraint. When changing between patterns that are governed by second order conditional probabilities, some of the conditional probabilities may remain, while other conditional probabilities may be violated. To ensure that the number of violations to higher order conditional probabilities were equal when changing from the training pattern to test 1, and when changing from the training pattern to test 2, while still upholding all other constraints, the rate of full coverage had to be violated for the strongly metrical test pattern 1.

Controlling the size of figural groupings and simple frequency information resulted in a set of metrical and non-metrical patterns that were identical in regards to the figural grouping structure and second order conditional probabilities, but differed in regards to the metrical structure, that is, the non-metrical pattern could not easily be interpreted through a metrical framework. Control of simple frequency information and the size figural grouping features is important, as it means differences between the learning of
metrical and non-metrical patterns cannot be attributed to differences in simple
frequency information, statistical structure, or rhythmic complexity. Instead, differences
between metrical and non-metrical patterns can only be attributed to the presence or
absence of meter, and the abstraction of a metrical framework.

In the set of metrical patterns, two patterns were strongly metrical and one was weakly
metrical as per the criteria set by Povel and Essens (1985). According to the clock
model, counter-evidence scores (c-score; where lower scores indicate greater metrical
strength) were lower for strongly metrical patterns (c-score = 1) than for weakly metrical
patterns (c-score = 4). Two pilot experiments were conducted to examine whether
participants perceived the hypothesized differences between metrical and non-metrical
patterns: a notation experiment (Pilot Experiment 2), and a beat tapping experiment
(Pilot Experiment 3). These experiments will now be reported.

3.4 Pilot Experiment 2: Music Notation of Metrical and Non-metrical Patterns

Pilot Experiment 2 was a notation task that was conducted to ensure that non-metrical
training patterns were not interpreted as metrical, and to ensure that the non-metrical
timing deviations could be detected. Five musicians were asked to musically notate two
metrical patterns (SM training and SM test 1 in Figure 3.3) and non-metrical training
patterns (NM training and test 1 in Figure 3.3).
3.4.1 Design

Independent variables were Metricality (metrical, non-metrical; within-subjects) and Pattern (training, test 1; within-subjects). Dependent variables were the number of timing deviations (see Section 3.4.4.1) that were notated and subjective difficulty ratings for notating the pattern (where 1 = Very Easy and 10 = Very Hard).

3.4.2 Hypotheses

It is hypothesized that more timing deviations are notated for non-metrical patterns than for metrical patterns. It is also hypothesized that metrical patterns are rated as easier to notate than non-metrical patterns. Differences are not expected between patterns within metrical and non-metrical conditions for the notation of timing deviations or difficulty ratings.

3.4.3 Method

3.4.3.1 Participants

Participants ($N = 5$) were adult volunteers from MARCS Institute at the University of Western Sydney. Ages ranged from 26-38 years ($M = 31.2$ years, $SD = 5.59$), and three were female. Years of musical training ranged from 6 to 22 years ($M = 10.6$ years, $SD = 6.47$). No participants reported a hearing impairment.

3.4.3.2 Materials

The stimulus was the 394Hz triangle waveform that was used in Pilot Experiment 1, presented binaurally on Sennheiser (HD 650) headphones. In the metrical condition,
patterns were the SM training pattern and SM test 1 pattern shown in Figure 3.3 (see Appendix R for stimuli). In the non-metrical condition, patterns were the NM training pattern and NM test 1 pattern shown in Figure 3.3. Stimuli were presented using Windows Media Player.

3.4.3.3 Procedure

Participants were explained that they would be performing a task where they would be presented with temporal patterns and that they would have to notate each pattern on a musical stave. Informed consent was obtained (H7764; see Appendix G). Participants were presented with the four patterns in a random order. For each pattern, participants could listen to the pattern until they felt comfortable they could notate it. Participants were then asked to notate the pattern as accurately as possible, and could listen to the pattern again to ensure they were satisfied with their attempt. If participants were dissatisfied with their attempt, they were able to notate the pattern again. For each participant and pattern, the attempt that the participant was most satisfied with was analyzed. Participants then rated how difficult it was to notate each pattern on a scale where 1 = Very Easy and 10 = Very Hard (see Appendix H). Experiment sessions did not exceed 20 minutes.

3.4.4 Results

3.4.4.1 Notated Timing Deviations

The strategies for notating non-metrical timing deviations differed between participants. Three participants interpreted timing deviations as increases or decreases in tempo, and
notated these in terms of tempo markings within a metrical framework. For example, if IOIs decreased in relation to the perceived beat, then participants wrote “accel.” indicating an increase (or acceleration) in tempo. Two participants interpreted the timing deviations as changes between the IOIs, and notated patterns without tempo markings. To accommodate both methods, a notation of timing deviation included counts of both tempo markings and IOIs that differed from the theorized metrical interpretation. For example, each IOI that notated a timing deviation from the metrical structure added one point to the number of notated timing deviations. Similarly, each tempo marking added one point to the number of notated timing deviations.

To examine the hypothesis that more timing deviations are notated for non-metrical patterns than for metrical patterns, a 2 (Metricality) by 2 (Pattern) repeated measures ANOVA was conducted on the frequency of notated timing deviations. There was a significant main effect of Metricality \([F (1, 4) = 30.00, p = .005, \eta^2_p = .88]\), no significant main effect of Pattern \([F (1, 4) = .12, p = .75, \eta^2_p = .03]\), and no significant interaction between Metricality and Pattern \([F (1, 4) = 1.39, p = .31, \eta^2_p = .26]\)\(^5\). Due to the small sample size \((N = 5)\), non-parametric tests As shown in Figure 3.4, the main effect of Metricality supports the hypothesis that more timing deviations are notated for non-metrical patterns than for metrical patterns.

\(^5\) Due to the small sample size \((N = 5)\), Friedman's non-parametric test was also used to test the main effects. Corroborating the results of the repeated measures ANOVA, there was a significant difference based on Metricality \([\chi^2 (1) = 9.00, p = .003]\) and no significant difference based on Pattern \([\chi^2 (1) = 1.00, p = .32]\) for the number of notated timing deviations.
Figure 3.4. Mean number of timing deviations notated in metrical and non-metrical conditions for the training pattern, and the test 1 pattern. The test 1 pattern in the metrical condition was unanimously notated without any tempo markings or timing deviations. Error bars represent standard error of the mean.

### 3.4.4.2 Difficulty Ratings

To test the hypothesis that metrical patterns are easier to notate than non-metrical patterns, a 2 (Metricality) by 2 (Pattern) repeated measures ANOVA was conducted on the difficulty ratings. There was a significant main effect of Metricality $[F (1, 4) = 62.30, p = .001, \eta_p^2 = .94]$, no significant main effect of Pattern $[F (1, 4) = .67, p = .46, \eta_p^2 = .14]$, and no significant interaction between Metricality and Pattern $[F (1, 4) = \ldots$
As shown in Figure 3.5, the main effect of Metricality indicated that difficulty ratings were higher for non-metrical patterns than for metrical patterns. Results support the hypothesis that metrical patterns are rated as easier to notate than non-metrical patterns.

Figure 3.5. Mean difficulty ratings in metrical and non-metrical conditions for the training pattern, and the test 1 pattern. Error bars represent standard error of the mean.

### 3.4.5 Discussion

The aim of Pilot Experiment 2 was to ensure that non-metrical timing deviations are perceivable and to test whether a metrical framework can be imposed onto non-metrical

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6 As conducted for notated timing deviations, Friedman’s non-parametric test was also used to test the main effects for difficulty ratings. In accordance with the results of the repeated measures ANOVA, there was a significant difference based on Metricality \( \chi^2 (1) = 12.80, p < .001 \) and no significant difference based on Pattern \( \chi^2 (1) = 0.14, p = .71 \).
patterns. Results of the notation experiment indicate that non-metrical timing deviations are perceivable by musicians, and that non-metrical patterns are perceived as more difficult to interpret than metrical patterns. It appears that some musicians were able to interpret non-metrical patterns as metrical patterns with increases and decreases in tempo. These results are in line with those of Large, Fink, and Kelso (2002), who demonstrated that participants are able to synchronize with and adapt to metrical rhythms that contain changes in tempo. However, as the notation of rhythms is usually conducted for musical patterns that are inherently metrical (Palmer & Krumhansl, 1990) the interpretation of non-metrical patterns as metrical patterns may be an artifact of the notation task. Furthermore, the sample consisted entirely of musicians who may interpret temporal patterns in terms of a metrical framework. For these reasons, a beat tapping task was also conducted in Pilot Experiment 3. Beat tapping tasks can be performed by both musicians and non-musicians (e.g. McAuley & Semple, 1999), and can be used to ascertain how people respond to timing deviations (Large & Jones, 1999).

3.5 Pilot Experiment 3: Abstracting the Beat from Metrical and Non-metrical Patterns

In Pilot Experiment 3, a beat tapping (i.e. sensorimotor synchronization) experiment was conducted to investigate whether metrical and non-metrical patterns were perceived as metrical and non-metrical, respectively. The primary task was to tap the perceived beat to three metrical and three non-metrical temporal patterns. In the metrical condition, two patterns were strongly metrical, and one was weakly metrical (see Figure 3.3). Non-metrical patterns matched metrical patterns with regard to figural groupings, but
contained intervals with a complex integer ratio relationship. The primary aim of the experiment was to ensure that metrical and non-metrical patterns were perceived as being different by musicians and non-musicians, and to examine whether non-metrical patterns might be interpreted as metrical patterns with tempo deviations.

3.5.1 Design

Independent variables were Metricality (metrical, non-metrical; \textit{within-subjects}), Pattern (training, test 1, test 2; \textit{within-subjects}), and Musical Training (musicians, non-musicians; \textit{between-subjects}). Dependent variables were the coefficient of variation (i.e. standard deviation divided by the mean) of the inter-tap interval (ITI), subjective difficulty ratings, and subjective metricality ratings.

3.5.2 Hypotheses

It is hypothesized that tapping variability is greater for non-metrical patterns than for metrical patterns. Based on Patel, Iverson, Chen, and Repp (2005), it is also hypothesized that tapping variability increases as metrical strength decreases. In other words, tapping variability would be greatest for non-metrical patterns, then the weakly metrical pattern (test 2), and strongly metrical patterns would have the least variability (NM > WM > SM). These hypotheses concern both musically trained and untrained participants. Based on the results of Repp and Doggett (2007), it was hypothesized that non-musicians will demonstrate larger tapping variability than musicians. It is also possible that there are differences between the way musicians and non-musicians abstract the beat for metrical and non-metrical patterns. For example, it may also be the
case that musically trained participants are better at maintaining a beat for weakly metrical patterns than untrained participants. However, as previous experiments have not examined differences between musicians and non-musicians for metrical and non-metrical patterns, no specific hypotheses were made regarding interactions between musical training and metricality. The rationale for comparing musicians and non-musicians was to ensure that differences between metrical and non-metrical patterns were evident for musicians and non-musicians.

It is hypothesized that tapping to non-metrical patterns are rated as more difficult than tapping to metrical patterns. It is also hypothesized that weakly metrical patterns are rated as more difficult to tap to than strongly metrical patterns. Lastly, it is hypothesized that strongly metrical patterns are rated as more metrical than weakly metrical patterns and non-metrical patterns, and that weakly metrical patterns are rated as more metrical than non-metrical patterns.

### 3.5.3 Method

#### 3.5.3.1 Participants

Participants ($N = 14$) were volunteers from MARCS Institute at the University of Western Sydney. Ages ranged from 24 to 50 years ($M = 31.00$ years, $SD = 7.15$) and seven were female. Seven of the participants were considered musically trained, with six or more years of formal training on a musical instrument or voice. Years of musical training for musicians ranged from 6 to 23 years ($M = 12.00$, $SD = 5.97$). Only one
participant in the non-musician group had received any musical training (2 years). No participants reported a hearing impairment.

3.5.3.2 Materials
The stimulus was the 394Hz triangle waveform (from Pilot Experiments 1 and 2), presented binaurally on Sennheiser (HD 650) headphones. Metrical and non-metrical patterns were the temporal patterns described in section 3.3 (see Figure 3.3). Two of the metrical patterns were strongly metrical and the third was weakly metrical. Rhythms were presented cyclically until participants had responded the required number of times (i.e. 54 taps). Each presentation of the rhythm contained eight events. For this reason, eight different starting points were used for the stimuli, one for each event. Thus, 48 sequences (6 patterns x 8 starting points) were examined. Instructions and stimuli were presented on a MacBook Pro using a custom made MatLab script (see Appendix R for stimuli). Auditory stimuli were presented through Sennheiser headphones (HD 650). Responses were captured by a Roland Handsonic 10 drum pad.

3.5.3.3 Procedure
Participants were seated in front of the computer and explained that, in the experiment, they would be presented with a number of different rhythms and that they were to tap the beat of the rhythm. Examples of what constitutes a beat were given by the experimenter. The concept of meter was also explained (for musicians and non-musicians), with metrical patterns defined as rhythms that fit a beat well, and non-metrical patterns described as rhythms that felt syncopated where events occurred away
from the beat. Informed consent was obtained (H7764; see Appendix I), and then participants commenced the experiment.

In each trial participants were presented one of the 48 sequences. Participants were to listen to the rhythm until they were confident that they could tap the beat. The rhythm repeated cyclically until 54 taps were made, at which point a woodblock sound would occur, indicating the end of the trial. If any inter-tap interval varied more than 60\% from the median inter-tap interval, this was considered a “missed tap” and participants were asked to repeat the trial. After successfully completing the trial, participants were asked to respond to two questions regarding difficulty and metricality on a 5-point Likert scale. The first question was “How difficult was it to tap the beat for this rhythm?” on a scale of 1 to 5 where 1 = Very Easy, 3 = Moderate, and 5 = Very Difficult. The second question was “How metrical was the rhythm?” on a scale of 1 to 5 where 1 = Non-metrical and 5 = Metrical. The order of the sequences was randomized for each participant. Trials were presented in a random order, and a 30 second break was enforced after 24 trials were completed (i.e. half the trials). The experiment took between 35-60 minutes, depending on the listening times of each participant.

3.5.4 Results

3.5.4.1 Data Analysis

As participants could choose to start tapping at any point during the pattern, data were collapsed across starting positions (there were no systematic differences in listening times or pattern position for the initial tap). In each trial, the first six inter-tap intervals
were removed, leaving 48 inter-tap intervals per trial. The tapping variability (i.e. the standard deviation of inter-tap intervals) was calculated in each trial for each participant. Data were subjected to a 2 (Metricality; metrical, non-metrical; *within-subjects*) by 3 (Pattern; training, test 1, test 2; *within-subjects*) by 2 (Musical Training; *between-subjects*) mixed models ANOVA.

### 3.5.4.2 Inter-tap Interval Variability

To examine whether beat perception differed as a result of metrical strength and metricality, the coefficient of variation was analyzed for each trial. There was a significant main effect of Metricality \([F (1, 13) = 43.37, p < .001, \eta_p^2 = .78]\), no main effect of Pattern \([F (2, 24) = 2.69, p = .09, \eta_p^2 = .18]\), and no main effect of Musical Training \([F (1, 13) = 0.11, p = .75, \eta_p^2 = .01]\). There was a significant interaction between Metricality and Musical Training \([F (1, 13) = 9.63, p = .009, \eta_p^2 = .45]\) but no other interactions were significant \((ps > .66)\). As shown in Figure 3.6, variability was generally greater for non-metrical patterns than metrical patterns. The lack of a significant main effect of Pattern, and the lack of a significant interaction between Pattern and Metricality, indicates that participants could tap to the different patterns within each Metricality condition with similar precision. Specifically, in the metrical condition, tapping variability was not greater for weakly metrical patterns compared with strongly metrical patterns. The lack of a significant main effect for Musical Training indicates that musicians and non-musicians were able to perform the task with similar effectiveness overall.
Figure 3.6. Coefficient of variation (i.e. standard deviation divided by the mean) for metrical and non-metrical patterns for musicians (a) and non-musicians (b) for the Training pattern and Tests 1 and 2. In the metrical condition, the Training pattern was strongly metrical, Test 1 was strongly metrical, and Test 2 was weakly metrical. For the non-metrical condition, patterns are non-metrical versions of the metrical patterns with non-metrical timing deviations. Error bars represent standard error of the mean.

To examine whether variability was greater for non-metrical patterns than metrical patterns for both musicians and non-musicians, musicians and non-musicians were analyzed separately. There were significant main effects of Metricality for both non-musicians \( F (1, 6) = 16.53, p = .007, \eta_p^2 = .73 \) and musicians \( F (1, 6) = 28.74, p < .001, \eta_p^2 = .83 \). The main effects of Metricality for musicians and non-musicians indicate that non-metrical patterns elicited greater variability than metrical patterns regardless of musical training. As shown in Figure 3.6, the interaction between Metricality and Musical Training shows larger differences between metrical and non-metrical conditions for musicians than for non-musicians. Overall, results support the
hypothesis that tapping variability is greater for non-metrical patterns than for metrical patterns. However, the hypothesis that tapping variability increases as metrical strength decreases was not supported; results indicated that tapping variability for the weakly metrical pattern (test 2) was not significantly different from tapping variability for strongly metrical patterns (training, test 1).

3.5.4.3 Difficulty Ratings

To examine whether the subjective experience of tapping the beat differed between metrical and non-metrical patterns, difficulty ratings were analyzed. There was a significant main effect of Metricality \( [F (1, 13) = 115.60, p < .001, \eta_p^2 = .91] \), a significant main effect of Pattern \( [F (2, 24) = 17.97, p < .001, \eta_p^2 = .60] \), and a near significant main effect of Musical Training \( [F (1, 13) = 4.45, p = .06, \eta_p^2 = .27] \). The interaction between Metricality and Musical Training was significant \( [F (1, 13) = 53.70, p < .001, \eta_p^2 = .82] \) but no other interactions were significant \( (ps > .17) \). As shown in Figure 3.7, the main effect of Metricality indicates that the non-metrical patterns were rated as more difficult than metrical patterns. Planned comparisons between patterns indicated that test 2 was rated as more difficult than training \( [F (1, 13) = 44.04, p < .001, \eta_p^2 = .77] \) and test 1 \( [F (1, 13) = 19.48, p = .001, \eta_p^2 = .60] \). However, as demonstrated in Figure 3.7, test 2 was rated as more difficult regardless of metricality. In other words, test 2 was rated as more difficult regardless of whether it was metrical or non-metrical. This indicates that the rated difficulty for test 2 in the metrical conditions cannot be attributed to the fact that it is weakly metrical. Rather, difficulty ratings may reflect perceived difficulty of the rhythmic groupings and figural arrangements of events.
Figure 3.7. Difficulty ratings for metrical and non-metrical patterns for musicians (a) and non-musicians (b) for the Training pattern and Tests 1 and 2. Higher ratings indicate greater difficulty ratings. In the metrical condition, the Training pattern was strongly metrical, Test 1 was strongly metrical, and Test 2 was weakly metrical. For the non-metrical condition, patterns are non-metrical versions of the metrical patterns with non-metrical timing deviations. Error bars represent standard error of the mean.

As indicated by the results shown in Figure 3.7, the significant interaction between Metricality and Musical Training could suggest that only musicians rated non-metrical patterns as being more difficult than metrical patterns. To test this hypothesis, musicians and non-musicians were analyzed separately. For non-musicians, there was a main effect of Metricality \([F(1, 6) = 8.23, p = .03, \eta_p^2 = .58]\]. For musicians, there was a significant main effect of Metricality \([F(1, 6) = 126.94, p < .001, \eta_p^2 = .96]\). These results support the hypothesis that non-metrical patterns are rated as more difficult to tap to than metrical patterns for musicians and non-musicians.
3.5.4.4 Metricality Ratings

To examine whether participants were able to subjectively report differences in metrical strength, metricality ratings were analyzed. There was a significant main effect of Metricality \([F (1, 13) = 146.10, p < .001, \eta_p^2 = .92]\), a significant main effect of Pattern \([F (2, 24) = 14.79, p < .001, \eta_p^2 = .55]\), and no main effect of Musical Training \([F (1, 13) = 0.48, p = .50, \eta_p^2 = .04]\). There was a significant interaction between Metricality and Musical Training \([F (1, 13) = 97.37, p < .001, \eta_p^2 = .89]\) but no other interaction was significant \((ps > .25)\). As shown in Figure 3.8, the main effect of Metricality indicated that metrical patterns were rated as more metrical than non-metrical patterns. Pair-wise comparisons on Pattern indicated that the main effect of Pattern was driven by significant differences between test 2 and training \([F (1, 13) = 28.43, p < .001, \eta_p^2 = .69]\), and test 2 and test 1 \([F (1, 13) = 13.63, p = .003, \eta_p^2 = .51]\). Test 2 was rated as less metrical than training and test 1. As test 2 was rated as less metrical than training and test 1 regardless of metricality, these differences cannot be explained by differences in metrical strength.
Figure 3.8. Metricality ratings for metrical and non-metrical patterns for musicians (a) and non-musicians (b) for the Training pattern and Tests 1 and 2. Higher ratings indicate greater metrical strength. In the metrical condition, the Training pattern was strongly metrical, Test 1 was strongly metrical, and Test 2 was weakly metrical. For the non-metrical condition, patterns are non-metrical versions of the metrical patterns with non-metrical timing deviations. Error bars represent standard error of the mean.

To examine the interactions between Metricality and Musical Training, musicians and non-musicians were analyzed separately. For non-musicians, there was a significant main effect of Metricality \( F (1, 6) = 6.85, p = .04, \eta^2_p = .53 \). For musicians, there was also a significant main effect of Metricality \( F (1, 6) = 146.94, p < .001, \eta^2_p = .96 \). Results support the hypothesis that non-metrical patterns were rated as less metrical than metrical patterns for musicians and non-musicians. However, differences between metrical and non-metrical patterns were larger for musicians than for non-musicians.
3.5.5 Discussion

The aim of the Pilot Experiment 3 was to examine differences between metrical and non-metrical patterns in a tapping task and in subjective ratings of tapping difficulty and rhythm metricality. In regards to behavioral data (i.e. tapping variability), both musicians and non-musicians were better at tapping to metrical patterns compared to non-metrical patterns. However, musicians demonstrated a larger difference between metrical and non-metrical patterns than non-musicians. This suggests that musicians may have been more sensitive to non-metrical timing deviations than non-musicians. Tapping variability did not indicate that tapping to a weakly metrical pattern was less precise than tapping to a strongly metrical pattern. This is in disagreement with the results of Patel et al. (2005) who indicated that participants tap more precisely with strongly metrical patterns compared to weakly metrical patterns. Insofar as the tapping data are concerned, there were only differences between the metrical condition and the non-metrical conditions, but no differences between patterns within the metrical and non-metrical conditions.

In line with the objective behavioral data (i.e. tapping data), subjective ratings of difficulty and metrical strength, non-metrical patterns were rated as more difficult and less metrical than metrical patterns for musicians and non-musicians. Subjective data of tapping difficulty and metrical strength differed from the behavioral data in that test 2 pattern was rated as more difficult and less metrical than the other patterns (training and test 1) for musicians and non-musicians. This indicates that differences in ratings were not solely based on metrical strength because test 2 was rated differently from other
patterns in its respected condition (metrical or non-metrical) regardless of whether it was weakly metrical (in the metrical condition) or non-metrical. The differences between the objective behavioral data and the subjective data may suggest differences between the way one perceives and responds to temporal patterns, and the way they subjectively experience the temporal pattern. That is, the beat could be tapped for strongly metrical and weakly metrical patterns with similar precision, but the weakly metrical pattern was still rated as less metrical and more difficult to tap to.

3.5.6 Conclusion

The primary aim of the tapping experiment was to test whether metrical and non-metrical patterns are perceived as being different by musicians and non-musicians, and to ensure that non-metrical patterns are not interpreted as metrical patterns with tempo deviations. The tapping task revealed that non-metrical patterns are indeed perceived as non-metrical. Furthermore, tapping to weakly metrical patterns was just as precise as tapping to strongly metrical patterns. This suggests that weakly metrical patterns were interpreted as metrical. Thus, the set of patterns appear to be suitable to test the implicit learning of metrical and non-metrical patterns.

3.6 Summary

The aim of Pilot Experiments 1, 2, and 3 was to find a suitable set of stimuli and paradigm for Experiments 2a, 2b, 3a, and 3b. The Pilot Experiment 1 indicated that tones emanating from the left headphone, right headphone, or both headphones are perceived as similar if the binaural stimulus is presented with a 4dB reduction in
intensity. Thus, tone location was used for Experiments 2a, 2b, 3a, and 3b as the stimuli in the ordinal dimension, and the cover story was changed to that of a computer game for the blind. Metrical and non-metrical patterns were constructed that had shorter durations, and contained smaller IOIs (no larger than 2000ms) and larger figural groupings (one group of two events, and one group of three events) than those used in Experiment 1. The Pilot Experiments 2 and 3 demonstrated that it is more difficult to abstract a metrical framework for the non-metrical pattern than for the metrical pattern, and that this occurred for musicians and non-musicians. The following chapters report Experiment Sets 2 and 3 that used the stimuli that were tested in this chapter.
Chapter 4

The Implicit Learning of Metrical and Non-metrical Patterns in a Serial Reaction-time Task
Chapter 4 has been accepted for publication:


Note: The formatting, headings, and experiment numbers of the manuscript have been changed in accordance with the formatting of the thesis. The information sheets and consent form (H7764) are in Appendix J. The questionnaire is in Appendix K. Results of linear trend analyses conducted for training blocks are presented in Appendix P. Results of analyses conducted on participants who were identified as implicit learners based on performance in the generation task are presented in Appendix Q. Stimuli and auditory files are in Appendix R (DVD-ROM).
4.1 The Implicit Learning of Metrical and Non-metrical Temporal Patterns

Rhythm surrounds us constantly, whether it is the hum of an oscillating fan or the drum and bass from an mp3-player. Exposure to rhythms allows humans to develop temporal expectancies, that is, knowledge of when something should occur. Temporal expectancies are useful in a range of human activities and interactions such as music, dance, and language. Temporal expectancies can be acquired with an intention to learn (Chapin, et al., 2010) or unintentionally (e.g. Brandon, Terry, Stevens & Tillmann, 2012; Karabanov & Ullén, 2008; Salidis, 2001; Ullén & Bengtsson, 2003). However, how humans unintentionally learn non-verbal rhythms has received little consideration. Furthermore, of the studies that have examined the unintentional learning of rhythm, only a few have demonstrated learning (e.g. Brandon et al., 2012; Karabanov & Ullén, 2008; Salidis, 2001; Ullén & Bengtsson, 2003). The present study has two aims: First, to investigate the conditions under which the implicit learning of temporal patterns can be observed; second, to examine how rhythmic properties of temporal patterns, namely meter, might aid implicit learning.

4.1.1 Implicit Learning of Temporal Patterns

Implicit learning (IL) is learning that occurs unconsciously, unintentionally, and without the ability to show declarative knowledge of what has been learned (Shanks, 2005). IL allows humans to learn complex structures with less effort and attention than deliberate learning (Perruchet & Pacton, 2006; Reber & Lewis, 1977). Temporal patterns are constructed from a series of temporal intervals between subsequent event onsets (Povel & Essens, 1985). A complex temporal pattern is formed through the sequencing of
temporal intervals of varying length. For example, the Morse code signal for “SOS” (· · · — — — · · ·), where intervals between the onsets of short (·) events are half as long as intervals between the onsets of long (—) events, is a temporal pattern that consists of the relative intervals 1-1-1-2-2-2-1-1-1. Ordinal patterns are constructed from an ordered series of movements or stimuli that vary along one or more categorical dimensions (e.g. different spatial locations or different pitches). For example, an ordinal pattern of letters A, B, and C could be A-C-B-C-A-B-C-B.

Few studies have investigated the IL of temporal patterns and, of those that have, most have only shown IL of temporal patterns in the presence of a predictable ordinal pattern (e.g. Buchner & Steffens, 2001; Miyawaki, 2006; O’Reilly, McCarthy, Capizzi, & Nobre, 2008; Shin, 2008; Shin & Ivry, 2002). Those studies have generally used visual stimuli (except Buchner & Steffens, 2001) and have been unable to observe temporal learning when the ordinal pattern is not predictable. In contrast, the studies that have demonstrated IL of temporal patterns in the absence of an ordinal pattern have used auditory-visual stimuli in an immediate recall task (Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003), or auditory stimuli in a stimulus-detection task (Salidis, 2001) or three-alternative forced-choice task with a random ordinal sequence (Brandon et al., 2012). The present study uses auditory stimuli to explore two possible explanations for the mixed results of temporal pattern learning in previous studies: probabilistic uncertainty regarding the identity of upcoming stimuli, and temporal uncertainty regarding inter-onset intervals.
4.1.2 Probabilistic Uncertainty of Stimulus Identities

Previous experiments have used the serial reaction-time task (SRT) to investigate the learning of temporal patterns in the presence of ordinal patterns of tones (Buchner & Steffens, 2001) or visual spatial locations (O’Reilly et al., 2008; Shin, 2008; Shin & Ivry, 2002). In the SRT, participants are presented with sequential stimuli and asked to identify each item as it occurs. Participants are not informed that stimuli follow a repeating pattern. Learning is characterized by decreases in reaction time (RT) over blocks containing the repeating pattern, increases in RT upon introduction of a block containing a random or novel sequence (i.e., a test block), and recovery of RT to pre-test levels when the repeating pattern is reintroduced.

In some SRT studies (O’Reilly et al., 2008; Shin & Ivry, 2002), both the timing and the identities of the stimuli followed a repeating pattern. Independent learning of the temporal pattern was measured by comparing RT increases when the temporal sequence was random but the ordinal pattern was maintained, with RT increases when the ordinal sequence was random but the temporal pattern was maintained. When examining RT increases in test blocks, these studies have found greater RT increases when the ordinal sequence is random compared to when the temporal sequence is random and concluded that temporal patterns cannot be learned in the absence of an ordinal pattern. However, in the SRT (which requires identification of the ordinal events), when the ordinal sequence is random, participants are unable to prepare for the next response because the identity of the stimulus is unpredictable, even if they have knowledge of the temporal pattern. Thus, it is possible that the multiple-alternative forced-choice SRT paradigm
was insensitive to temporal knowledge due to probabilistic uncertainty of the identity of the next stimulus.

Based on probabilistic uncertainty, whenever the ordinal sequence is random, the exhibition of temporal knowledge could be underestimated or masked by uncertainty of the identity of the upcoming stimulus (as suggested by Ullén & Bengtsson, 2003). A task that does not require stimulus identification, such as a stimulus-detection task, might be a more sensitive test of temporal pattern learning. In fact, Salidis (2001) demonstrated IL of temporal patterns using a stimulus-detection task. Salidis, however, used non-musical temporal patterns whereas our present study uses complex musical rhythms.

To examine whether temporal pattern learning occurs when responses are not dependent on the identity of the stimulus, the present study compares a multiple-alternative forced-choice task with a stimulus-detection task. It is hypothesized that IL of temporal patterns occurs more strongly in the absence of probabilistic uncertainty of responding to the identity of the stimulus, that is, in the stimulus-detection task.

4.1.3 Temporal Uncertainty of Inter-onset Intervals

Another possible reason for why temporal pattern learning was not observed in previous studies is that the majority of these studies (e.g. Buchner & Steffens, 2001; Miyawaki, 2006; Shin & Ivry, 2002: Experiment 1) have used patterned response-stimulus intervals. With response-stimulus intervals, the inter-onset interval (IOI) consists of both
the response-stimulus interval itself (controlled by the experimental design) and the RT of the participant (uncontrolled). As IOIs produced by response-stimulus intervals (inclusive of RT) can be variable, participants may have difficulty acquiring temporal expectancies for the onset of events. Musical rhythms, however, consist of fixed IOIs that could facilitate the acquisition of temporal expectancies.

Research into music cognition (e.g. Järvinen & Toiviainen, 2000; Palmer & Krumhansl, 1990) suggests that musical rhythm has properties, such as meter, that aid in the acquisition of temporal expectancies. Rhythm is the “systematic patterning of sound in terms of timing, accent, and grouping” (Patel, 2008, pp. 96). Meter is a cognitive framework that can be abstracted from rhythm. A metrical framework consists of an underlying isochronous (evenly-spaced) pulse that periodically aligns with event onsets at the level of the pulse and equal groupings of pulses (London, 2004). An arrangement of the pulse and pulse groupings is shown in Figure 4.1. The grouping of pulses depends on the meter that is abstracted and how often events correspond with pulses (Lerdahl & Jackendoff, 1983).
Three types of rhythms are described here: strongly metrical (SM), weakly metrical (WM), and non-metrical rhythms (Essens & Povel, 1985; Povel & Essens, 1985). Rhythms are SM if events always occur on the first pulse (i.e., the strong beat) of a group of pulses (also called a measure). Rhythms are WM when events do not always occur on the strong beat, but still often align with the pulse. Lastly, a rhythm is considered non-metrical if events rarely align with the pulse or the strong beat. Examples of SM, WM, and non-metrical rhythms are presented in Figure 4.1. In the SM example, events occur periodically every four pulses. This periodicity is not realized in the WM example. In the case of non-metrical patterns, events rarely fall on pulses and do not occur periodically.
The *dynamic attending theory* (Jones & Boltz, 1989) relates to how temporal expectancies are formed. The dynamic attending theory supposes that attention oscillates over time and that attending oscillations adaptively synchronize to regularities in the timing of external events. This process is called entrainment. The periodic occurrence of events within a metrical framework can induce entrainment, thus strengthening expectancies (and quicken responses) for event onsets that conform to the metrical framework. The *metric binding hypothesis* (Jones, 2009) is an extension of the dynamic attending theory that relates to how meter is learned through exposure to rhythm. While the dynamic attending theory relates to “‘in-the-moment’ expectancies” (Jones, 2009, pp. 83), the metric binding hypothesis posits that when two or more oscillations are concurrently established, the levels of entrainment will eventually bind and form a “metric cluster” (Jones, 2009, pp. 84). Metric clusters consist of multiple concurrent oscillations with continuing associations at various time levels based on bindings. Metric clusters strengthen expectancies to various metrical levels; in other words, expectancies are strengthened in pulse locations, the first pulse of groups, and coincidences of the two.

With repeated exposure to an external rhythm, internal entrainment to the rhythm and the formation of a metrical framework may occur (Large & Jones, 1999). In this way, temporal regularities activate oscillators that guide attention to metrical points in time when a metrical framework is available, and can be momentarily perturbed if an event does not align with the metrical framework. In line with the dynamic attending theory, evidence from sensorimotor synchronization (e.g. Essens & Povel, 1985; Patel et al.,
2005; Povel & Essens, 1985), psychophysical (e.g. Grube & Griffiths, 2009), and neuroscience (e.g. Vuust, Ostergaard, Pallesen, Bailey, & Roepstorff, 2009) research suggests that people have greater difficulty developing temporal expectancies in response to WM and non-metrical patterns compared to SM patterns.

Based on the dynamic attending theory and the metric binding hypothesis, we hypothesized that metrical patterns can be learned more readily than non-metrical patterns. We also hypothesized that, when trained on SM patterns, greater performance decrements occur when a new rhythm with a weaker metrical framework is introduced (i.e., WM patterns) than when the new rhythm maintains the original metrical framework (i.e., a novel SM pattern) (in Experiments 2a and 2b). Such differences were not expected for non-metrical patterns as metric binding cannot occur during training (in Experiment 2b).

4.1.4 Using the Modified Process Dissociation Procedure to Determine Implicit Learning

The SRT assesses whether learning has occurred and how much learning has occurred, but it does not assess whether the newly acquired knowledge is implicit. To ensure that learning in the SRT is implicit, modified versions of the process dissociation procedure (Jacoby, 1991) were used. The process dissociation procedure is a method of assessing whether newly acquired knowledge is implicit that avoids the assumption of process purity, that is, the assumption that performance in a particular task represents one process (Shanks & St. John, 1994). In the process dissociation procedure, each
participant is required to perform a task under two different types of instruction - inclusion and exclusion. The inclusion instruction requires participants to demonstrate knowledge of what has been learned. The exclusion instruction requires participants to suppress knowledge about what has been learned (e.g. completing word stems with different words than those learned in a study phase; Jacoby, Toth, & Yonelinas, 1993). While performance under the inclusion instruction is facilitated by both explicit and implicit processes, performance under the exclusion instruction is facilitated by explicit processes and interfered with by implicit processes. Thus, differences between the two instructions can provide insights into the contribution of implicit and explicit influences.

Initially, the process dissociation procedure involved only a recollection task but several modifications of the process dissociation procedure have since been established (e.g. Destrebecqz & Cleeremans, 2001; 2003). An adaptation of the process dissociation procedure that has been successfully used to ascertain implicit and explicit temporal pattern learning is the free-generation task (Karabanov & Ullén, 2008). In the free-generation task, participants generate patterns under two types of instruction: 1) an inclusion instruction, where participants are asked to reproduce the training pattern, and 2) an exclusion instruction where participants are asked to create new rhythmic sequences. The sequences produced in both tasks are then compared to the pattern learned in the SRT and given similarity scores that reflect how much they resemble the training pattern. If similarity in the inclusion instruction is less than or equal to similarity in the exclusion instruction, then declarative knowledge of the training pattern has not
been shown and learning is implicit. By contrast, higher similarity scores in the inclusion instruction than the exclusion instruction indicate that learning is explicit.

Karabanov and Ullén (2008) demonstrated that similarity was greater in the inclusion instruction compared to the exclusion instruction for an explicit learning condition, but not an implicit learning condition. Thus, the generation task can be used to assess whether learning is implicit. The present study used a generation task and analysis (see Appendix) based on the process dissociation procedure, using the methods of Karabanov and Ullén (2008), to test whether learning was implicit.

4.2 Experiment 2a

The aim of Experiment 2a was to determine whether metrical rhythms can be learned implicitly in an SRT. We investigated whether the IL of (strongly) metrical rhythms is evident in the single response SRT (i.e. stimulus-detection task) compared with the traditional multiple response SRT (i.e. a three-alternative forced-choice task).

4.2.1 Design & Hypotheses

In the SRT, participants completed nine blocks where blocks 1-5, 7, and 9 contained the repeating temporal pattern, and blocks 6 and 8 contained the SM and WM test patterns (the presentation order of test patterns was counter-balanced across participants). Independent variables were Block (1-9; within-subjects), Test block type (SM, WM; within-subjects), and Task (single response, multiple response; between-subjects). Responses were retained if the spatial location was correctly identified (in the multiple
response SRT) and if the response occurred close to the stimulus onset, that is, between 100ms and 850ms for the multiple response SRT, and between -100ms and 650ms for the single response SRT. Dependent variables were proportion of retained responses, RT, improvement of RT over training blocks (i.e., RT difference between first and last training block), and RT increase in test blocks defined as the difference between RT in test blocks and mean RT in adjacent training blocks (Shin & Ivry, 2002).

It is hypothesized that metrical rhythms can be learned implicitly. Learning would be indicated by a decline in RT over training blocks in the SRT. RT increases in test blocks were used to examine whether the rhythmic structure and metrical framework were learned. If the metrical framework is learned, then greater RT increases should occur when the strength of the metrical structure is changed in the WM test block, than when it remains the same in the SM test block. IL is indicated in the generation task if similarity in the inclusion instruction is not greater than similarity in the exclusion instruction. It is also hypothesized that temporal pattern learning should be demonstrated when the task is not affected by probabilistic uncertainty of stimulus identities, indicated by greater RT improvement in the single response SRT compared to the multiple response SRT.

### 4.2.2 Method

#### 4.2.2.1 Participants

Participants ($N = 60$) were first year Psychology students from the University of Western Sydney. Of these students, 12 were male. Ages ranged from 17 to 45 years, with a mean
age of 22.5 years ($SD = 6.70$). No participants reported a hearing impairment and 59 of the participants were right-handed.

### 4.2.2.2 Materials

Sequences consisted of tones constructed from a triangle waveform of 394Hz (200ms duration, 94dB SPL, 10ms rise/decay times) created with MAX-MSP software. The tone was presented through the left channel, the right channel, or both channels, henceforth referred to as “tone location”. Tone location is the stimulus identity in the present study. To prevent effects of binaural summation (Marks, 1978), the presentation through both channels was 4dB less (i.e. 90dB) than monaural presentation. Each block consisted of 24 repetitions of the eight-event pattern (plus one event to complete the final interval) without breaks between patterns, with a total of 193 events per block. Within each block, the order of tone location was pseudorandom so that the frequency of occurrence of each location was equal, no location was repeated twice in a row, and the location frequency was equally distributed over the eight events of a pattern. Different location orders were used for each of the nine blocks. Three different distributions of the nine location orders across blocks were used (counterbalanced across participants). The eight-item patterns (duration 8 seconds) were repeated 24 times to create an auditory file for each block (using MatLab).

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7 An experiment ($N = 12$) was conducted to approximate the point of subjective equality between the loudness of the binaural and monaural stimuli (see Chapter 3). A 4dB reduction in the intensity of the binaural stimulus resulted in more “Same” judgements (than chance) for 11 of the 12 participants.
Temporal patterns were constructed based on the SM and WM patterns of Povel and Essens (1985). Povel and Essens presented a clock model where metrical strength was defined by how often rhythmic accents corresponded with metrical accents. Rhythmic accents are perceptual accents that occur on i) isolated events, ii) on the second event of a group of two events, and iii) on the first and last event of a group of three or more (Povel & Essens, 1985). The clock model measured metrical strength with a counter-evidence score (c-score) where lower scores represented greater metrical strengths. Patterns in the present study were categorically SM and WM as per the clock model with SM patterns (training and test patterns) fitting in the more strongly metrical categories (c-score = 1), and the WM pattern fitting in the more weakly metrical categories (c-score = 4).

The timing of tones occurred according to metrical rhythms based on patterns of IOIs, as shown in Figure 4.2. For example, the SM training pattern in Figure 4.2 refers to an IOI pattern of 500-1500-1000-1000-500-500-1000-2000. Patterns in Experiment 2a consisted of three 500ms IOIs, three 1000ms IOIs, one 1500ms IOI, and one 2000ms IOI. Patterns maintained simple frequency information as outlined by Reed and Johnson (1994). Simple frequency information refers to statistical features of patterns that follow second-order conditional probabilities. Namely, these features are the item frequency (the number of times an IOI occurs in a pattern), transition frequency (the number of times a pair of items occur in the same order), the rate of full coverage (the average number of items necessary to view each unique IOI in the pattern at least once), and the
rate of full transition usage (the average number of items necessary to view each transition at least once).

Figure 4.2. Pulses (short vertical lines), strong beats (long vertical lines), and events (crosses) of the metrical (SM Training, SM Test 1, WM Test 2) and non-metrical (NM Training, NM Test 1, NM Test 2) temporal patterns used in the present study. Metrical patterns were used in Experiments 2a and 2b and non-metrical patterns were only used in Experiment 2b.

These features were maintained for the SM training, SM test (except for rate of full coverage), and WM test patterns. Furthermore, the number of changes to higher order conditional probabilities (i.e., third-, fourth-, fifth-order conditional probabilities and higher) was kept constant between the training block and SM and WM test blocks. Control of these features is important so that RT increases in test blocks cannot be
attributed to changes in simple frequency information (i.e., not to changes in surface statistical features) but, instead, to changes in metrical and rhythmic features.

It should also be noted that the size of rhythmic groupings (i.e. groups of two or three proximal events) were kept constant between patterns in the training block and test blocks, while the order in which groups occurred changed. This means that RT increases in test blocks cannot be attributed to differences in motor demands or grouping differences related to changes in the sizes of groups of temporally proximal events.

The SRT consisted of five blocks containing the SM training pattern followed by the SM or WM test pattern in the sixth and eighth blocks (the test block). The order in which the test blocks were introduced (i.e. first SM then WM, or first WM then SM) was counterbalanced over participants. The training pattern was reintroduced in the seventh and ninth blocks. Each block had a duration of 3.12 minutes. A 15s break occurred between blocks.

Auditory stimuli were presented through Sennheiser headphones using Edirol UA-25EX sound drivers. PsyScope (Cohen, MacWhinney, Flatt, & Provost, 1993) software (installed on Macbook Pros) was used to present the auditory file and collect responses.

4.2.2.3 Procedure

Participants were given an information sheet that provided the cover story of a computer game for the blind where they would hear a sound from the left, right, or both
headphones. The cover story was used to promote IL and reduce awareness of temporal patterns. After reading the information sheet and signing the consent form, participants were seated in front of the computer and received instructions that related to the specific condition. Participants in the multiple response SRT were asked to use keys “1”, “2”, and “3” on the number pad to respond to the left channel, both channels, or right channel, respectively. Keys were labeled according to stimulus identity and participants were able to view these labels at all times. Participants in the single response SRT were asked to press the “0” key every time they heard a beep regardless of which channel(s) the sound came from. Prior to the blocks, there was a practice block that contained approximately four repetitions of a different WM pattern (with duration of 30s). Following the practice, the SRT commenced.

After the SRT, participants were asked if they: 1) noticed anything peculiar in the SRT, or 2) noticed any regularity in the SRT, and to write down the peculiarities or regularities they noticed (Karabanov & Ullén, 2008; Shin & Ivry, 2002; Ullén & Bengtsson, 2003). These responses were coded according to whether participants reported a timing regularity/rhythm or not. Any terminology that reflected a timing regularity (e.g. rhythm, timing pattern, regular timing) was accepted as an indication of awareness of the temporal pattern. Then participants completed the generation task. The order of Instruction (inclusion and exclusion) within the generation task was counterbalanced across participants.
In the generation task, participants were to generate sequences by tapping the “0” key. The binaural tone used in the SRT was presented for each key-press. In the inclusion instruction, participants were asked to reproduce the temporal patterns from the SRT. The exclusion instruction required participants to create new temporal patterns that are different from those in the SRT, but use the same number of beeps and the same groups of beeps (e.g. groups of one, two, three, etc.). This instruction was given to prevent participants from producing isochronous temporal sequences in the exclusion instruction. Participants were instructed to produce the pattern at least twice, were given 20s for each attempt, and five attempts overall. Experiment sessions did not exceed 60 minutes.

4.2.2.4 Data Analysis

Only RTs to correct responses were analyzed. In each block, the response to the first item was removed. Responses that were inaccurate, early (multiple response task < 100ms; single response task < -100ms), or late (multiple response task > 850ms; single response task > 650ms) were removed. As only one response was possible for the single response condition, proportion of retained responses for the single response condition only reflects the percentage of responses that fell within the window -100ms to 650ms. Anticipatory responses were allowed for the single response condition because participants were able to predict when a stimulus should occur (as in O’Reilly et al., 2008; Shin & Ivry, 2002). To examine rate of learning in the SRT, we compared RT.

A number of different thresholds for early and late responses were implemented for the multiple response and single response conditions. These thresholds were chosen in order to maximise the number of responses retained. Using other thresholds did not greatly affect the pattern of RT, but it did result in decreases in the proportion of retained responses in the single response condition when anticipatory responses occurred. No such anticipatory responses were evident in the multiple response condition.
improvement over training blocks (i.e., the difference between the first and fifth block) between the single response and multiple response SRT. To assess differences between SM and WM test blocks, the dependent variable RT increase (calculated as the RT difference between the mean of adjacent training blocks and the test block) was used with Test block Meter (SM, WM) as a within-subjects independent variable and Task (single response, multiple response) as a between-subjects independent variable. For the generation task, similarity was compared between Instruction (inclusion, exclusion; within-subjects) and between Task (single response, multiple response; between-subjects).

4.2.3 Results

Two participants in the multiple response group were excluded due to more than 33% of responses being inaccurate, early, or late. To ensure the sample only contained implicit learners, participants who reported a timing regularity or rhythm in the free verbal reports were excluded from the analysis. However, it should be mentioned that previous studies have suggested that verbal reports are an insensitive measure of IL (Karabanov & Ullén, 2008; Shanks & St John, 1994). The remaining sample consisted of 19 participants in the single response condition (of 25 participants) and 30 participants in the multiple response condition (of 35 participants).
4.2.3.1 The Serial Reaction-time Task

4.2.3.1.1 Proportion of retained responses

A repeated measures ANOVA was conducted on the proportion of retained responses with Block (1-9) as a *within-subjects* variable, and Task (single response, multiple response) as a *between-subjects* variable. There was a significant main effect of Task \(F(1, 47) = 42.97, p < .001, \eta^2_p = 0.48\] indicating that fewer responses were retained in the multiple response condition \((M = .71, SD = .17)\) than the single response condition \((M = .94, SD = .06)\). No significant main effect of Block \(F(8, 376) = 0.69, p = .70, \eta^2_p = 0.01\] or interaction between Block and Task \(F(8, 376) = 0.88, p = .53, \eta^2_p = 0.02\] was evident.

4.2.3.1.2 Reaction time

A repeated measures ANOVA was conducted on RT with Block (1-9) as a *within-subjects* variable, and Task (single response, multiple response) as a *between-subjects* variable. Only RTs for correct responses were considered in the analysis. The main effect of Block \(F(8, 376) = 8.37, p < .001, \eta^2_p = 0.15\] and Task \(F(1, 47) = 338.08, p < .001, \eta^2_p = 0.88\] was significant, as was the interaction between Block and Task \(F(8, 376) = 4.61, p = .003, \eta^2_p = 0.09\]. The main effect of Task reflects that RTs were slower for the multiple response SRT than for the single response SRT. The interaction between Block and Task reflects that there were differences in the pattern of RT over blocks between single response and multiple response tasks.
To test the hypothesis that learning is more evident in the single response SRT than in the multiple response SRT, RT improvement over training blocks (i.e., the difference between blocks 1 and 5) was calculated for each participant. A significant main effect of Task was evident $[F (1, 47) = 19.27, p < .001, \eta^2_p = 0.29]$ with RT improvement for the single response condition ($M = 67.10, SD = 62.28$) being significantly greater than that of the multiple response condition ($M = 8.01, SD = 31.79$). RT improvement for the single response condition differed significantly from zero $[t (18) = 4.70, p < .001]$ and RT improvement for the multiple response condition was not significantly different from zero $[t (29) = 1.38, p = .18]$. This suggests that the single response SRT demonstrated stronger learning than the multiple response SRT (see Figure 4.3)\(^9\).

To test the hypothesis that metrical patterns are learned, RT differences between test blocks (SM, WM) and the mean RT of adjacent blocks (preceding and following blocks) were examined in a repeated measures analysis of variance with Test block type as a within-subjects factor and Task as a between-subjects factor. Main effects were significant for Test block type $[F (1, 46) = 34.80, p < .001, \eta^2_p = 0.43]$ and Task $[F (1, 46) = 19.86, p < .001, \eta^2_p = 0.30]$, and a significant interaction was evident between Test block type and Task $[F (1, 46) = 12.02, p = .001, \eta^2_p = 0.21]$. One-sample $t$-tests revealed that RT increases were significantly greater than zero in the single response SRT for both SM ($p = .03$) and WM ($p < .001$) test blocks. The multiple response SRT did not show a significant RT increase for the SM test block ($p = .98$), but demonstrated

\(^9\) Linear trend analyses were also conducted for the five training blocks for the single response and multiple response tasks (see Appendix P, Table P1). The linear trend analyses corroborated the results reported here: learning was evident in the single response task $[F (1, 18) = 18.08, p < .001, \eta^2_p = 0.50]$ but not the multiple response task $[F (1, 29) = 1.64, p = .21, \eta^2_p = 0.05]$. 

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a significant RT increase for the WM Test block \((p = .004)\). Planned comparisons for Test block type (SM, WM) were conducted for the single response and multiple response tasks. As shown in Figure 4.3b, in the single response SRT, RT increases were significantly greater for the WM test block than for the SM test block \([F (1, 24) = 10.23, p = .004, \eta_p^2 = 0.30]\). Similarly, in the multiple response SRT, RT increases were significantly greater for the WM test block than for the SM test block \([F (1, 30) = 5.76, p = .02, \eta_p^2 = 0.16]\).

**Figure 4.3.** Results from the SRT in Experiment 2a. 3a) Mean RT (correct responses only) for the single response and multiple response conditions over blocks. Blocks 1-5 contain the training pattern. Error bars represent standard error of the mean. 3b) Mean RT increases between the test block and the mean of the adjacent blocks for strongly metrical and weakly metrical test blocks in the single response and multiple response conditions. Error bars represent standard error of the mean.
4.2.3.2 Generation Task

Similarity scores between the IOI sequence generated by participants and the IOI sequence of the training pattern were calculated by comparing the sequences generated under inclusion and exclusion instructions with the pattern from the training blocks. To adjust for differences in tempo, the generated IOIs were normalized so that the shortest IOI was equal to 500ms (i.e., the shortest IOI of the training pattern). A generated interval was considered correct if it was within +/-30% of the training pattern interval and occurred in the correct position of the pattern, that is, in the correct order. To account for the use of different starting positions, a similarity score was calculated using each possible starting point of the generated sequence and the maximum score was used in analyses (see Appendix L).

Similarity scores in the generation task were analyzed using a 2 x 2 repeated measures ANOVA with Instruction (inclusion, exclusion) as a within-subjects factor and Task as a between-subjects factor. There was no significant main effect of Instruction \([F(1, 47) = 0.06, p = .80, \eta_p^2 = 0.001]\), no significant main effect of Task \([F(1, 47) = 0.30, p = .59, \eta_p^2 = 0.006]\), and no significant interaction between Instruction and Task \([F(1, 47) = 0.20, p = .68, \eta_p^2 = 0.004]\) (see Figure 4.4). This suggests that learning in the SRT was implicit. Performance under both Instructions and for both Tasks was significantly greater than chance (estimated at .27; see Appendix L) \((ps < .001)\) indicating that participants were not responding randomly and were able to reproduce some part of the
pattern under the inclusion instruction, and were unable to suppress learned knowledge in the exclusion instruction\(^\text{10}\).

*Figure 4.4.* Similarity scores (between the training and produced patterns) in the inclusion and exclusion instructions of the generation post test for the single response and multiple response conditions. Error bars represent standard error of the mean. The dashed line represents chance levels (.27) as determined by a pseudo-random number generator (see Appendix L).

### 4.2.3.3 Reports of Awareness

In the single response condition, six participants reported awareness of a timing regularity or rhythm and 19 participants did not reported awareness of a temporal pattern. In the multiple response condition, three participants reported awareness of a timing regularity or rhythm and 30 participants did not report awareness of a temporal pattern.

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\(^{10}\) Reaction times were also analysed for participants who produced smaller similarity scores under the inclusion instruction than in the exclusion instruction (see Appendix Q, Table Q1). Results did not significantly differ from those reported here, with the exception that the main effect of Task for improvement (i.e., the RT difference between the first and last block) went from significant \([F(1, 47) = 19.27, p < .001, \eta_p^2 = 0.29]\) to near significant \([F(1, 25) = 3.50, p = .07, \eta_p^2 = 0.13]\).
pattern. When the above analyses were conducted including participants who reported awareness of the temporal pattern, similar results to those reported above were obtained.

4.2.4 Discussion

Experiment 2a demonstrated IL of metrical patterns in the single response SRT but evidence for learning was not as strong in the multiple response SRT. Only the single response SRT demonstrated a significant RT decrease over training blocks, and significant RT increases in both test blocks. The multiple response SRT did not demonstrate a significant RT decrease over test blocks and only showed a significant RT increase for the WM test block (but not for the SM test block). In the generation task, no differences in similarity scores were demonstrated between inclusion and exclusion instructions. This indicated that learning that occurred in the single response and multiple response SRT (if any) was implicit.

Overall, weaker evidence of learning was indicated in the multiple response SRT compared with the single response SRT, probably due to probabilistic uncertainty of the identity of upcoming stimuli in the multiple response SRT. The results of Experiment 2a support the hypothesis that responding to the identity of an uncertain stimulus prevents temporal learning or may underestimate learning. As participants could not anticipate the identity of the next stimulus in the multiple response SRT, RTs were less sensitive to the learning of the temporal pattern. Thus, the IL of temporal patterns may not have been demonstrated in previous studies (e.g. Miyawaki, 2006; O’Reilly et al., 2008; Shin, 2008; Shin & Ivry, 2002) due to the use of a multiple response SRT (or multiple-
alternative forced-choice task). In these studies, blocks containing random ordinal sequences may have prevented RTs from reflecting learned knowledge of the temporal pattern. In other words, decision times in a multiple-alternative forced-choice task with uncertain identities may obscure or prevent the learning of temporal patterns.

In light of probabilistic uncertainty, it is likely that the acquisition of temporal expectancies is evident in tasks where stimulus-identification is not the primary focus. The process of identifying stimuli may mediate response speed as a result of responding to an unpredictable identity, even if the timing is predictable. This resulted in a lack of robust RT decreases over blocks in the multiple response SRT that did not show learning over blocks (beyond, perhaps, task learning). This suggests that the learning of temporal patterns occurs in pure speed tests more than multiple-alternative forced-choice paradigms where the identity cannot be anticipated, at least insofar as the SRT is concerned. The results of Experiment 2a suggest that the SRT is sensitive to temporal learning when the task is not reliant on stimulus identification.

Experiment 2a provides evidence for why the previous study using a stimulus-detection task (Salidis, 2001) was somewhat successful in ascertaining temporal learning; the stimulus-detection task used was not dependent on stimulus identities. Thus, RT more adequately reflected temporal pattern learning. The study by Salidis showed IL of temporal patterns consisting of a symmetrical pattern of response-stimulus intervals (e.g. short-medium-short-long-medium-long). In the present study, Experiment 2a
demonstrates IL of complex rhythmic patterns consisting of IOIs using a stimulus-detection task.

In the single response SRT (and multiple response SRT), RT increases were greater for WM test blocks than for SM test blocks. This can be viewed as evidence for the metric binding hypothesis: expectancies to metrical temporal locations were strengthened over training blocks allowing speeded responses to upcoming events. When expectancies were violated in the WM test block, expectancies were forced to be revised in accordance with the weaker metrical framework, resulting in slowed responses to upcoming events. In contrast, metrical expectancies were not violated in the SM test block and this facilitated the processing and detection of upcoming events even though the temporal pattern was new. This is in line with the notion of attentional oscillators attuning to the temporal pattern and guiding attention to expected points in time. In this way, perceivers could anticipate and efficiently process upcoming events. Furthermore, metric binding increased expectancy at periodic or metrical points in time as indicated by larger performance decrements when the metrical framework was changed, than when the metrical framework was maintained.

Results of Experiment 2a support the hypothesis that metrical patterns can be implicitly learned. The acquisition of temporal expectancies was demonstrated and learning was possibly facilitated by the metrical framework as implied by the dynamic attending theory (Jones & Boltz, 1989). The hypothesis that greater performance decrements occur when a new temporal pattern with a weaker metrical framework is introduced (i.e., the
WM test pattern) than when the new temporal pattern maintains the original strength of the metrical framework (i.e., the SM test pattern) was supported. This provides partial support to the metric binding hypothesis (Jones, 2009). However, to ensure that these differences are attributable to metric binding and not to baseline differences between SM and WM test patterns, a comparison of metrical and non-metrical patterns is required, as done in Experiment 2b.

4.3 Experiment 2b

The first aim of Experiment 2b was to compare the IL of strongly metrical and non-metrical rhythms. According to the dynamic attending theory, events that conform to a periodic or metrical framework should correspond to moments of high expectancy. Thus, once a metrical framework has been abstracted, faster responses should occur for metrical patterns compared to non-metrical patterns.

A secondary aim was to test the metric binding hypothesis by examining whether differences between SM and WM test blocks are attributable to metric binding. Non-metrical versions of the SM training pattern and SM and WM test block patterns were constructed (i.e., NM training, NM test 1 and NM test 2, respectively). Non-metrical patterns matched the metrical patterns in regards to figural groupings and statistical structure, but used IOIs with complex integer ratios to prevent periodic alignment with metrical frameworks. According to the metric binding hypothesis, this should prevent metric binding in the non-metrical condition. By comparing the effects of test blocks in metrical and non-metrical conditions, one can examine whether differences between SM
and WM test blocks occurs as a result of metric binding. If differences between test 1
and test 2 exist for both metrical and non-metrical patterns, then disruptions cannot be
attributable to metric binding and may, instead, be attributable to baselines differences
between test patterns 1 and 2. If, however, the RT increases do not differ between non-
metrical test blocks that were matched with the SM and WM test blocks in all aspects
except for the presence of meter, then differences between SM and WM test blocks in
the metrical condition must be due to metric binding.

The design was identical to that of Experiment 2a except that Metricality (i.e., metrical,
non-metrical) was examined as a between-subjects factor. As results of Experiment 2a
indicated that learning is better demonstrated in the single response SRT than the
multiple response SRT, the single response task was used. The metrical condition in
Experiment 2b is a replication of the single response condition of Experiment 2a. As in
Experiment 2a, the dependent variables were proportion of retained responses, RT, RT
improvement over training blocks, and RT increase in test blocks (Shin & Ivry, 2002).

Based on previous experiments on the IL of temporal patterns, it was hypothesized that
metrical (Brandon et al., 2012) and non-metrical (Salidis, 2001) temporal patterns can be
implicitly learned. Based on the dynamic attending theory (Jones & Boltz, 1989), it was
hypothesized that temporal expectancies are acquired more readily for metrical rhythms
than non-metrical temporal patterns. As per the metric binding hypothesis, it was
hypothesized that larger RT increases occur in the WM test block compared to those in
the SM test block in the metrical condition. Differences between the non-metrical
versions of SM and WM test blocks are not anticipated in the non-metrical condition as metric binding should not be possible.

4.3.1 Method

4.3.1.1 Participants

Participants (\( N = 51 \)) were first year Psychology students from the University of Western Sydney who had not participated in Experiment 2a. Of these, 11 were male. Ages ranged from 17 to 54 years, with a mean age of 22 years (\( SD = 6.60 \)). No participant reported a hearing impairment and 46 of the participants were right-handed.

4.3.1.2 Materials

Metrical patterns were identical to those of Experiment 2a. Non-metrical patterns were constructed based on the metrical patterns, but used IOIs with complex integer ratios. The use of complex integer ratios results in temporal patterns that are not conceivable in terms of a metrical framework (Essens & Povel, 1985). Furthermore, as in Essens and Povel (1985), only the between-group IOIs (i.e. IOIs greater than 500ms) were manipulated, but the within-group IOI (i.e. 500ms IOI) was maintained. As shown in Figure 4.2, the rhythmic groupings for all patterns in the non-metrical condition were identical to those in the metrical condition. However, the non-metrical patterns consisted of three 500ms IOIs, three 1100ms IOIs, one 1350ms IOI, and one 1850ms IOI. These intervals were chosen so that events in non-metrical patterns rarely aligned with any metrical framework, and that timing deviations were larger than the just noticeable
difference (2.5% of the pulse, for the tempi of our patterns; Friberg & Sundberg, 1995).  

4.3.1.3 Procedure

The procedure was identical to that of the single response SRT and generation task in Experiment 2a except for the addition of non-metrical patterns in the non-metrical condition.

4.3.2 Results

4.3.2.1 The Serial Reaction-time Task

Data were analyzed in the same way as the single response condition in Experiment 2a. Participants who reported awareness of a temporal pattern or rhythm in free verbal report were excluded from analysis. The final sample consisted of 18 participants (of 25) in the metrical condition, and 20 participants (of 26) in the non-metrical condition.

A finger tapping experiment (N = 11) was conducted to examine whether participants were sensitive to differences between metrical and non-metrical patterns. Seven participants were considered musically trained, with more than five years of musical training (M = 12.00, SD = 5.97); three others had received no training, and one other had received two years of informal training. Participants were presented with the metrical (SM training, SM test 1, and WM test 2) and non-metrical (NM training, NM test 1, NM test 2) patterns and were instructed to tap the perceived beat. Patterns were presented eight times each (each starting from a different interval in the pattern), and the order of patterns was randomized. In trials, the pattern was cycled continuously until the participant produced 54 taps. There was a significant difference between metrical and non-metrical patterns in regards to standard deviations of inter-tap intervals [F(1, 9) = 22.14, p = .002, ηp² = 0.74], with larger standard deviations for non-metrical patterns (M = 32.76, SEM = 2.54) compared to metrical patterns (M = 24.04, SEM = 1.29). However, there were no differences between the training pattern and test patterns 1 and 2 for metrical or non-metrical conditions. These results suggest that metrical patterns were interpreted as metrical regardless of whether they were strongly or weakly metrical.
4.3.2.1.1 Proportion of retained responses

A repeated measures ANOVA was conducted on the proportion of retained responses with Block (1-9) as a within-subjects variable, and Metricality (metrical, non-metrical) as a between-subjects variable. There was a near-significant effect of Block \( F(8, 288) = 1.72, p = .09, \eta_p^2 = 0.05 \), no significant main effect of Metricality \( F(1, 36) = 0.35, p = .56, \eta_p^2 = 0.01 \), and no interaction between Block and Metricality \( F(8, 288) = 0.54, p = .83, \eta_p^2 = 0.02 \). The near-significant main effect of block reflects that the proportion of retained responses decreased in the test blocks compared to other blocks. Overall, there were no differences in the proportion of retained responses between metrical \( M = .94, SD = .07 \) and non-metrical \( M = .93, SD = .09 \) conditions.

4.3.2.1.2 Reaction time

A repeated measures ANOVA was conducted on RT with Block (1-9) as a within-subjects variable, and Metricality (metrical, non-metrical) as a between-subjects variable. The main effect of Block was significant \( F(8, 288) = 12.00, p < .001, \eta_p^2 = 0.25 \), but there was no main effect of Metricality \( F(1, 36) = 1.23, p = .27, \eta_p^2 = 0.03 \) or significant interaction between Block and Metricality \( F(8, 288) = 0.78, p = .62, \eta_p^2 = 0.02 \). This suggests that RT decreased over training blocks and increased in test blocks regardless of Metricality (see Figure 4.5).
Figure 4.5. Results of the SRT in Experiment 2b. 4.5a) Mean RT (correct responses only) for the metrical and non-metrical conditions over blocks. Error bars represent standard error of the mean. 4.5b) Mean RT increases for tests 1 and 2 in the metrical and non-metrical conditions. In the metrical condition, test 1 was strongly metrical (SM) and test 2 was weakly metrical (WM). In the non-metrical condition, tests 1 and 2 were non-metrical versions of the patterns in the metrical condition. Error bars represent standard error of the mean.

To test the hypothesis that metrical and non-metrical temporal patterns were learned, RT improvement was calculated for RT over training blocks (i.e. the difference between blocks 1 and 5) for each participant. RT improvement was then compared in a two-way ANOVA with Metricality as the between-subjects factor. No significant main effect of Metricality was evident \( [F(1, 36) = 0.30, p = .59, \eta^2_p = 0.01] \) with RT improvement for the metrical condition \( (M = 67.33, SD = 75.82) \) not differing significantly from that in the non-metrical condition \( (M = 54.47, SD = 69.21) \)\(^{12}\). RT improvement was significantly

\(^{12}\) A measure of slope that included the gradient across all five data points was also calculated and subjected to these analyses. Results replicated the same data pattern as those reported here.
different to zero for the metrical \([t (17) = 3.77, p = .002]\) and non-metrical conditions \([t (19) = 3.52, p = .002]\). This confirms that learning was evident for both the metrical and non-metrical conditions, but that metrical patterns were not learned more readily than non-metrical patterns (see Figure 4.5a)\(^{13}\).

To test for structure learning of the temporal patterns, RT increases between the test block and the mean of adjacent blocks were examined in a repeated measures analysis of variance with Test block type (test 1, test 2) as a within-subjects factor and Metricality as a between-subjects factor. There was a main effect of Test block type \([F (1, 36) = 4.75, p = .04, \eta_p^2 = 0.12]\), no main effect of Metricality \([F (1, 36) = 1.14, p = .29, \eta_p^2 = 0.03]\), and a significant interaction between Test block and Metricality \([F (1, 36) = 5.46, p = .03, \eta_p^2 = 0.13]\).

Planned comparisons revealed that, for the metrical condition, RT increases were significantly smaller in test 1 (SM) \((M = 25.08, SD = 79.88)\) than in test 2 (WM) \((M = 67.81, SD = 74.53)\) \([F (1, 17) = 7.18, p = .02, \eta_p^2 = 0.30]\). In the metrical condition, test 1 (SM) did not show a significant RT increase \([t (17) = 1.33, p = .20]\) but test 2 (WM) demonstrated a significant RT increase \([t (17) = 3.86, p = .001]\). For the non-metrical condition, there was no significant difference in RT increase between test 1 \((M = 29.23, SD = 39.55)\) and test 2 \((M = 27.76, SD = 33.23)\) \([F (1, 19) = 0.19, p = .89, \eta_p^2 = 0.001]\). The non-metrical condition demonstrated significant RT increases for test 1 \([t (19) =

\(^{13}\) Linear trend analyses were also conducted for the five training blocks for the metrical and non-metrical conditions (see Appendix P, Table P1). The linear trend analyses corroborated the results reported here: learning was evident in both the metrical \([F (1, 17) = 13.59, p = .002, \eta_p^2 = 0.44]\) and the non-metrical condition \([F (1, 19) = 9.73, p = .006, \eta_p^2 = 0.34]\).
3.31, \( p = .004 \) and test 2 \( t (19) = 3.74, \ p = .001 \)^14. These results indicate that metric binding occurred for the metrical group, as disruptions to the metrical framework in test 2 (WM) resulted in greater RT increases than when the metrical framework was maintained in test 1 (SM). It is in line with our predictions that no significant differences between test 1 and test 2 were evident for the non-metrical condition as there was no metrical framework to disrupt (see Figure 4.5b).

### 4.3.2.2 Generation Task

Similarity scores in the generation task were analyzed using a 2 x 2 repeated measures ANOVA with Instruction (inclusion, exclusion) as a *within-subjects* factor and Metricality as a *between-subjects* factor. The generation task demonstrated no significant effects for Instruction \( F (1, 36) = 0.13, \ p = .72, \ \eta^2 = 0.004 \), Metricality \( F (1, 36) = 1.04, \ p = .31, \ \eta^2 = 0.03 \), or the interaction between Instruction and Metricality \( F (1, 36) = 0.10, \ p = .72, \ \eta^2 = 0.003 \). As in Experiment 2a, results of the generation task indicate that learning in the SRT was implicit (see Figure 4.6). Performance was significantly above chance for both tasks in both conditions \( (ps < .001) \) demonstrating that participants could reproduce parts of the temporal pattern in both metrical and non-metrical conditions under inclusion and exclusion instructions\(^1\)

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^14 Raw RT reflects that performance in test 2 was similar for metrical \( M = 255ms, SD = 35.38 \) and non-metrical \( M = 244ms, SD = 53.04 \) conditions. The metrical condition demonstrated faster RT in the adjacent blocks, resulting in a larger RT increase in test 2 (WM).

^15 Reaction time was also analysed for participants who produced smaller similarity scores under the inclusion instruction than in the exclusion instruction (see Appendix Q, Table Q2). Results in training blocks did not significantly differ from those reported here. However, the interaction between Metricality and Test Block Type was not significant \( F (1, 23) = 0.25, \ p = .78, \ \eta^2 = 0.02 \). It is possible that the smaller group sizes for this subgroup (especially for the metrical condition, which drove the interaction; metrical \( N = 11 \), non-metrical \( N = 13 \) ) reduced the power required to detect an interaction effect.
Figure 4.6. Similarity scores in the inclusion and exclusion instructions of the generation post test for the metrical and non-metrical conditions. Error bars represent standard error of the mean. The dashed line represents chance levels as determined by a pseudo-random number generator (see Appendix L).

4.3.2.3 Reports of Awareness

In the metrical condition seven participants reported awareness of a timing regularity and 18 did not report awareness of the temporal pattern. In the non-metrical condition, six participants reported awareness of a timing regularity and 20 did not report awareness of the temporal pattern. Analyses that included participants who reported awareness of the temporal pattern did not produce results that differed substantially from those reported above. However, it should be noted that a main effect of Block for the proportion of retained responses became significant \( F(8, 392) = 2.78, p = .005, \eta^2_p = 0.05 \]. This main effect reflected decreases in the number of retained responses in tests 1 and 2.
4.3.3 Discussion

The results of Experiment 2b show that temporal expectancies are acquired for metrical and non-metrical temporal patterns, that is, both are learned. Exposure to the temporal patterns in training blocks allowed participants to form more precise expectancies for upcoming events, thus speeding responses. The generation task indicated that this learning was implicit. The results support the hypothesis that metrical and non-metrical temporal patterns can be implicitly learned in the absence of an ordinal pattern (i.e. the sequence of tone locations here were random). Results for the metrical condition replicated those found in the single response condition in Experiment 2a: RT decreased over training blocks, RT increases were greater in the WM test block than in the SM test block, and the generation task indicated that learning was implicit.

The hypothesis that temporal expectancies are acquired more readily for metrical patterns than for non-metrical patterns was not supported. In light of the dynamic attending theory (Jones & Boltz, 1989), it is possible that with repeated exposure to the non-metrical pattern, attending oscillations were able to adapt and synchronize to local periodic timings such as in rhythmic groups and when an inter-onset interval occurs more than once, consecutively. In this way, expectancies may have been guided to points in time without the occurrence of metric binding or the utilization of a periodic pulse on a more global level.

A difference between SM and WM test blocks was evident for the metrical condition, but not between non-metrical versions of the SM and WM test blocks for the non-
metrical condition. This suggests that in the metrical condition metric binding occurred (Jones, 2009), thus expectancies were strengthened for events occurring in metrical (i.e. periodic) locations. Furthermore, when a metrical framework persists for a novel metrical pattern, the extrapolated expectancies are utilized and RT increases are not as large. This is in line with the metric binding hypothesis: entrainment to the metrical structure of the metrical pattern can occur and strengthen temporal expectancies for upcoming events. However, when temporal expectancies to metrical locations were violated (i.e. the WM test block) participants could not use the same metrical structure to facilitate responses to the new metrical pattern.

The non-metrical pattern did not contain events on metrically salient points, so metric binding was not possible. The lack of a difference between RT increases in test 1 and test 2 for the non-metrical pattern suggests that expectancies were not based on a periodic or metrical framework. Thus, the metrical condition indicated that temporal expectancies were based on metric binding whereas the non-metrical condition demonstrated that a metrical structure could not be abstracted. However, learning of the non-metrical patterns still occurred.

Overall, results suggest that while metric binding only occurs when a metrical framework can be abstracted, temporal expectancies to temporal patterns may be implicitly acquired with similar effectiveness regardless of the presence or absence of meter. However, the manner in which temporal expectancies are acquired appears to be
different depending on the presence or absence of meter, that is, metric binding occurred in the metrical condition but not the non-metrical condition.

4.4 General Discussion

Two experiments demonstrated the learning of complex metrical and non-metrical patterns in an SRT, and provided evidence that this learning was implicit. Experiment 2a demonstrated that IL of metrical patterns is evident in a single response SRT, but less so in the multiple response SRT where probabilistic uncertainty might obscure learning. Thus, the single response SRT is a useful method for revealing IL of temporal patterns, as this paradigm more directly measures the development of temporal expectancies and the impedimentary effects of violating these expectancies.

Experiment 2b demonstrated that metrical and non-metrical patterns can be implicitly learned but that metrical patterns are not learned more readily or more effectively than non-metrical patterns. However, differences between SM and WM test blocks still occurred for metrical patterns. The rhythmic groupings and rhythmic complexity were equivalent for metrical and non-metrical patterns for training and test blocks. Thus, this result suggests that metric binding only occurred when a metrical framework was available (i.e. in the metrical condition). As hypothesized, metric binding was not indicated when no metrical framework was available (i.e. in the non-metrical condition) even though other rhythmic aspects were maintained, such as interval sizes and the size of groups of temporally proximal events.
It might be argued that differences between the metrical and non-metrical patterns in the present study were too subtle to evoke significantly different responses. In other words, although the non-metrical patterns were mathematically non-metrical, they may have been perceived as categorically metrical (Clarke, 1987) or as metrical patterns performed with expressive timing (Repp, 1990). This is congruent with Handel (1998, pp. 1546) who states that “each rhythm is metric to some degree, depending on the strength of the meter interpretation it evokes.” However, in the present study there was no evidence of metric binding in the non-metrical condition (i.e. no difference between non-metrical versions of the SM and WM test blocks). Thus, it is unlikely that the non-metrical pattern was interpreted as metrical.

In line with the present findings, there is evidence that timings that deviate from metrical frameworks can be imitated (albeit, explicitly) with some precision (Clarke, 1993). Such timing deviations could be interpreted as the speeding or slowing of a pattern in order to fit the pattern to a metrical framework. Large, Fink, and Kelso (2002) found evidence that participants are able to synchronize with and adapt to metrical patterns that contain phase and tempo perturbations. Similarly, the present study found evidence that the learning of non-metrical patterns may involve a flexible and adaptive mechanism when timing deviations are predictable.

In contrast with the dynamic attending hypothesis, no differences in the rate of learning were evident between metrical and non-metrical patterns even though average RT in the metrical condition were (non-significantly) faster than in the non-metrical condition. The
lack of a difference between metrical and non-metrical pattern learning may reflect that, for the non-metrical group, attentional oscillators were able to adapt and synchronize to the timing pattern even though the timings were not metrical (Large 2008; Large et al., 2002). Although the learning of non-metrical patterns may seem surprising, it is in line with previous evidence of temporal pattern learning using response-stimulus intervals (Salidis, 2001). However, the patterns used by Salidis were simple symmetrical temporal patterns composed of response-stimulus intervals whereas the present study used complex temporal patterns that are more closely aligned with musical rhythms.

In the present study, it is evident that metrical frameworks aided responses to novel metrical patterns, as demonstrated by the larger increases for WM test blocks compared to SM test blocks for the metrical condition. These results suggest that attentional oscillators in the metrical condition allowed expectancies to be based on the metrical framework, subsequently leading to metric binding (as per the metric binding hypothesis; Jones, 2009). However, despite the fact that meter was abstracted in the metrical condition, RT improvement over training blocks was similar for metrical and non-metrical conditions. It is possible that learning in the non-metrical condition may have been compensated via a flexible and adaptive oscillator to account for the learning of regular timing deviations (Large, Fink, & Kelso, 2002). The activation of a flexible and adaptive oscillator may have prevented metric binding from occurring in the non-metrical condition, as suggested by the present results.
Taking into consideration previous evidence for a benefit of meter in tasks where participants were made explicitly aware of the temporal pattern (e.g. Essens & Povel, 1985; Keller & Burnham, 2005; Large & Jones, 1999), it is possible that temporal expectancies are acquired differently when temporal patterns are learned implicitly. In particular, the abstraction of musical meter may not improve the rate at which temporal expectancies are developed implicitly. There might be more general mechanisms for implicitly learning temporal patterns that do not necessarily rely on the presence of meter such as learning the serial order of IOIs. Previous rhythm perception studies have used temporal patterns that do not necessarily have probability-based structures (e.g. Povel, 1981; Povel, 1984; Sternberg & Knoll, 1984) and instead use complex temporal patterns consisting of distributions of IOIs that may occur in any order. Based on these studies, it has been concluded that a series of intervals cannot be stored in memory in the absence of a facilitating structure (e.g. meter). In the present study, however, it is possible that temporal patterns were learned via expectancies of the IOI length based on the second order conditional probability from preceding IOIs. Thus, learning of the temporal patterns in the present study might be based on statistical structures (as well as metrical structures for metrical patterns).

The results have implications for temporal cognition relating to both rhythm and meter perception, and implicit learning. Regarding music cognition, numerous studies use methods where participants are under explicit instruction to perceive, produce, or synchronize with temporal patterns and have found that participants synchronize to and reproduce metrical patterns better than non-metrical patterns (Povel, 1984; Essens &
Povel, 1985). It is possible that metric hierarchies may assist explicit learning more than implicit learning. Also, previous studies examining differences between metrical and non-metrical patterns have used recognition, discrimination, or reproduction tasks that focus on memory of a rhythm or meter (e.g. Essens & Povel, 1985; Keller & Burnham, 2005; Large & Jones, 1999). To be successful in these tasks, the temporal pattern must be successfully encoded and retrieved from memory. Thus, a possible explanation for discrepancies between previous results and those in the present study could be that the benefit of metrical frameworks may be more pronounced in the encoding and retrieval of memory than for online attending (in tasks such as the SRT).

Now that the IL of metrical and non-metrical patterns has been ascertained using the single response SRT, a next step is to find a way to apply this method to examine the independent learning of temporal patterns from concurrently presented ordinal patterns. As previous studies have claimed that temporal patterns cannot be learned independently from concurrent patterns (Buchner & Steffens, 2001; O’Reilly et al., 2008; Shin & Ivry, 2002), it is important to establish whether prior results could be attributed to probabilistic uncertainty of stimulus identities. It is a challenge for future investigations of the independent and integrated learning of temporal and ordinal patterns to develop a method that allows response to both the timing of the stimuli (as in the single response SRT) and the identities of the stimuli (as in the multiple response SRT). Furthermore, future studies could examine how people implicitly learn other metrical frameworks, such as triple meters or temporal patterns with ambiguous metrical interpretations. Future research could also investigate the IL of complex rhythms and meters that occur.
less commonly in Western music (see Tillmann, Stevens, & Keller, 2011) to examine the extent to which previous exposure to rhythms (and meters) affects the acquisition of temporal (and metrical) expectancies.
Chapter 5

A Sequence Identification Measurement Model to Investigate the Implicit Learning of Metrical and Non-metrical Temporal Patterns
Chapter 5 has been submitted for publication:


*Note:* The formatting, headings, and experiment numbers of the manuscript have been changed in accordance with the formatting of the thesis. Stimuli and auditory files are in Appendix R (DVD-ROM).
5.1 Introduction

Implicit learning (IL) is learning that occurs unconsciously, unintentionally, and without necessarily having declarative knowledge about what has been learned (Shanks, 2005; Shanks & St. John, 1994). IL remains controversial in two ways. First, no agreement on the precise components of IL has been reached (see Perruchet, 2008). Second, there is some debate over how much control one can have over implicitly acquired knowledge for learning to be considered implicit (e.g. Franco, Cleeremans, & Destrebecqz, 2011; Fu, Dienes, & Fu, 2010; Shanks & Berry, 2012). The present paper investigates the contribution of conscious and unconscious processes in the IL of temporal patterns using a recognition task based on the process dissociation procedure (Jacoby, 1991) and a model-based analysis adapted from a model by Buchner and colleagues (Buchner & Steffens, 2001; Buchner, Steffens, Erdfelder, & Rothkegel, 1997; Buchner, Steffens, & Rothkegel, 1998). Using previously unreported (post-test) recognition data from two experiments that demonstrated the IL of temporal patterns (Schultz, Stevens, Keller, & Tillmann, 2012), we investigate the extent of conscious control in temporal pattern recognition and the role of fluency-based processes.

5.1.1 The Process Dissociation Procedure

It is methodologically difficult to disentangle implicit and explicit processes while avoiding concerns of process purity (Dunn & Kirsner, 1988; Jacoby, 1991). Process purity is the assumption that performance in a task reflects a single process. However, this assumption is problematic when it is likely that both conscious and unconscious processes are engaged (Curran, 2001). The process dissociation procedure (Jacoby,
1991) is a measure of IL that avoids concerns of process purity by using the same task under two types of instruction. For example, Karabanov and Ullén (2008) used a generation task where the inclusion instruction required the reproduction of a learned temporal pattern and the exclusion instruction required the creation of novel temporal patterns. In the inclusion instruction, it is assumed that responses are facilitated by both implicit and explicit processes. In the exclusion instruction, it is assumed that explicit processes aid the suppression of the learned pattern but that implicit processes hinder the suppression of the learned pattern, at least partially due to motor fluency. Motor fluency is the speeded and/or relatively automatic response to a learned stimulus or pattern. By comparing performance under inclusion and exclusion instructions, it is possible to ascertain the degree to which learning was implicit. That is, if learning was implicit, then the learned pattern would be generated under the exclusion instruction with similar or greater accuracy to that explicitly generated under the inclusion instruction.

The IL of patterns of visual spatial locations (Destrebecqz & Cleeremans, 2001) and auditory temporal patterns (Karabanov & Ullén, 2008; Schultz et al., 2012) has been demonstrated in generation tasks based on the process dissociation procedure. Furthermore, the generation task has been shown to be a sensitive test of implicit and explicit pattern knowledge (Perruchet & Amorim, 1992). In two experiments by Schultz et al. (2012), IL was investigated using a serial reaction-time task (SRT), a generation task, and a recognition task based on the process dissociation procedure. Recognition data were not reported in the previous study as they were designed for the model-based analysis that is described in more detail here. The present paper reports data from the
recognition task based on the process dissociation procedure where IL of auditory temporal patterns had been demonstrated in the SRT and the generation task referred to above.

5.1.2 The Recognition Task

Recognition tasks based on the process dissociation procedure have been used to investigate whether participants can consciously recognize learned sequences (Destrebecqz & Cleeremans, 2001; 2003; Jacoby, 1991). In recognition tasks, participants are presented with a number of sequences or sequence fragments, some of which are the original acquisition pattern (i.e., the learned sequence) and some of which are novel sequences. Participants are asked to indicate whether they recognize the sequences or sequence fragments. If participants are able to identify the original sequence and reject the novel sequences above the levels expected by chance, then they are said to have explicit knowledge of the sequence.

A criticism of recognition tasks using the process dissociation procedure is that recognition and familiarity are positively correlated (Bower & Schacter, 1990; Graf & Komatsu, 1994; Schacter & Graf, 1986) and that the process dissociation procedure is not sensitive to this relationship. The relationship between familiarity and recognition is a concern for recognition tasks based on the process dissociation procedure as responses indicating recognition may actually be attributable to familiarity of sequence features as opposed to true recognition of the learned sequence. Familiarity with a stimulus in the absence of true recognition may also be elicited by perceptual fluency. Perceptual
fluency is the ease with which previously perceived features are processed (Jacoby, 1991), even if the object that possesses those features is novel. Perceptual fluency is conceptualized as a sense of familiarity without the ability to make accurate judgments regarding why the object is familiar. A similar concept is the remember-know distinction, where the remember aspect reflects conscious memory, and the know aspect reflects familiarity without true recognition, that is, perceptual fluency (e.g. Gardiner, Gregg, & Karayianni, 2006).

For example, the nursery rhymes “Twinkle twinkle, little star” and the “Alphabet song” have the same melody but different lyrics. If someone who had never heard either nursery rhyme were taught “Twinkle twinkle, little star”, then presented with the “Alphabet song” in a recognition task, they might recognize the melody feature but not truly recognize the “Alphabet song” that differs in regards to the lyrics. Thus, they might make a recognition judgment based on features of the melody. Similarly, they could make a correct recognition judgment of “Twinkle twinkle, little star” solely based on the melody, without any knowledge of the lyrics. A true recognition of the original nursery rhyme would consist of recognition of the lyrics and melody. The sequence identification measurement model (SIMM; Buchner et al., 1997; Buchner et al., 1998; Buchner & Steffens, 2001) has been proposed as a computational method for separating the familiarity of pattern features (e.g. statistical regularities) from conscious recognition.
5.1.3 The Sequence Identification Measurement Model (SIMM)

Buchner and colleagues (Buchner et al., 1997; Buchner et al., 1998; Buchner & Steffens, 2001) used the recognition task based on the process dissociation procedure for the purpose of a model-based analysis referred to as the sequence identification measurement model (SIMM). The SIMM uses probability-based multinomial processing trees (Batchelder & Riefer, 1999; Erdfelder et al., 2009; Riefer & Batchelder, 1988) to separate processes relating to the true recognition of the learned sequence, detection of systematicity (i.e., second-order conditional probabilities), and detection of a lack of structure to extract parameters for conscious (explicit) and unconscious (implicit) recognition. The original SIMM has been successfully evaluated in a series of experiments (Buchner et al., 1997; 1998) using the recognition task based on the process dissociation procedure.

In the SIMM, the parameter reflecting unconscious processes only represents IL under the assumption that IL and perceptual fluency are closely related or equivalent. The assumption that perceptual fluency is related to unconscious processing and IL was proposed by Buchner et al. (1997). However, Shanks and Johnstone (1999) argue that perceptual fluency should not be viewed as equivalent to IL because fluency may be experienced consciously. Furthermore, perceptual fluency may be an indicator of the level of conscious control one has over implicitly learned information (Fu, Dienes, & Fu, 2010). For example, some experiments (Dienes et al., 1995; Wan, Dienes, & Fu, 2008) have demonstrated that participants can correctly choose which of two artificial grammars to use in a given situation, despite reporting that they are guessing. This
indicates that, although an individual may be able to recognize and use learned information (via conscious or unconscious recognition), they may not be able to identify how or why they are able to do so. Thus, it is possible that recognition (conscious or otherwise) can occur without awareness that learning has occurred, that is, learning was unintentional and, possibly, implicit.

Generation tasks are less affected by perceptual fluency because responses cannot be based on recognition or familiarity, that is, participants are not given a stimulus and, subsequently, cannot use features of a stimulus to make recognition judgments. Instead, the reproduction of the pattern can be based on pattern knowledge and motor fluency. Thus, the generation task is not subject to the criticisms of the recognition task. A generation task based on the process dissociation procedure indicated that learning in Schultz et al. (2012) was implicit. The recognition task and SIMM reported here were used to investigate IL under the assumption that perceptual fluency is experienced unconsciously.

5.1.4 Report of the Previous Study on the Implicit Learning of Temporal Patterns

In Schultz et al. (2012), an SRT was used to investigate the IL of auditory temporal patterns. In the SRT, participants are presented with sequential stimuli and are asked to respond to each stimulus as quickly and accurately as possible (Nissen & Bullemer, 1988). Learning is characterized by: 1) a decrease in RT over blocks containing the
repeating pattern, 2) RT increases when novel patterns are introduced, and 3) recovery of RT to previous latencies when the original pattern is reintroduced.

The temporal patterns used in Schultz et al. (2012) were patterns of inter-onset intervals (IOI) that are characteristic of musical rhythms (as in Povel & Essens, 1985). Rhythm is the “systematic patterning of sound in terms of timing, accent, and grouping” (Patel, 2008, pp. 96). Meter is the sense of an isochronous pulse (or beat) that can be abstracted from a musical rhythm. Furthermore, the pulses are interpreted as alternating between strong and weak beats to form a hierarchical framework based on periodic timings (London, 2004; Palmer & Krumhansl, 1990). Examples of rhythms, the beat, and first pulse of a group (strong beats) are given in Figure 5.1. Two types of rhythms were used: strongly metrical and weakly metrical (Essens & Povel, 1985; Povel & Essens, 1985). A strongly metrical pattern contains events that occur on the beat and each strong beat contains an event. A weakly metrical pattern contains events that occur on the beat but do not always occur on the strong beat. It is possible that the metrical strength of a temporal pattern is a feature that is used when assessing whether a pattern is recognized or familiar.
Figure 5.1. Beats (short vertical lines), strong beats (long vertical lines), and events (crosses) of the strongly metrical, weakly metrical, and non-metrical temporal patterns. Beats and strong beats are a hypothetical cognitive framework and are not part of the stimulus itself.

Schultz et al. (2012) examined IL of strongly metrical patterns in two experiments. Although the two conditions reported here were identical, the aim of the two experiments differed (see Schultz et al., 2012). In Experiment 2a, IL in a multiple response task was compared to IL in a single response task (i.e., both were adaptations of the classical SRT). In Experiment 2b, the IL of metrical and non-metrical patterns was investigated. In Experiments 2a and 2b, results of the SRT indicated that metrical patterns were learned. There was also evidence that the metrical framework was learned in both experiments, as the introduction of a novel weakly metrical pattern resulted in a greater RT increase than the introduction of a novel strongly metrical pattern. Importantly, differences in RT increases to strongly and weakly metrical patterns demonstrate that people are sensitive to the feature of metrical strength. Thus, it is imperative that models of the recognition of temporal patterns are sensitive to the
detection of metrical frameworks and metrical strength. To ascertain whether learning was implicit, a generation task (based on Karabanov & Ullén, 2008) was employed following the SRT. Results of the generation task in Experiments 2a and 2b indicated IL in the absence of familiarity and perceptual fluency-based cues and demonstrated that learning was implicit. After the generation task, participants performed the recognition task described in the present paper.

5.1.5 Hypotheses

The SIMM indicates IL insofar as the premise that perceptual fluency reflects unconscious processes is true (Buchner et al., 1997; 1998). As the generation task in Schultz et al. (2012) indicated that learning was implicit, if the SIMM indicates that unconscious processes play a greater role than conscious processes in the recognition of sequences, then it is likely that perceptual fluency is related to IL. Alternatively, if the SIMM indicates that conscious processes contribute to recognition judgments more than unconscious processes, then it is possible that perceptual fluency is not equivalent to IL. In this way, a comparison of the outcomes of the SIMM and the results of the generation task can be used to examine whether IL and perceptual fluency reflect the same process.

Perceptual fluency is indicated in the SIMM (applied to recognition data) by obtaining probability estimates for unconscious processes that are above zero and above the probability estimates for conscious processes (Buchner et al., 1997; 1998). If probability estimates for conscious processes are above zero and above the probability estimates of unconscious processes, then this indicates explicit knowledge of the learned pattern. If
probability estimates for conscious and unconscious processes do not differ, then the
SIMM is unable to confirm or negate IL (insofar as IL is represented by perceptual fluency), and learning may be viewed as partly implicit and partly explicit.

5.2 Recognition Task: Behavioral Data

5.2.1 Participants

Participants were first year Psychology students from the University of Western Sydney. In Experiment 2a, participants ($N = 25; 21$ female) had a mean age of 23.24 years ($SD = 6.89$, range 17-45). In Experiment 2b, participants ($N = 25; 12$ female) had a mean age of 22.16 years ($SD = 8.36$, range 17-54). Participants in Experiment 2b had not participated in Experiment 2a. No participant reported a hearing impairment.

5.2.2 Stimuli

In training blocks of the SRT, the stimuli could emanate from the left headphone, the right headphone, or both headphones in accordance with the cover story of a computer game for the blind (see Schultz et al., 2012). The cover story was implemented to reduce awareness of the temporal pattern in the SRT. In the recognition task, all stimuli were presented through both headphones (i.e., binaurally). The stimulus was a 394Hz triangle waveform of 200ms duration with 10ms rise and fall times. Stimuli were created using MAX-MSP and were presented using PsyScope software (Cohen, MacWhinney, Flatt, & Provost, 1993) through Sennheiser (HD 650) headphones.
The strongly metrical pattern used in the acquisition phase and the four patterns in the recognition task in the two experiments are shown in Figure 5.2. For example, the acquisition pattern in Figure 5.2 displays an IOI sequence (in ms) of 500-1500-1000-1000-500-500-1000-2000. All patterns consisted of three 500ms IOIs, three 1000ms IOIs, one 1500ms IOI, and one 2000ms IOI. In the recognition task, the acquisition pattern had been previously encountered in the SRT, and other four patterns were novel patterns (i.e., different from those presented in SRT test blocks).

Parameter estimates in the SIMM are calculated by taking into account which features of a sequence (e.g. statistical regularities and, in our case, also metrical strength) might be used to make recognition judgments and how these features are weighted. For this reason, temporal patterns in the recognition task must consider and implement all possible combinations of features. The acquisition pattern has two features that may be learned: the statistical systematicities and the metrical structure. The statistical systematicities that we refer to here are the simple frequency information as outlined by Reed and Johnson (1994). Simple frequency information refers to statistical features of patterns that follow second order conditional probabilities, that is, a statistical property where each item can be predicted based on the two items that preceded it. For example, consider the pattern 1-3-1-2-3-2 where items 1, 2, and 3 represent different temporal intervals. The pair 1-3 is always followed by 1, 3-1 is always followed by 2, 1-2 is always followed by 3, 2-3 is always followed by 2, 3-2 is always by 1, and 2-1 is always followed by 3.
Figure 5.2. Metrical temporal patterns used in the recognition task. Events are represented by crosses, beats are represented by short vertical lines, and strong beats are represented by long dashed vertical lines. Patterns were: strongly metrical acquisition (SM Acq), strongly metrical systematic (SMS), strongly metrical distracter (SMD), weakly metrical systematic (WMS), and weakly metrical distracter (WMD).

Temporal patterns in Schultz et al. (2012) were governed by second order conditional probabilities. For this reason, it is possible that participants were able to learn not only the second order conditional probabilities, but also the statistical structure or the simple frequency information (Reed & Johnson, 1994), such as: the item frequency (the number of times an IOI occurs in a sequence), transition frequency (the number of times bigrams of items occur), the rate of full coverage (the average number of items that must occur to view each unique IOI in the sequence at least once), and the rate of full transition usage (the average number of items necessary to view each bigram at least once).
To use the SIMM to measure the influence of statistical features (i.e., simple frequently information) on recognition judgments, patterns with the same and different simple event frequencies were presented. Novel systematic sequences in the recognition task had the same simple frequency information as the acquisition pattern. By contrast, novel distracter sequences in the recognition task had different simple frequency information than the acquisition pattern. Furthermore, to ensure that differences in responses in the recognition task cannot be attributed to recognition of temporal grouping differences, the size of rhythmic groupings (i.e., groups of two or three proximal events) was kept constant between patterns in the acquisition phase and the recognition phase.

To measure the influence of metrical features on recognition judgments (via the SIMM), metrical strength (i.e., strongly metrical, weakly metrical) was manipulated for novel sequences in the recognition task. Novel strongly metrical patterns had the same metrical strength as the acquisition pattern, and novel weakly metrical patterns had a weaker metrical strength than the acquisition pattern. The original SIMM of Buchner and colleagues (Buchner et al., 1997; 1998; Buchner & Steffens, 2001) was used for non-metrical temporal patterns (Buchner & Steffens, 2001) and, consequently, was not concerned with metrical features that specifically pertain to metrical temporal patterns. Hence, we adapted the SIMM to include a parameter that represents the conscious detection of metrical strength. The recognition task consisted of five sequences (see Figure 5.2): the strongly metrical acquisition (SM Acq) sequence, a strongly metrical systematic (SMS) sequence, a strongly metrical distracter (SMD) sequence, a weakly
metrical systematic (WMS) sequence, and a weakly metrical distracter (WMD) sequence.

5.2.3 Procedure

For a full description of the SRT and generation task, see Schultz et al. (2012). Informed consent was obtained (ethics approval number H7764). The recognition task was performed after the SRT and the generation task had been completed. In the recognition task, patterns were presented in a random order within each instruction (inclusion and exclusion). The order of inclusion and exclusion instruction was counterbalanced across participants. The inclusion instruction required participants to respond “Yes” when the rhythmic pattern was identical to the one presented in the SRT or if it was structured similarly to the one presented in the SRT. Participants were asked to respond “No” if the pattern did not seem structured, or appeared to be random. In this way, a “Yes” response in the inclusion instruction could reflect conscious or unconscious recognition, or the detection of structure. The exclusion instruction required participants to only respond “Yes” if the sequence was structured similarly to the one presented in the SRT but NOT identical to the one presented in the SRT. If participants recognized the pattern from the SRT, or if the pattern appears to be unstructured or random, they were to respond “No”. In this way, a “Yes” response in the exclusion instruction reflects the detection of structure or unconscious recognition via perceptual fluency, but not true recognition of the acquisition pattern.
Under each instruction, responses to the five sequences can be either “Yes” or “No”. In total 20 different responses can be made: 2 (instruction) x 5 (sequences) x 2 (answer, “yes”/”no”), and each response corresponds to a different outcome in the processing tree (see Figure 5.4). Participants were presented with each sequence three times and the order of sequence presentations was random and, therefore, 60 responses were made per participant in the recognition task. The combined frequencies of responses from all participants were used to calculate the probabilities of the latent variables using the multinomial processing tree. The proportion of “yes” and “no” responses in Experiments 2a and 2b are shown in Figure 5.3. These proportions are used in the SIMM to obtain parameter estimates.
Figure 5.3. Behavioral data in the recognition task. Proportion of “Yes” (white bar) and “No” (grey bar) responses in the recognition task for the metrical condition for Experiment 2a (top panel) and Experiment 2b (bottom panel). The temporal patterns presented under the inclusion and exclusion instruction were: the acquisition (Acq) sequence, the strongly metrical systematic (SMS) sequence, the weakly metrical systematic (WMS) sequence, the strongly metrical distracter (SMD) sequence, and the weakly metrical distracter (WMD) sequence.

5.3 The Sequence Identification Measurement Model
Both the SIMM and the process dissociation procedure (Jacoby, 1991) share the assumption that participants respond differently under inclusion and exclusion instructions when a sequence is identified implicitly or explicitly. As mentioned, the
original SIMM (Buchner et al., 1997; 1998; Buchner & Steffens, 2001) did not consider
temporal patterns and how rhythmic features, such as meter, might be learned and used
to make recognition judgments. Due to the additional information given by meter and
metrical strength, the original SIMM and parameter calculations need to be modified
accordingly. Here, we include the parameter $m$ that represents the conscious detection of
meter and/or metrical strength. The processing trees in Figure 5.4 illustrate the
probabilities for responses to the strongly metrical acquisition pattern, the SMS
sequence, the WMS sequence, the SMD sequence, and the WMD sequence according to
the modified SIMM (Buchner et al., 1997; 1998; Buchner & Steffens, 2001).

Parameter $c$ (representing conscious processes) is the conditional probability that
participants show true recognition of the acquisition pattern. The probability of not truly
recognizing an acquisition pattern is $1 - c$ (see the tree a in Figure 5.4). If the acquisition
pattern is not consciously recognized, a recognition judgment may still be based on the
conscious detection of sequence systematicity with the conditional probability $s$. If the
acquisition pattern is not consciously recognized, and its systematicity is not detected,
then a recognition judgment may still be based on the conscious detection of metrical
strength with the conditional probability $m$. The detection of metrical strength is based
on whether the sequence is considered strongly metrical with the same metrical
framework as the acquisition pattern. If the sequence is not consciously recognized, and
neither the systematicity nor the metrical strength is detected, the sequence might still
receive a recognition judgment through perceptual fluency with the conditional
probability $uc$- (reflecting unconscious processes). If the acquisition pattern is not
consciously recognized, its systematicity is not detected, the metrical strength is not
detected, and is not unconsciously recognized via perceptual fluency, then participants
may still make a recognition based on a guess. Parameters $g_i$ and $g_e$ represent the
conditional probability of guessing under inclusion and exclusion instructions,
respectively. The parameter $uc^+$ is the unconditional probability of unconscious
processes affecting conscious recognition judgments, and is left unrestricted following
Buchner at al. (1997; 1998).

Novel sequences cannot be consciously recognized or processed fluently in the same
manner as the acquisition pattern. However, systematicity ($s$) and metrical strength ($m$)
can be detected in novel sequences that contain these features. For the novel strongly
metrical systematic sequence (see tree b in Figure 5.4) participants could detect either
the systematicity ($s$) or the metrical strength ($m$). If systematicity is not detected (with a
probability of $1 - s$), then it is still be possible that participants detected the metrical
strength (with a probability of $m$). If neither the systematicity nor metrical strength is
detected, with a probability of $(1 - s)(1 - m)$, then no other stimulus information is
available and it is assumed that participants will guess ($g_i$ and $g_e$). For the novel strongly
metrical distracter sequence (see tree c in Figure 5.4), participants could detect the
metrical strength with probability ($m$). Otherwise, it is assumed that participants guess
($g_i$ and $g_e$). For the novel weakly metrical systematic sequence (see tree d in Figure 5.4),
participants could detect the systematicity with probability ($s$). Otherwise, it is assumed
that participants guess ($g_i$ and $g_e$).
Figure 5.4. The adapted sequence identification measurement model for the inclusion and exclusion test conditions. The pattern types are shown on the left, participants’ responses (“Yes” and “No”) are shown on the right, and the parameters denoting the probabilities with which the underlying cognitive states are arrived at constitute the middle. The parameters represent the probability of consciously recognizing the acquisition pattern systematicity (parameter $c$), the probability of detecting the systematicity in a pattern that cannot be recognized (parameter $s$), the probability of detecting the metrical strength in a pattern that cannot be recognized (parameter $m$), the probability of unconsciously recognizing the acquisition pattern (parameter $uc$), the guessing that a pattern requires a “Yes” response in the absence of any other information about the pattern (parameters $g_i$ and $g_e$ in the inclusion and exclusion test conditions, respectively), and the detection of a lack of structure (parameter $d$).
<table>
<thead>
<tr>
<th>Acqu. Pattern</th>
<th>Inc.</th>
<th>Exc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;No&quot;</td>
</tr>
<tr>
<td>$1-c$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;No&quot;</td>
</tr>
<tr>
<td>$s$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;Yes&quot;</td>
</tr>
<tr>
<td>$m$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;No&quot;</td>
</tr>
<tr>
<td>$1-m$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;Yes&quot;</td>
</tr>
<tr>
<td>$uc^+$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;Yes&quot;</td>
</tr>
<tr>
<td>$1-uc^+$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;No&quot;</td>
</tr>
<tr>
<td>$uc^-$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;Yes&quot;</td>
</tr>
<tr>
<td>$1-uc^-$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;No&quot;</td>
</tr>
</tbody>
</table>

<table>
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<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$s$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;Yes&quot;</td>
</tr>
<tr>
<td>$1-s$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;Yes&quot;</td>
</tr>
<tr>
<td>$m$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;Yes&quot;</td>
</tr>
<tr>
<td>$1-m$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;Yes&quot;</td>
</tr>
<tr>
<td>$g_{UE}$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;Yes&quot;</td>
</tr>
<tr>
<td>$1-g_{UE}$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;No&quot;</td>
</tr>
<tr>
<td>$uc^+$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;Yes&quot;</td>
</tr>
<tr>
<td>$1-uc^+$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;No&quot;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Strongly Met. Distractor Pattern</th>
<th>Inc.</th>
<th>Exc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;Yes&quot;</td>
</tr>
<tr>
<td>$1-m$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;Yes&quot;</td>
</tr>
<tr>
<td>$g_{UE}$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;Yes&quot;</td>
</tr>
<tr>
<td>$1-g_{UE}$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;No&quot;</td>
</tr>
</tbody>
</table>

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<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$s$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;Yes&quot;</td>
</tr>
<tr>
<td>$1-s$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;Yes&quot;</td>
</tr>
<tr>
<td>$g_{UE}$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;Yes&quot;</td>
</tr>
<tr>
<td>$1-g_{UE}$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;No&quot;</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Weakly Met. Distractor Pattern</th>
<th>Inc.</th>
<th>Exc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$d$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;Yes&quot;</td>
</tr>
<tr>
<td>$1-d$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;Yes&quot;</td>
</tr>
<tr>
<td>$g_{UE}$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;Yes&quot;</td>
</tr>
<tr>
<td>$1-g_{UE}$</td>
<td>&quot;Yes&quot;</td>
<td>&quot;No&quot;</td>
</tr>
</tbody>
</table>
The novel weakly metrical distracter sequence cannot be recognized or processed fluently in the same way as the acquisition pattern. However, participants may still detect the lack of structure of a novel weakly metrical distracter sequence or a violation to simple frequency information and metrical strength with conditional probability \(d\) (see tree e in Figure 5.4). If the lack of structure is not detected (with probability \(1 - d\)), it is assumed that participants will guess \((g_i\) and \(g_e)\). Based on the rationale outlined above and represented in the processing trees, one is able to derive probability estimates from the responses given in inclusion and exclusion conditions.

As in Buchner et al. (1997; 1998), an acquisition phase sequence may be truly recognized with probability \(c\). Now, the sequence may not be recognized but it may be identified as systematic with probability \((1 - c)\times s\) or identified as strongly metrical with probability \((1 - c)\times m\). However, systematicity may be identified but not metricality with probability \((1 - c)\times(1 - m)\times s\). Conversely, metricality may be identified but not systematicity with probability \((1 - c)\times(1 - s)\times m\). If neither systematicity nor metricality is identified, then the sequence may still be accepted as well-formed due to perceptual fluency with probability \((1 - c)\times(1 - s)\times(1 - m)\times uc-\) or \((1 - c)\times(1 - m)\times(1 - s)\times uc-\). Finally, a “Yes” response may simply be the result of guessing with probability \((1 - c)\times(1 - s)\times(1 - m)\times(1 - uc-)\times g_i\) or \((1 - c)\times(1 - m)\times(1 - s)\times(1 - uc-)\times g_i\).

From the multinomial processing tree, ten equations can be derived for the probability of responding “Yes” to the five sequences in the inclusion and exclusion instructions.
Inclusion Instruction:

Acquisition pattern (ACQi)

1. \[ ACQi = c \times u_{ac} + c \times (1 - u_{ac}) + (1 - c) \times s + (1 - c) \times m + (1 - c) \times (1 - s) \times (1 - m) \times u_{ac} \]
   \[ + (1 - c) \times (1 - s) \times (1 - m) \times (1 - u_{ac}) \times g_i \]

Strongly metrical systematic sequence (SMSi)

2. \[ SMSi = s + (1 - s) \times m + (1 - s) \times (1 - m) \times g_i \]

Weakly metrical systematic sequence (WMSi)

3. \[ WMSi = s + (1 - s) \times g_i \]

Strongly metrical distracter sequence (SMDi)

4. \[ SMDi = m + (1 - m) \times g_i \]

Weakly metrical distracter sequences (WMDi)

5. \[ WMDi = (1 - d) \times g_i \]

Exclusion instruction:

Acquisition pattern (ACQe)

6. \[ ACQe = (1 - c) \times s + (1 - c) \times (1 - s) \times m + (1 - c) \times (1 - s) \times (1 - m) \times u_{ac} + (1 - c) \times (1 - s) \times (1 - m) \times (1 - u_{ac}) \times g_e \]

Strongly metrical systematic sequences (SMSe)

7. \[ SMSe = s + (1 - s) \times m + (1 - s) \times (1 - m) \times g_e \]

Weakly metrical systematic sequences (WMSe)

8. \[ WMSe = s + (1 - s) \times g_e \]

Strongly metrical distracter sequences (SMDe)

9. \[ SMDe = m + (1 - m) \times g_e \]
Weakly metrical distracter sequences (WMDe)

\[ WMDe = (1 - d) \times g e \]

The SIMM (Buchner et al., 1997; 1998; Buchner & Steffens, 2001) as adapted here was used to analyse responses in inclusion and exclusion instructions and determine the value of the parameters reflecting conscious processes (c), unconscious processes (uc-), detection of systematicity (s), detection of metrical strength (m), detection of a lack of structure (d), and guessing under the inclusion (gi) and exclusion (ge) instructions.

5.5 Sequence Identification Measurement Model Results

Recognition data from Schultz et al. (2012) were analysed using multiTree software (Moshagen, 2010), designed specifically for the analysis of joint multinomial processing tree models such as the SIMM and the adapted SIMM. MultiTree can be used to estimate model parameters, calculate variability (e.g. confidence intervals and standard error), and goodness-of-fit statistics. The Δ Akaike’s Information Criterion (ΔAIC) was used to assess the model fit to the data\(^{16}\). Specifically, the lowest positive value of ΔAIC was used to assess whether there was substantial evidence for the model (Akaike, 1974; 1987). Model fits were considered significant if the \( p \) value of the PD\(^{\lambda} \) goodness-of-fit statistic is less than .05. Reference to a parameter estimate as “different” from a value (or another parameter estimate) refers to whether the upper and lower confidence

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\(^{16}\) The ΔAIC is a measure of a model relative to the “best” model given the current parameters (Burnham & Anderson, 2002). ΔAIC does not give a significance level but, instead, provides a measure of the strength of evidence supporting the model where: 0 < ΔAIC < 2 suggests substantial evidence for the model; 3 < ΔAIC < 7 suggests considerably less support, and ΔAIC > 10 indicates that the model is unlikely. Negative ΔAIC values reflect overdispersion in the data, that is, greater variability in the data set than would be expected given the statistical model.
interval (CI) of the parameter estimate overlap with the upper and lower CI of the other parameter estimate. Bootstrapped CIs (20,000 samples) were obtained following the advice of Hu (1999) who stated that the Fisher information matrix (the default in multiTree) is a poor approximation of the true variance-covariance matrix in the case of small sample sizes.

First, following Buchner et al. (1997; 1998; Buchner & Steffens, 2001) the processing trees were doubled so that separate parameter estimates could be obtained for Experiments 2a and 2b. When the model was fitted to the data without any restrictions (i.e., all parameters were free) the model fit fell short of significance ($PD^k = 10.16, p = .26$), but there was decent evidence for the model ($\Delta AIC = 2.16$). The results of the unrestricted model are shown in Table 1.

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17 When the model was run separately for each condition, the parameter estimates did not change. Furthermore, model fits for each condition were generally significant (or not significant) under the same model restrictions.
Table 1.

*Parameter estimates for the unrestricted model in Experiments 2a and 2b.*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Experiment 2a</th>
<th></th>
<th></th>
<th>Experiment 2b</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Parameter</td>
<td>CI</td>
<td>Parameter</td>
<td>CI</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Estimate</td>
<td>(lower-upper)</td>
<td>Estimate</td>
<td>(lower-upper)</td>
<td></td>
</tr>
<tr>
<td>c</td>
<td>0.30</td>
<td>0.21 - 0.39</td>
<td>0.28</td>
<td>0.12 - 0.45</td>
<td></td>
</tr>
<tr>
<td>uc</td>
<td>0.55</td>
<td>0.37 - 0.73</td>
<td>0.16</td>
<td>-0.21 - 0.53</td>
<td></td>
</tr>
<tr>
<td>s</td>
<td>0.00</td>
<td>-0.25 - 0.25</td>
<td>0.11</td>
<td>-0.17 - 0.40</td>
<td></td>
</tr>
<tr>
<td>m</td>
<td>0.08</td>
<td>-0.16 - 0.32</td>
<td>0.17</td>
<td>-0.10 - 0.43</td>
<td></td>
</tr>
<tr>
<td>d</td>
<td>0.05</td>
<td>-0.31 - 0.40</td>
<td>0.00</td>
<td>-0.48 - 0.48</td>
<td></td>
</tr>
<tr>
<td>g\textsuperscript{i}</td>
<td>0.46</td>
<td>0.32 - 0.59</td>
<td>0.37</td>
<td>0.14 - 0.61</td>
<td></td>
</tr>
<tr>
<td>g\textsuperscript{e}</td>
<td>0.53</td>
<td>0.34 - 0.71</td>
<td>0.55</td>
<td>0.36 - 0.74</td>
<td></td>
</tr>
</tbody>
</table>

To refine the model, several parameter restrictions were applied (following Buchner et al., 1997; 1998). Based on the expectation that guessing under inclusion and exclusion instruction occurs with a probability of 0.5 (chance level), and the results of the unrestricted model that suggested these values were not different from 0.5 for all conditions (see Table 1), the parameters representing guessing under inclusion ($g_i$) and exclusion ($g_e$) instruction were set to 0.5. This resulted in a significant model fit ($PD^3 = 22.00, p = .02$), but there was less evidence for the model ($\Delta AIC = 6.00$). As the parameters reflecting detection of systematicity ($s$), detection of metrical strength ($m$), and detection of a lack of structure ($d$) were not significantly different from zero in the
unrestricted model (see Table 1), we systematically fit the model to the data with the restriction that each parameter was equal to zero for Experiments 2a and 2b (as performed by Buchner et al., 1997; 1998; 2001 for parameter s). Setting a parameter to zero is equivalent to removing the parameter from the model. The primary parameters of interest (reflecting conscious and unconscious processes) were not restricted.

*Figure 5.5.* Parameter estimates for in Experiments 2a and 2b. Probabilities range from 0 to 1. Parameters represent conscious processes (c; unfilled bars), unconscious processes (uc-; grey bars), and detection of the metrical strength (m; diagonally striped bars). Whiskers represent confidence intervals estimated from 20,000 bootstrap samples. In Experiment 2a, parameters c and uc- are considered different. In Experiment 2b parameters c and uc- are not considered different.

Of the large number of models tested (approximately 16), the model with the most substantial evidence ($\Delta AIC = 0.16, PD^2 = 24.16, p = .049$) resulted when the parameters reflecting the probability of guessing under inclusion ($g_i$) and exclusion ($g_e$) instruction
were set to chance levels (0.5), and parameters reflecting the detection of systematicity (s) and the detection of a lack of structure (d) were set to zero. In effect, this reflects that the parameters of the detection of systematicity and the detection of a lack of structure were not notably contributing to the model. The resulting probability estimates for conscious recognition (c), unconscious recognition (uc-), and the detection of metrical strength (m) are shown in Figure 5.5.

The parameter representing conscious (c) processes was greater than zero for Experiment 2a and Experiment 2b. Similarly, the parameter representing unconscious processes (uc-) was greater than zero for Experiments 2a and 2b. As can be seen in Figure 5.5, for Experiment 2a, unconscious processes (indicative of perceptual fluency) contributed more to recognition judgments than conscious processes. For Experiment 2b, conscious and unconscious processes contributed similarly to recognition judgments, indicating that responses were not governed by perceptual fluency. Thus, there is a disagreement between the model-based evidence for perceptual fluency in Experiments 2a and 2b. Although the parameter estimate for the detection of metrical strength was not significantly greater than zero in Experiment 2a, there was greater evidence for the model (i.e., ΔAIC) when this parameter was included for Experiments 2a and 2b, indicating that the detection of metrical strength may still have contributed somewhat to recognition judgements.
5.6 Discussion

The present study used a model-based analysis to examine the contribution of conscious and unconscious processes to recognition judgments of temporal patterns that were learned in an SRT (Schultz et al., 2012). Results of the SIMM do not consistently support or refute the hypothesis that unconscious processes play a greater role in the recognition of temporal patterns than conscious processes. In Experiment 2a, it appears that conscious and unconscious processes were both involved, but that unconscious processes played a greater role than conscious processes. This finding is in line with the results of the generation task (Schultz et al., 2012: Experiment 2a, single response condition) that indicated that learning was implicit. However, in Experiment 2b, the SIMM indicates that both conscious and unconscious processes were equally reflected in recognition judgments. Results of Experiment 2b are in contrast with the results of the generation task (Schultz et al., 2012: Experiment 2b) that indicated that learning was implicit.

The discrepancy between the results of the generation task and the recognition task (and SIMM) might indicate a difference between perceptual fluency as indicated in the recognition task and motor fluency as indicated in the generation task. In other words, the discrepancy between the results of the generation and recognition tasks may indicate that the assumption that perceptual fluency is equivalent to IL does not always hold true, and that IL is better captured by the generation task that is not affected by familiarity-based processes. If we reject the assumption that perceptual fluency reflects IL, and instead treat perceptual fluency as a process that is separate from IL (as suggested by
Shanks & Johnstone, 1999), then we can conclude that learning of metrical patterns was implicit (as indicated in the generation task). However, it must be acknowledged that perceptual fluency may not have contributed to familiarity-based responses more strongly than conscious processes in Experiment 2b (as revealed by the recognition task and SIMM). In other words, unconscious processes contributed less to the recognition of patterns in Experiment 2b than in Experiment 2a.

These results are not interpreted as evidence that the SIMM is invalid or unreliable: the SIMM has already been shown to be a reliable measure of perceptual fluency in a series of experiments (Buchner et al., 1997; 1998; Buchner & Steffens, 2001). Instead, we suggest that the SIMM parameter representing unconscious processes may not reflect IL, but still reflects perceptual fluency as per the assumptions of the model. One hypothesis is that, contrary to the assumptions of the process dissociation procedure (Buchner et al., 1997; 1998; Jacoby, 1991), perceptual fluency is not a necessary component of IL. Experimental conditions in Experiments 2a and 2b only differed with respect to the participants, and the results of the generation task indicated IL for both conditions. Thus, the disagreement between the results of the SIMM in Experiments 2a and 2b supports the hypothesis that perceptual fluency may not be equivalent to, or a component of, IL.

It is also possible that the disagreement between the results of the generation task and the SIMM indicate differences in the amount of conscious control participants have over implicitly learned information. For example, Franco et al. (2011) used an adaptation of a recognition process dissociation procedure to examine the degree of conscious control that could be exerted over acquired knowledge. Franco et al. demonstrated learning of
two different artificial languages in the same participants. Results of Franco et al. showed that words from the languages could not be differentiated from one another, suggesting that learning was implicit. However, the words from the languages could be differentiated from new words, suggesting that participants could still exert conscious control over the learned information. In our present study, results of Experiment 2b are in line with the results of Franco et al. (2011): participants were able to differentiate the learned pattern from novel patterns in the recognition task, but could not create novel patterns that differed from the learned pattern in the generation task. These results suggest that, even though patterns may have been implicitly learned, the learned information was still available to conscious control in a recognition task. Furthermore, Norman, Price, and Jones (2011) have suggested that there may be differences in the strategies and criteria used by individuals in recognition tasks. The use of different strategies or criteria might explain why conscious control differed between Experiments 2a and 2b presented here, that are similar in all respects other than participant sample.

Another possibility that is suggested by the disagreement between the generation task and the SIMM for Experiment 2b (Schultz et al., 2012) is that there might be a difference between perceptual fluency and motor fluency. Perceptual fluency and motor fluency are sometimes discussed as interrelated processes (e.g. perceptual-motor fluency) in the SRT and implicit learning literature (e.g. Destrebecqz & Cleeremans, 2001; Shanks, 1999). It is possible that perceptual fluency and motor fluency represent different types of control that one has over the identification of sequences (i.e., perceptual fluency) and the recollection or reproduction of sequences (i.e., motor
fluency). As the recognition task primarily relies on perceptual influences, and the generation task primarily relies on motor influences, it is possible that the results from recognition and generation tasks in the present study have revealed that perceptual fluency and motor fluency may be dissociable.

Some evidence that perceptual and motor fluency are dissociable has already surfaced. A study by Gaillard and Cleeremans (submitted) investigated the effects of increased attentional load during a generation post-test using visual spatial sequences. During the generation task, participants performed either an articulatory suppression task, a foot-tapping task, or no secondary task. Gaillard and Cleeremans found greater evidence for motor fluency in the exclusion task (i.e., an inability to suppress learned sequences) under conditions with a secondary task. Furthermore, participants could recognize sequence fragments above chance levels in a recognition task for all groups. This was viewed as evidence for a dissociation between conscious control and recognition memory. Another interpretation that was not suggested by Gaillard and Cleeremans is that, in the generation task, the secondary task interfered with perceptual processes, resulting in more automatic motor responses. This interpretation would indicate that, while perceptual fluency and motor fluency may be related, they may also play separate roles.

There is also evidence that motor fluency may affect perception. A study by Yang, Gallo, and Beilock (2009) found that expert typists make more false recognition errors to perceived (no performed) letter dyads (i.e., non-words) that are considered more
fluent to type, than those that are less fluent to type. This effect was reduced when a secondary finger-press motor task is performed during the recognition phase. Furthermore, novice typists did not exhibit fluency effects in the recognition task. This indicates that motor fluency may interfere with recognition judgments. Taken together, the results of Gaillard and Cleeremans (submitted) and Yang et al. (2009) indicate that perceptual fluency and motor fluency have a complex association that begs investigation. If perceptual and motor fluency are dissociable, then this might explain the discrepancy between the generation task and the recognition task (and SIMM) in Experiments 2a and 2b in the present study. However, the role of perceptual fluency in implicit learning is still uncertain.

5.7 Conclusion

The present study presented a model-based analysis for examining the IL of temporal patterns. The adapted SIMM included a parameter for the detection of metrical strength, and results of the model indicated that the inclusion of this parameter improved the model. In tandem with the results of Schultz et al. (2012), the model suggests that perceptual fluency may not necessarily be equivalent to IL. These results are in line with the conclusions of Shanks and Johnstone (1999) that fluency can be experienced consciously. Alternatively, the model suggests differences in the amount of control that individuals have over implicitly learned information (as suggested by Franco et al., 2011), a speculation that cannot be confirmed in the present study, and requires further testing. Another interpretation of the present results is that perceptual and motor fluency could be dissociable processes. Future experiments examining perceptual and motor
fluency under conditions of attentional load or with a secondary motor task are necessary to uncover how perceptual and motor fluency are related. Furthermore, the relationship between IL and motor/perceptual fluency should be explored. As the results of Buchner and colleagues (1997; 1998; 2001) have suggested that the SIMM is a measure of perceptual fluency, the SIMM might be useful for exploring the role of perceptual fluency in the recognition of sequences when perceptual or motor processes are engaged in a secondary task. However, the present results suggest that there may be an uncertain relationship between IL and perceptual fluency that requires further investigation.
Chapter 6

The Implicit Learning of Metrical and Non-metrical Patterns:
Comparing the Serial Reaction-time Task and the Immediate Recall Task
Chapter 6 consists of a journal manuscript that is in preparation. The manuscript will be divided into two manuscripts to be submitted to *The Journal of Experimental Psychology: Learning, Memory, and Cognition*:


And


*Note:* The formatting, headings, and experiment numbers of the manuscript have been changed in accordance with the formatting of the thesis. The information sheets and consent form (H7764) are in Appendix N. The questionnaire is in Appendix K. Results of linear trend analyses conducted for training blocks are presented in Appendix P. Results of analyses conducted on participants who were identified as implicit learners based on performance in the generation task are presented in Appendix Q. Stimuli and auditory files are in Appendix R (DVD-ROM).
6.1 Introduction

Human behaviors such as music, dance, and speech are complex action sequences that require the learning of at least two components. One component is the sequence of categorical movements and/or stimuli, for example, sequence of spatial locations. A sequence of categorical movements and/or stimuli is called an ordinal pattern. A second component is the sequence of temporal intervals between successive movements and/or stimuli. A sequence of temporal intervals is called a temporal pattern. The learning of temporal patterns occurs through the development of temporal expectancies. There is some evidence that temporal expectancies can be acquired perceptually without an intention to learn by infants (e.g. Bergeson & Trehub, 2006; Trehub & Hannon, 2005). Learning that occurs unconsciously and without intention is called implicit learning (IL; Shanks, 2005). IL of temporal patterns by adults has received little attention and results are mixed regarding whether IL of temporal patterns can occur when the temporal pattern does not correlate with the ordinal pattern. The aims of the present study were: 1) to investigate whether IL of auditory temporal patterns could occur independently of an ordinal pattern, 2) to examine how musical properties of temporal patterns (e.g. rhythm and meter) affect the IL of temporal patterns, and 3) to compare two different paradigms to investigate whether earlier mixed results can be explained by differences in the method and measures used.

6.1.1 Independent Learning of Ordinal and Temporal Patterns

Previous studies have reached different conclusions for whether temporal patterns can be implicitly learned in the absence of an ordinal pattern. Using a serial reaction-time task
(SRT), Buchner and Steffens (2001) demonstrated IL of temporal patterns when
temporal patterns were perfectly correlated with an ordinal pattern, but not when
temporal and ordinal patterns were less correlated. Similarly, using an SRT, Shin and
Ivry (2002) found learning of temporal patterns when the ordinal and temporal patterns
were correlated (although, not perfectly), but not when the relationship between
temporal and ordinal patterns was uncorrelated. These two studies (Buchner & Steffens,
2001; Shin & Ivry, 2002) suggest that temporal patterns cannot be learned independently
of a correlated ordinal pattern, that is, they indicate that an integrated representation of
ordinal and temporal patterns is formed. In contrast, studies using immediate serial recall
paradigms (Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003) found learning of
temporal patterns when the ordinal sequence was randomized each trial. As no
relationship could be formed between the random ordinal sequence and the predictable
temporal pattern, these studies (Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003)
concluded the temporal pattern can be learned independently of an ordinal sequence.

A theory that supports the independent learning of ordinal and temporal patterns is that
responses to sequences are controlled by generalized motor programs. The generalized
motor program theory (Heuer, 1988, 1991; Schmidt, 1980, 1985) posits that motor
programs for the timing of actions (i.e. temporal patterns) can exist independently of an
action sequence (i.e. ordinal patterns). A generalized motor program defines a pattern of
movement that allows for flexibility, where relative movement time and amplitude can
be adjusted, and the effectors (e.g. limbs) can be changed without losing the ability to
reproduce the movement sequence (Schmidt, 1985).
From the outset, it must be stated that the process of learning of ordinal and temporal structures may not occur entirely independently (Ullén & Bengtsson, 2003); changing one dimension of a correlated ordinal-temporal pattern is likely going to affect performance in the other dimension due to a range of factors, such as expectancy violations and integration of new sequence information. Here, we define independent learning as the ability to demonstrate knowledge of one implicitly learned structure in the absence of the other. In other words, it might be possible to have independent knowledge about one or both structures as separate entities, but also have an integrated concept of the ordinal and temporal pattern; these are not mutually exclusive. The present study investigates whether knowledge of implicitly learned temporal patterns can be demonstrated independently of a patterned (Experiment 3a) and random (Experiment 3b) ordinal sequence, as stipulated by the generalized motor program. Furthermore, we examine whether an explanation for the previously reported mixed results for the IL of temporal patterns (e.g. Brandon, Terry, Stevens & Tillmann, 2012; Buchner & Steffens, 2001; Karabanov & Ullén, 2008; Schultz, Stevens, Keller & Tillmann, 2012; Shin & Ivry, 2002; Ullén & Bengtsson, 2003) can be derived from differences between the methods and stimuli used.

### 6.1.2 Implicit Learning of Temporal Patterns

The predominant method used to examine the IL of temporal patterns is the SRT (Brandon et al., 2012; Buchner & Steffens, 2001; Miyawaki, 2006; O’Reilly, McCarthy, Capizzi, & Nobre, 2008; Salidis, 2001; Schultz, Stevens, Keller, & Tillmann, 2012;
In the SRT, participants are presented with a sequence of stimuli and are asked to identify each stimulus as it occurs. Unbeknownst to participants, the stimulus identities (ordinal sequence) and/or timing of stimuli (temporal sequence) follow a cyclically repeating pattern. Learning is indicated by reaction time (RT) decreases over training blocks containing the repeating pattern and RT increases when novel sequences are introduced in test blocks. As decreases in RT over training blocks could reflect learning of the ordinal pattern, learning of the temporal pattern, or integrated learning of the two (i.e. integrated learning), independent learning of ordinal and temporal patterns is measured using test blocks containing: 1) a novel ordinal sequence, while maintaining the original temporal pattern, and 2) a novel temporal sequence, while maintaining the original ordinal pattern. Generally, SRT studies have demonstrated that implicit knowledge of temporal patterns is not evident when the ordinal and temporal patterns are uncorrelated (Buchner & Steffens, 2001; Shin & Ivry, 2002) or when the ordinal sequence is unpredictable (O’Reilly et al., 2008; Schultz et al., 2012; but see Brandon et al., 2012; Salidis, 2001; Schultz et al., 2012).

Some concerns have been raised regarding the SRT and its use for assessing temporal pattern learning (Karabanov & Ullén, 2008; Schultz et al., 2012; Ullén & Bengtsson, 2003). The first concern is that SRT experiments have generally used temporal patterns consisting of response-stimulus intervals (e.g. Buchner & Steffens, 2001; Salidis, 2001; Shin & Ivry, 2002, Experiment 1). Response-stimulus intervals are temporal intervals between the response to the previous stimulus and the onset of the next stimulus. However, in an SRT, the use of response-stimulus intervals results in temporal intervals
between stimulus-onsets that are the sum of the RT to the previous stimulus and the response-stimulus interval. Although response-stimulus intervals are controlled, RT is variable and can be affected by a range of perceptual, cognitive, and motor processes. Thus, the intervals between subsequent events would vary as a function of RT. Due to this variability, it might be more difficult to form temporal expectancies for temporal patterns consisting of response-stimulus intervals. In contrast, inter-onset intervals (IOI) are temporal intervals between the onsets of successive stimuli that are controlled and unaffected by RT variations. As IOIs do not vary as a function of RT, it should be easier to develop temporal expectancies for temporal patterns using IOIs. The present study uses temporal patterns constructed from a series of IOIs (as used by Brandon et al., 2012; Karabanov & Ullén, 2008; Schultz et al., 2012; Shin & Ivry, 2002, Experiment 2; Ullén & Bengtsson, 2003).

The second concern associated with the SRT is that if the identity of the upcoming stimulus is unknown (i.e. the identity is random), then participants are unable to prepare for the next response regardless of whether the temporal pattern has been learned, because the stimulus is unpredictable. Consequently, RT decreases in training blocks and increases in test blocks may not occur, and temporal pattern learning may be underestimated or obscured. Schultz et al. (submitted) demonstrated IL of temporal patterns (of IOIs) with a random ordinal sequence in the stimulus detection SRT where participants responded to stimulus onsets, but not in the multiple response SRT where the task was stimulus identification. Results indicated a disadvantage of the SRT when investigating temporal pattern learning with stimulus identification: When the identity of
an upcoming stimulus is unpredictable, preparation for the next response cannot occur even if the timing of the stimulus is predictable. Subsequently, temporal learning in an SRT may still have occurred despite the lack of RT decreases over training blocks and RT increases in test blocks. Thus, the SRT may not be a sensitive measure of temporal learning under circumstances where the ordinal pattern is unknown.

This criticism has also been advanced by Ullén and Bengtsson (2003; also see Karabanov & Ullén, 2008) who proposed the immediate recall task (IRT) as an alternative method of examining IL of temporal and ordinal patterns. In the IRT, the preparation of responses is not reliant on knowledge of the upcoming stimulus identity. Participants are presented with a sequence and are asked to reproduce the sequence as accurately as possible. Participants are not informed that the temporal and/or ordinal sequence is the same in every trial. At the end of the trial, feedback is provided regarding the number of errors made. Error of reproduction of stimulus identities, or ordinal error, is calculated as the number of incorrect responses and the number of responses given in the wrong order. Temporal error is calculated as the degree to which the produced intervals differ from the sequence intervals. Learning of the ordinal pattern and the temporal pattern is demonstrated by decreases in ordinal error and temporal error over trials, respectively. Furthermore, test blocks containing random sequences are used before and after the training phase to ensure that learning effects cannot be attributed to overall task or perceptual-motor improvement. The IRT has been used to demonstrate independent knowledge of ordinal and temporal patterns using audio-visual sequences (Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003). To examine whether mixed
findings are the result of methodological differences, the present study uses both an SRT and an IRT to investigate the IL of auditory temporal patterns. To assess that learning was implicit, a generation task based on the *process dissociation procedure* was implemented following the SRT and IRT.

### 6.1.3 Process Dissociation Procedure: Assessing Implicit Learning

Despite research that suggests that humans can extract regularities (e.g. ordinal and temporal) from sequential stimuli (see Cleeremans, Destrebecqz, & Boyer, 1998 for a review), dissociating IL from explicit processes is methodologically challenging (see Stadler & Frensch, 1998; Shanks & St. John, 1994). Tests of explicit awareness of learned materials may either be an insensitive measure of explicit knowledge (e.g. verbal reports), or the task may not be process pure, that is, a specific task may be influenced by both implicit and explicit processes. The *process dissociation procedure* (Jacob, 1991) is a measure of implicit knowledge that avoids the assumption of process purity. The *process dissociation procedure* presents participants with the same task under two sets of instruction. The inclusion instruction requires participants to demonstrate knowledge of the learned sequence. Performance under the inclusion instruction is facilitated by implicit and explicit knowledge. The exclusion instruction requires participants to suppress knowledge of the learned sequence. Performance under the exclusion instruction is facilitated by explicit knowledge, but implicit knowledge provides a source of interference. By looking at the difference between performance under inclusion and exclusion instruction, one can assess whether learning was implicit.
Generation tasks based on the *process dissociation procedure* have previously been used to demonstrate IL of ordinal (Destrebecqz & Cleeremans, 2001) and temporal (Karabanov & Ullén, 2008) patterns. In the generation task, participants are asked to reproduce the learned pattern under the inclusion instruction, and to create a new pattern under the exclusion instruction. Generated patterns are given a similarity score based on how similar they are to the learned pattern. If similarity under the exclusion instruction is equal to or greater than similarity under the inclusion instruction, then learning is implicit. The present study will use a generation task to assess IL of temporal and ordinal patterns.

### 6.1.4 Temporal Patterns and Musical Rhythm

Auditory temporal patterns used in the present study were constructed by sequencing IOIs of varying length. These temporal patterns consisting of IOIs are characteristic of musical rhythm, that is, the patterned onsets of sound in terms of timing, accent, and grouping (Patel, 2008). Rhythm and its properties (e.g. meter) have been investigated in music cognition research and, drawing on this research, one can derive hypotheses about how temporal patterns are learned and which temporal regularities are learned.

In the present study, we compare the learning of metrical and non-metrical patterns (Essens & Povel, 1985; Povel & Essens, 1985). A metrical rhythm is a rhythm from which an underlying isochronous pulse (or beat) can be abstracted, where event onsets often align with the pulse and equal groupings of pulses (London, 2004). The first pulse of a group of pulses is commonly referred to as a strong beat, and other pulses are called
the weak beat. The strong beat is often perceived as accented (Lerdahl & Jackendoff, 1981), even in the absence of other physical accents (e.g. pitch change, increased intensity, or increased duration). A metrical rhythm where all strong beats contain an event is called a strongly metrical (SM) rhythm. A metrical rhythm where event onsets align with the pulse, but not all strong beats contain an event, is called a weakly metrical rhythm. A non-metrical rhythm is a rhythm where the timing of event onsets regularly deviates from the pulse. Examples of SM, WM, and non-metrical patterns are shown in Figure 6.1.

Evidence from music cognition (e.g. Essens & Povel, 1985; Patel et al., 2005; Povel & Essens, 1985), psychophysical (e.g. Grube & Griffiths, 2009), and neuroscience (e.g. Vuust, Ostergaard, Pallesen, Bailey, & Roepstorff, 2009) research suggests that temporal expectancies are easier to acquire for SM patterns than for WM and non-metrical patterns. Thus, it is hypothesized that SM patterns are learned more readily than non-metrical patterns. Furthermore, it is hypothesized that, when trained on an SM pattern, decreases in metrical strength (e.g. in a WM test block) will result in greater performance decrements than when a novel pattern with the same metrical strength is introduced (in an SM test block).
Figure 6.1. Events (Xs), strong beats (long vertical lines), and weak beats (short vertical lines), of an example of strongly metrical (SM), weakly metrical (WM), and non-metrical temporal patterns used in the present study.

6.1.5 Dynamic Attending Theory: The Benefit of Meter

Dynamic attending theory (Jones, 2009; Jones & Boltz, 1989; Large & Jones, 1999) describes the acquisition of temporal expectancies in terms of attentional oscillators. Internal attentional oscillators synchronize and adapt to external temporal patterns and attention is guided to periodic points in time. According to dynamic attending theory, meter should strengthen in-the-moment expectancies for the timing of upcoming event onsets and, in turn, facilitate the preparation of responses. The metric binding hypothesis (Jones, 2009) extends the dynamic attending theory to incorporate the learning and abstraction of hierarchical metrical structures. Metric binding hypothesis proposes that, when two or more levels of oscillatory entrainment co-occur, binding will occur at points in time where attentional oscillations align resulting in metric clusters. These metric clusters strengthen expectancies at metrically strong points in time, such as the pulse and, in particular, the first pulse of a metric group. According to metric binding
hypothesis, when novel patterns are introduced after exposure to a rhythm, performance decrements can be predicted by the degree to which previously acquired metrical expectancies are maintained or violated. Specifically, performance decrements should increase as the relative metrical strength decreases.

Based on dynamic attending theory, it is hypothesized that metrical patterns are learned more readily than non-metrical rhythms. That is, improvement in the reproduction of the temporal pattern over training blocks is greater for the metrical pattern compared to the non-metrical pattern. Based on the dynamic attending theory and the metric binding hypothesis, it is hypothesized that, for the metrical patterns, performance decrements (in test blocks) are greater when the metrical strength of the novel pattern is weaker (i.e. WM) than when the metrical framework is maintained (i.e. SM). As no metrical framework is available for the non-metrical condition, no differences between non-metrical versions of SM and WM tests are expected.

### 6.2 Experiment 3a

Experiment 3a investigated IL of metrical and non-metrical temporal patterns in the presence of an ordinal pattern of auditory tones presented from different spatial locations. Both an SRT and an IRT were used to examine learning. A generation task based on the process dissociation procedure and verbal reports were used to assess IL.
6.2.1 Design and Hypotheses

Independent variables were Block (1-11; within-subjects), Test block type (temporal test 1, temporal test 2, ordinal test; within-subjects), and Metricality (metrical, non-metrical; between-subjects). In the metrical condition, temporal tests 1 and 2 were SM and WM patterns, respectively. In the non-metrical condition, temporal tests 1 and 2 were non-metrical versions of the SM and WM patterns where temporal intervals had a complex integer ratio with the smallest IOI. In the SRT, the dependent variable (DV) was RT. In the IRT, DVs were ordinal error and relative timing error (see Method). For each DV, learning was calculated as the difference between performance in the first and fifth training block. Performance decrements in tests were calculated as the difference between performance in test blocks and mean performance in adjacent blocks.

Based on previous experiments using the SRT (Buchner & Steffens, 2001; Shin & Ivry, 2002), it was hypothesized that the SRT indicates learning in training blocks, but that independent learning of the temporal pattern may not be evident in temporal test blocks.

Based on previous experiments using the IRT (Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003), we hypothesize that independent learning of the temporal and ordinal patterns is demonstrated in the IRT. Independent learning of the ordinal pattern is indicated by larger decreases in ordinal error in the ordinal test compared to the temporal test. Independent learning of the temporal pattern is indicated by larger increases in relative timing error in the temporal test block compared to the ordinal test block.
Based on previous studies of IL of temporal patterns (Brandon et al., 2012; Karabanov & Ullén, 2008; Salidis, 2001; Schultz et al., 2012; Ullén & Bengtsson, 2003), we hypothesize that metrical and non-metrical patterns can be learned implicitly. Based on dynamic attending theory (Jones & Boltz, 1989), we hypothesize that metrical patterns are learned more readily than non-metrical patterns. Furthermore, if expectancies are heightened at periodic locations (as per the metric binding hypothesis; Jones, 2009) then changing the strength of the metrical structure should result in a greater performance decrement. For this reason, two types of novel temporal patterns will be introduced: an SM pattern where the metrical strength is maintained and a WM pattern where the metrical strength is relatively diminished. It is hypothesized that there is a greater performance decrement in the metrical condition for the introduction of a WM pattern compared to the introduction of an SM pattern. It is also predicted that in the non-metrical condition, there is no difference between non-metrical versions of SM and WM patterns as there is no metrical structure to be disrupted. Lastly it is hypothesized that ordinal patterns will be learned.

6.2.2 Method

6.2.2.1 Participants

Participants (N = 66) were first year Psychology students from the University of Western Sydney. Of these students, eight were male, and 58 were female. Ages ranged from 18 to 41 years, with a mean age of 21.3 years (SD = 4.9). No participants reported a hearing impairment.
6.2.2.2 Materials

Sequences consisted of tones constructed from a triangle waveform of 394Hz (200ms duration, 94dB SPL, 10ms rise/decay times) created with MAX-MSP software. The tone was presented through the left channel, the right channel, or both channels (henceforth referred to as “tone location”). To prevent effects of binaural summation (Marks, 1978), the presentation through both channels was 4dB less (i.e. 90dB) than monaural presentations.\(^\text{18}\)

Trials consisted of one presentation of the 9-item/8-interval sequence. In training blocks, the correlated temporal-ordinal pattern was constant: the combination was either temporal pattern 1 (SM) with ordinal pattern 1, or temporal pattern 2 (SM) with ordinal pattern 2. The ordinal/temporal pattern combination (Pattern 1x1 or 2x2) in training blocks was counterbalanced across participants, and they received the other patterns in test blocks (see Table 6.1).

In test blocks, either the temporal pattern was changed with the ordinal pattern maintained (i.e. the temporal test block) or the ordinal pattern was changed with the temporal pattern maintained (i.e. the ordinal test block). In the temporal test block, both SM and WM test patterns were used. To prevent continued learning of the patterns during tests, ordinal and temporal patterns were presented in two different rotations during the test block (see Table 6.1). This was done so that the patterns matched the

\(^{18}\)A prior stimulus selection experiment (\(N = 12\)) was conducted to approximate the point of subjective equality (i.e., perceived similarity) between the loudness of the binaural and monaural stimuli. A 4dB reduction in the intensity of the binaural stimulus resulted in perceived similarity for 11 of the 12 participants. Thus, the binaural stimulus was 4dB less than monaural stimuli in experiments reported here.
original patterns in regards to simple frequency information (Reed & Johnson, 1994). Thus, the temporal test block contained two trials of test pattern 1 (SM for the metrical condition) with the original ordinal pattern, two trials of test pattern 2 (WM in the metrical condition) with the original ordinal pattern, and two trials of temporal test patterns 1 and 2 with the rotated ordinal pattern. The ordinal test block contained two trials of the ordinal test pattern with the original temporal pattern (SM), two trials of the rotated test pattern with the rotated original temporal pattern (WM), two trials of the ordinal test pattern with the original temporal pattern (SM), and two trials of the rotated test pattern with the rotated original temporal pattern (WM). For the temporal tests, the SM and WM rotations trials with the original ordinal pattern were analyzed, and the other trials (henceforth called ‘distracter trials’) were discarded. For the ordinal test, only the trials with the original temporal pattern with the same rotation (SM training) were analyzed, and the distracter trials were discarded. The order of temporal and ordinal test blocks was counterbalanced across participants.
Table 6.1.

Order of tone locations for Patterns 1 and 2 in the training blocks, temporal test blocks, and in the ordinal test blocks.

<table>
<thead>
<tr>
<th>Ordinal Pattern</th>
<th>Rotation 1</th>
<th>Rotation 2</th>
<th>Pattern 1</th>
<th>Rotation 1</th>
<th>Rotation 2</th>
<th>Pattern 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pattern</td>
<td>(SM 1, NM 1.1)</td>
<td>(WM 1, NM 1.2)</td>
<td>(SM 2, NM 2.1)</td>
<td>(WM 2, NM 2.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2-3-3-2-1-1-3-1-2</td>
<td>2-3-3-2-1-1-3-1-2</td>
<td>2-3-3-2-1-1-3-1-2</td>
<td>2-3-3-2-1-1-3-1-2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2-1-1-3-1-2-3-3-2</td>
<td>2-1-1-3-1-2-3-3-2</td>
<td>2-1-1-3-1-2-3-3-2</td>
<td>2-1-1-3-1-2-3-3-2</td>
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<tr>
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<td>2-1-2-3-1-1-1-3-2</td>
<td>2-1-2-3-1-1-1-3-2</td>
<td>2-1-2-3-1-1-1-3-2</td>
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<tr>
<td>2</td>
<td>2-3-3-1-1-3-2-1-2</td>
<td>2-3-3-1-1-3-2-1-2</td>
<td>2-3-3-1-1-3-2-1-2</td>
<td>2-3-3-1-1-3-2-1-2</td>
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</tr>
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</table>

Note. 1 = Left, 2 = Both, and 3 = Right headphone. For the metrical condition, A = 400ms, B = 800ms, C = 1200ms, and D = 1600ms. In the non-metrical condition, A = 400ms, B = 880ms, C = 1080ms, and D = 1480ms. Participants trained on ordinal and temporal Patterns 1 (with rotation 1), received Pattern(s) 2 in the test-block, and vice versa (with rotation 1).

The timing of tones was determined by metrical or non-metrical rhythms based on sequences of IOIs, as shown in Figure 6.2. For example, SM 1 sequence in Figure 6.2 refers to an IOI sequence of 800-800-400-400-800-1600-400-1200 (ms). NM 1.1 in Figure 6.2 matches the groupings of temporally proximal events (i.e. the 400ms IOI) in SM 1, but consists of timing deviations from the pulse. All patterns in the metrical condition consisted of three 400ms IOIs, three 800ms IOIs, one 1200ms IOI, and one 1600ms IOI. Patterns in the non-metrical condition consisted of three 400ms IOIs, three
880ms IOIs, one 1080ms IOI, and one 1480ms IOI. Metrical and non-metrical patterns were identical to those used in Schultz et al. (submitted) except that the present study uses a base IOI of 400ms instead of 500ms (i.e. the tempo here is faster). Timing deviations in the non-metrical patterns were designed to be larger than the just-noticeable difference, that is, larger than 2.5% of the beat as outlined by Friberg and Sundberg (1995)\(^{19}\).

\textit{Figure 6.2.} Events (Xs), strong beats (long vertical lines), and weak beats (short vertical lines), of the Metrical (SM 1, SM 2, WM 1, WM 2) and Non-metrical (NM 1.1, NM 2.1, NM 1.2, NM 2.2) temporal patterns used in the present study.

\(^{19}\)A study of five musically trained participants was conducted using a music notation task to ensure that these timing deviations were noticeable. Although the timing deviations were noticeable, there was a variety of ways in which these were interpreted and notated. Some participants attempted to provide a metrical structure that did not fit the non-metrical pattern. Others interpreted the timing deviations as expressive timings such as the slowing and speeding of phrases within the pattern.
Temporal and ordinal sequences (see Table 6.1) maintained simple frequency information as outlined by Reed and Johnson (1994). Simple frequency information refers to statistical features of patterns where the order of items follows second-order conditional probabilities. These features include item frequency (the number of times an IOI occurs in a sequence), transition frequency (the number of times a pair of items occur in the same order), the rate of full coverage (the average number of items necessary to view each unique IOI in the sequence at least once), and the rate of full transition usage (the average number of items necessary to view each transition at least once).

Simple frequency information (except for rate of full coverage) was maintained between the training sequence and test sequences for temporal and ordinal patterns. The control of these features allows elimination of the possibility that changes in performance in test blocks are the result of changes in simple frequency information. In the case of temporal patterns, the number and size of rhythmic groupings (i.e. groups of two or three proximal events) were also kept constant for all patterns. These controls were put in place so performance decrements will more directly reflect manipulations of metrical and rhythmic features, as opposed to changes in task demands or changes in surface structure of the sequences.

Auditory stimuli were presented through Sennheiser headphones using an Edirol UA-25EX sound driver. A custom script written in MatLab (installed on Lenovo laptops)
was used to present instructions and sequences, and to collect responses (see Appendix R for stimuli).

### 6.2.2.3 Procedure

Participants were told that they were playing a computer game for the blind. The game scenario was that the participant was driving a flying vehicle, and that tones emanating from different headphone channels would direct them to avoid oncoming obstacles. This cover story was used to reduce awareness of the temporal and ordinal patterns. Informed consent was then obtained (ethics approval number: H7764). Participants were instructed to use keys “1”, “2”, and “3” on the number pad to respond to the left channel, both channels, or the right channel, respectively. Participants were trained on the stimulus-key correspondences until they reached 100% accuracy, and then completed four practice trials with random ordinal-temporal sequences. Following practice trials, experimental trials commenced.
Figure 6.3. Outline of an experimental trial in Experiments 3a and 3b. a) In the serial reaction-time task (SRT), participants were presented with a sequence of auditory tones from the left (left headphone black), right (right headphone black), or both headphones (left and right headphones black) and were instructed to identify each tone location (1 = left, 2 = both, 3 = right) as quickly and accurately as possible. b) In the IRT, participants were instructed to reproduce the pattern that was presented in the SRT and were given 10,000ms to do so. A feedback tone, with location corresponding to the key pressed, occurred for each key press. c) Each trial consisted of the SRT, the IRT, and then reproduction accuracy of the temporal and ordinal sequence in the IRT was displayed as a score out of ten.
In each trial (see Figure 6.3), participants were first asked to respond to identify the location of each tone as quickly and accurately as possible. This first task is the SRT. Then participants were immediately asked to recall the sequence they were presented in the SRT and given ten seconds to do so. This second task is called the IRT. Participants were not given explicit instruction regarding which dimension(s) of the sequence they were to reproduce, nor were they informed that the temporal and ordinal sequence was the same in each trial of the training blocks. Following each trial, participants were given a score out of ten reflecting how accurately they reproduced the sequence in the IRT. This was done to motivate participants in the IRT. Participants were not informed of what the score reflected. The score was calculated from the accuracy of the temporal and ordinal sequences (weighted equally).

Each block consisted of eight trials, with a five second break between blocks. The first five blocks were training blocks where the temporal and ordinal patterns were the same. Following the training blocks, the temporal and ordinal test phases commenced. Each test phase consisted of a training block followed by the test block, followed by another training block. The order of test phases was counterbalanced across participants. There was a total of 11 blocks.

After both test phases were completed, participants were asked if they noticed that the ordinal and temporal patterns were always the same in the first five blocks and responses were recorded. Participants then completed the generation task by generating sequences
using the “1”, “2”, and “3” keys. Each key press resulted in a corresponding auditory tone from the left channel, both channels, or the right channel. The inclusion instruction was to reproduce the temporal and ordinal patterns heard most often in the SRT. Conversely, the exclusion instruction was to create temporal and ordinal patterns that were different from those in the training blocks, but used the same distribution of tone locations and the same rhythmic groupings of tones (e.g. one, two, three etc…. tones in a row). This instruction was given to prevent participants from producing isochronous rhythms in response to the exclusion instruction. Participants were given 20 seconds for each attempt, and five attempts overall.

After the generation task, verbal reports of awareness of the temporal and ordinal patterns were obtained (order counterbalanced). For the temporal pattern, the experimenter explained that the temporal pattern in the first five blocks was always the same and participants were then asked whether they noticed that the timing was always the same. The same question was asked of the ordinal pattern. Experiment sessions did not exceed 60 minutes.

6.2.2.4 Data Analysis

In the SRT, the dependent variable was RT for correct responses. A response was considered correct if the ordinal item was correctly identified within a temporal window of 0-1000ms after the onset of a stimulus. In the IRT, dependent variables were ordinal error and relative timing error (RTE). Ordinal error is defined as the percentage of correct items reproduced in the correct order. RTE (Karabanov & Ullén, 2008) is the
mean absolute error of produced intervals in each trial. RTE is calculated as the mean of the absolute difference between the duration of the produced interval \( p \) and the duration of the pattern (i.e. the presented) interval \( s \) divided by the duration of the pattern interval \( s \). The calculation for RTE is shown in Equation 1 below, where \( i \) represents intervals 1-8 of the pattern, that is, the intervals between the 9 events.

\[
RTE = \frac{\sum_{i=1}^{8} \left| \frac{p_i - s_i}{s_i} \right|}{8}
\]  

Performance improvement was quantified as the difference between the first and last training blocks for RT, ordinal error, and RTE. Performance decrements in test blocks were quantified as the difference between the test block and the mean of the two adjacent blocks containing the training pattern. Performance decrements were calculated separately for temporal test 1 (SM), temporal test 2 (WM), and the ordinal test. Distracter trials in test blocks were not included in analyses.

6.2.3 Results and Discussion

For RT in the SRT, and ordinal error and relative timing error in the IRT, a 5 (Block) x 2 (Metricality) mixed factorial ANOVA with Block (1-5; within-subjects) and Metricality (metrical, non-metrical; between-subjects) was conducted on training blocks. Improvement, measured as the difference between block 1 and block 5, was compared in a two-way ANOVA with Metricality as the between-subjects factor. For change in performance in the temporal test blocks, a 2 x 2 mixed factorial ANOVA with Test (test 1, test 2; in the metrical condition these are the SM and WM tests, respectively) as a within-subjects variable and Metricality as a between-subjects variable was conducted;
change in performance is defined as the difference between the test block and the mean of the adjacent blocks (for RT, ordinal error, and relative error of timing). Change in performance in the ordinal test block was analyzed in a univariate ANOVA with Metricality as the between-subjects factor. Degrees of freedom have been adjusted according to the Greenhouse-Geisser correction in cases where sphericity was violated.

Eight participants had difficulty performing the SRT and means could not be obtained in some blocks (no more than three blocks). The analyses reported here include data from these participants wherever possible. These participants were not excluded because they were able to perform the IRT adequately for all blocks.

6.2.3.1 Serial Reaction-time Task

6.2.3.1.1 Training blocks

To examine whether learning of the ordinal and temporal patterns occurred in the SRT, RT in training blocks was analyzed. For RT in the training blocks, there was a main effect of Block \( [F (2.42, 130.80) = 52.20, p < .001, \eta_p^2 = 0.49] \), no main effect of Metricality \( [F (1, 54) = 0.02, p = .89, \eta_p^2 = 0.00] \), and no interaction between Block and Metricality \( [F (2.42, 130.80) = 0.45, p = .78, \eta_p^2 = 0.01] \). As shown in Figure 6.4a, RT significantly decreased \( [t (59) = 9.51, p < .001] \) over training blocks regardless of Metricality \( [F (1, 58) = 0.52, p = .47, \eta_p^2 = 0.01] \). Linear trend analyses also demonstrated that there were significant RT decreases over blocks for the metrical condition \( [F (1, 25) = 81.13, p < .001, \eta_p^2 = 0.76] \) and the non-metrical condition \( [F (1, 25) = 64.58, p < .001, \eta_p^2 = 0.74] \).
29) = 28.39, \( p < .001, \eta_p^2 = 0.50 \) (see Appendix P, Table P2). Results of the training
blocks indicate that the ordinal and temporal patterns were learned.

### 6.2.3.1.2 Test blocks

To test the hypothesis that learning of the ordinal and temporal patterns occurred in the
SRT, RT increases in the ordinal test, and temporal tests 1 (SM) and 2 (WM), were
analyzed. As shown in Figure 6.4b, there were significant increases in RT for temporal
test 1 (SM) \[ t (53) = 8.92, p < .001 \], temporal test 2 (WM) \[ t (55) = 9.61, p < .001 \], and
the ordinal test \[ t (57) = 14.10, p < .001 \] regardless of Metricality. This indicates that
both the ordinal and temporal patterns were learned and that temporal patterns can be
learned in the presence of an ordinal pattern. The ordinal and temporal patterns in the
present experiment were not perfectly correlated. These results contrast with those of
Buchner and Steffens (2001) who found that temporal patterns are only learned when
perfectly correlated with the ordinal pattern, but not when the temporal and ordinal
patterns were less correlated. However, Buchner and Steffens (2001) used temporal
patterns consisting of response-stimulus intervals so it may have been easier to form
temporal expectancies in the present study due to the use of IOIs.

In the temporal test block, there was no significant main effect of Test Block Type \[ F (1, 53) = 0.13, p = .72, \eta_p^2 = 0.002 \], no significant main effect of Metricality \[ F (1, 53) = 0.05, p = .83, \eta_p^2 = 0.001 \], and no significant interaction between Test Block Type and
Metricality \[ F (1, 53) = 0.08, p = .79, \eta_p^2 = 0.001 \]. This indicates that the metrical and
non-metrical temporal patterns were both learned. However, for the metrical condition,
there was no difference between the SM test 1 and the WM test 2. Greater RT increases in the WM test block compared to the SM test block would indicate abstraction of the metrical framework. Results of the SRT did not demonstrate such a difference. Thus, the metrical structure may not have been abstracted in the metrical condition. To examine whether there were differences between RT increases in test blocks that were indicative of temporal and ordinal learning, planned comparisons were conducted between temporal and ordinal test blocks. Planned comparisons revealed that there were no significant differences between temporal test blocks and the ordinal test block ($ps > .10$). This indicates that learning of temporal and ordinal patterns was similarly represented in the SRT.

Results of the SRT support the hypothesis that ordinal and temporal patterns were learned. However, no significant differences between metrical and non-metrical conditions were evident. Thus, results of the SRT do not support the hypothesis that metrical patterns are learned more readily than non-metrical patterns. These findings are in disagreement with the dynamic attending theory and may suggest that attentional oscillators may have adapted to non-metrical points in time for the non-metrical condition.
Figure 6.4. Results of Experiment 3a. Panels 6.4a and 6.4b show RT over training blocks and RT increases in test blocks, respectively (for the serial reaction-time task). Panels 6.4c and 6.4d show ordinal error over training blocks and error increases in test blocks, respectively (for the IRT). Panels 6.4e and 6.4f show relative timing error (temporal) over training blocks and error increases in test blocks, respectively (for the IRT). Error bars represent standard error of the mean.
6.2.3.2 Immediate Recall Task Ordinal Error

In the IRT, data were complete for ordinal error and relative timing error and there were no missing cells. Consequently, the full dataset was analyzed for the IRT.

6.2.3.2.1 Training blocks

To test the hypothesis that ordinal patterns were learned, decreases in ordinal error over training blocks and increases in the ordinal test block were examined. For ordinal error in training blocks, there was a main effect of Block \([F (2.60, 161.14) = 141.29, p < .001, \eta_p^2 = 0.70]\), no main effect of Metricality \([F (1, 63) = 0.09, p = .77, \eta_p^2 = 0.001]\), and no interaction between Block and Metricality \([F (2.60, 161.14) = 2.03, p = .12, \eta_p^2 = 0.03]\). Linear trend analyses also demonstrated that there were significant decreases in ordinal error over blocks for the metrical condition \([F (1, 31) = 159.29, p < .001, \eta_p^2 = 0.84]\) and the non-metrical condition \([F (1, 31) = 102.65, p < .001, \eta_p^2 = 0.77]\) (see Appendix P, Table P2). Regarding error decreases between blocks 1 and 5, ordinal error significantly improved \([t (63) = 16.70, p < .001]\) over training blocks, and there was a near significant effect of Metricality \([F (1, 63) = 3.21, p = .08, \eta_p^2 = 0.05]\). As shown in Figure 6.4c, the significant decrease in ordinal error over training blocks indicates that the ordinal pattern was learned.

The near significant effect of Metricality reflected that decreases in ordinal error tended to be greater for the metrical condition compared with the non-metrical condition, which suggests that the presence of a metrical framework aided learning of the ordinal pattern. This result is congruent with that of Jones, Boltz, and Kidd (1982) who found that the
identification of target pitches is more accurate when the target occurs as part of a metrical framework. Interpreted through *dynamic attending theory* (Jones & Boltz, 1989), greater ordinal error in the metrical condition suggests that attentional oscillators guided attention to metrical points in time and improved the perception and reproduction of the ordinal pattern.

### 6.2.3.2.2 Test blocks

To examine whether the ordinal structure was learned, increases in ordinal error in the test blocks were examined. As shown in Figure 6.4d, there were significant increases in ordinal error for temporal test 1 (SM) \( t(63) = 14.26, p < .001 \), temporal test 2 (WM) \( t(63) = 14.37, p < .001 \), and the ordinal test \( t(63) = 18.50, p < .001 \) regardless of Metricality. In the temporal test blocks, there was no significant main effect of Test block Type \( F(1, 63) = 0.45, p = .50, \eta_p^2 = 0.01 \), no significant main effect of Metricality \( F(1, 63) = 0.18, p = .67, \eta_p^2 = 0.003 \), and no significant interaction between Test Block Type and Metricality \( F(1, 63) = 0.11, p = .75, \eta_p^2 = 0.002 \). In the ordinal test, there was no significant main effect of Metricality \( F(1, 63) = 0.002, p = .97, \eta_p^2 = 0.00 \). The significant increase in ordinal error in the ordinal test block indicates that the ordinal pattern was learned. However, the significant ordinal error increases in the temporal test blocks indicate that changing the temporal structure also affects ordinal accuracy. Such a result suggests that the relationship between the ordinal items and the temporal items may also have been learned.
To test the hypothesis that ordinal patterns were learned independently of the temporal pattern, differences in increases in ordinal error between ordinal and temporal test blocks were examined. If increases in ordinal error are greater in the ordinal test block than in the temporal test block, then it is possible that the ordinal pattern was learned independently of the temporal pattern. Planned comparisons between the temporal and ordinal test blocks revealed significant differences between the ordinal test block and temporal test 1 ($p = .01$) and the ordinal test block and temporal test 2 ($p = .048$). This indicates that ordinal error was more affected by a change in the ordinal pattern than a change in the temporal pattern. Thus, it is possible that the ordinal pattern may have been learned independently of the temporal pattern. However, the significant increases in ordinal error in the temporal test blocks indicate that some learning of the ordinal and temporal patterns as an integrated pattern may have occurred.

### 6.2.3.3 Immediate Recall Task Relative Timing Error

#### 6.2.3.3.1 Training blocks

To test the hypothesis that the temporal pattern was learned in the IRT, decreases in RTE over training blocks, and RTE increases in the temporal test blocks were examined. For RTE in training blocks, there was a main effect of Block [$F (2.50, 154.87) = 33.82, p < .001, \eta_p^2 = 0.35$], no main effect of Metricality [$F (1, 63) = 0.03, p = .87, \eta_p^2 = 0.00$], and no interaction between Block and Metricality [$F (2.50, 154.87) = 0.70, p = .59, \eta_p^2 = 0.01$]. Linear trend analyses indicated that there were significant decreases in RTE over blocks for the metrical condition [$F (1, 31) = 32.44, p < .001, \eta_p^2 = 0.51$] and the non-metrical condition [$F (1, 31) = 32.03, p < .001, \eta_p^2 = 0.51$] (see Appendix P, Table
As shown in Figure 6.4e, the main effect of Block reflects a significant decrease in RTE over training blocks. This result suggests that the temporal pattern was learned. To test the hypothesis that metrical patterns are learned more readily than non-metrical patterns, overall improvement between training blocks 1 and 5 was examined. RTE significantly decreased \[ t (63) = 7.56, p < .001 \] over training blocks regardless of Metricality \[ F (1, 63) = 1.03, p = .31, \eta^2_p = 0.02 \]. The lack of a significant difference between improvement of RTE over training blocks fails to support the hypothesis that metrical patterns are learned more readily than non-metrical patterns.

### 6.2.3.3.2 Test blocks

To examine whether the temporal structure was learned and whether the metrical condition demonstrates greater RTE increases in the WM test block compared to the SM test block, increases in ordinal error in the test blocks were examined. There were significant increases in RTE for temporal test 1 (SM) \[ t (63) = 8.18, p < .001 \], temporal test 2 (WM) \[ t (63) = 9.12, p < .001 \], and the ordinal test \[ t (63) = 5.47, p < .001 \] regardless of Metricality. The significant increases in RTE in temporal test blocks indicate that the temporal structure was learned. To test the hypothesis that greater performance decrements occur for WM patterns compared to SM patterns for the metrical condition, RTE increases in temporal tests 1 and 2 were compared for metrical and non-metrical conditions. In the temporal test blocks, there was a near significant main effect of Test Block Type \[ F (1, 63) = 3.84, p = .06, \eta^2_p = 0.06 \], no significant main effect of Metricality \[ F (1, 63) = 0.04, p = .84, \eta^2_p = 0.001 \], and no significant interaction between Test Block Type and Metricality \[ F (1, 63) = 0.42, p = .52, \eta^2_p = \]
The near significant main effect of Test Block Type indicated that RTE increases were greater in temporal test 2 than in temporal test 1. As RTE differed between temporal tests 1 and 2 regardless of Metricality, this result does not support the hypothesis that the metrical framework was abstracted in the metrical condition.

To test the hypothesis that temporal patterns were learned independently of the ordinal pattern, increases in RTE in temporal and ordinal test blocks were compared. Planned comparisons between the temporal and ordinal test blocks demonstrated significant differences between the ordinal test block and temporal test 1 ($p = .001$) and the ordinal test block and temporal test 2 ($p = .005$). This indicates that RTE was more affected by changes in the temporal pattern than a change in the ordinal pattern. Such a result suggests that the temporal patterns may have been learned independently of the ordinal pattern. However, the significant RTE increases in the ordinal test block also indicate that the ordinal and temporal pattern may have been partially learned as an integrated pattern.

### 6.2.4 Independent Learning of Temporal Patterns

Experiment 3a demonstrated that metrical and non-metrical temporal patterns can be learned, and that temporal and ordinal patterns can be learned somewhat independently. Learning of the temporal pattern was evident in both the serial reaction-time task and the IRT. This finding is in agreement with previous studies that used the IRT (Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003), but not those that used the SRT (Buchner & Steffens, 2001; Shin & Ivry, 2002). Results did not indicate any differences between
metrical and nonmetrical conditions, except for a slight benefit of meter for learning of the ordinal pattern in the IRT.

The present results contrast with the previous SRT studies (Buchner & Steffens, 2001; Shin & Ivry, 2002) that suggested that temporal patterns cannot be learned independently of a correlated ordinal pattern. In relation to independent learning, results of the SRT provide some evidence that ordinal and temporal patterns may have been learned independently from one another. In the IRT, there was evidence that temporal pattern was learned independently as RTE increases were greater for the temporal tests compared to the ordinal test. Similarly, decreases in ordinal error were greater in the ordinal test compared to the temporal test. This might indicate that ordinal patterns were also learned independently from the temporal pattern. However, significant performance changes were evident for both ordinal error and RTE for both the ordinal and temporal tests. This shows that a change in one dimension can also affect performance in the other dimension, a finding that suggests that integration of the two patterns might have occurred. In other words, participants may have also learned something about the specific relationship between the ordinal sequence and the temporal sequence. The present results can be explained by a generalized motor program where timing and action can be learned separately (Heuer, 1988, 1991; Schmidt, 1980, 1985), although ordinal and temporal patterns may not be learned entirely independently of one another. However, it can be concluded that knowledge of the temporal pattern can be demonstrated in the absence of the learned ordinal pattern, and vice-versa.
6.2.5 Learning Temporal Patterns without Explicit Knowledge

Two measures of implicit learning were used to assess whether participants were aware of ordinal or temporal patterns, or had explicit knowledge of the ordinal and temporal patterns. Verbal reports were used to assess whether participants were aware of the patterns and whether they could report anything about the regularities. The generation task used the process dissociation procedure to ascertain the degree to which participants could demonstrate explicit knowledge and suppress implicit knowledge of the patterns.

6.2.5.1 Verbal Reports

All participants reported awareness of the ordinal pattern. In the metrical condition, 16 (of 31) participants were unaware that the temporal pattern was repeated in training blocks. In the non-metrical condition, 12 (of 31) participants were unaware that the temporal pattern was repeated in training blocks.

6.2.5.2 Generation Task

Following the method of Karabanov and Ullén (2008), IL was investigated by calculating an explicit score. The explicit score was calculated as the difference between similarity scores under inclusion and exclusion instructions. In this way, explicit scores that are close to zero reflect implicit learning, and explicit scores that are greater than zero reflect explicit learning. Verbal reports of awareness of the rhythmic pattern were used as a between-subjects variable for RTE.
6.2.5.2.1 Ordinal error explicit scores

To assess the degree to which learning of the ordinal pattern was implicit in metrical and non-metrical conditions, explicit scores were analyzed in a two-way ANOVA with Metricality as \textit{between-subjects} factor. There was no main effect of Metricality \([F (1, 61) = 0.72, p = .40, \eta_p^2 = 0.01]\) and explicit scores for the ordinal pattern were significantly greater than zero \((ps < .01)\). Overall, this indicates that learning of the ordinal pattern was explicit for metrical and non-metrical conditions.

6.2.5.2.2 Relative timing error explicit scores

To test the hypothesis that learning of temporal patterns can be implicit, explicit scores were analyzed in a 2 (Metricality; metrical, non-metrical) x 2 (Awareness; unaware, aware) \textit{between-subjects} ANOVA. Explicit scores for RTE were not significantly greater than zero for unaware participants in the metrical condition \([t (13) = 1.26, p = .23]\) but were near significantly different than zero for the aware \([t (13) = 1.97, p = .07]\) participants in the metrical condition. Similarly, in the non-metrical condition explicit RTE scores were not significantly greater than zero for unaware participants \([t (10) = 1.32, p = .22]\), but were significantly greater than zero for aware participants \([t (18) = 2.62, p < .05]\) (see Figure 6.5). There was no significant main effect of Metricality \([F (1, 63) = 0.001, p = .98, \eta_p^2 = 0.00]\) a near significant main effect of Awareness \([F (1, 63) = 3.42, p = .07 \eta_p^2 = 0.06]\), and no interaction between Metricality and Awareness \([F (1, 63) = 0.09, p = .77, \eta_p^2 = 0.002]\). Results of the generation task indicate that participants who did not report awareness of the temporal pattern learned the pattern more implicitly than participants who reported awareness of a temporal regularity.
Furthermore, participants \((N = 28)\) who were unaware of the temporal pattern did not demonstrate RTE explicit scores that were significantly greater than zero.

_Figure 6.5._ Relative error explicit scores in Experiment 3a for the metrical (16 unaware, 15 aware) and non-metrical (12 unaware, 19 aware) conditions for participants who did (aware) or did not (unaware) report awareness of a temporal pattern in verbal reports. Error bars represent standard error of the mean.

6.2.5.3 Relative timing error in the unaware group

Results suggest that learning of temporal patterns was implicit for participants who did not report awareness of a temporal pattern. To more exclusively examine IL of temporal patterns, RTE of participants who did not report awareness of the temporal pattern was analysed\(^{20}\).

\(^{20}\) Analyses on RTE were also conducted for participants who produced explicit scores of zero or less (see Appendix Q, Table Q3). While there was evidence of learning in metrical and non-metrical conditions in training blocks \([F(4, 64) = 5.87, p < .001 \eta_p^2 = 0.27]\), there was no evidence that the metrical framework was abstracted in the metrical condition (see RTE Increase in Table Q3). However, there were only seven (of 33) participants in the metrical condition (and 11 of 31 in the non-metrical condition), so a larger group would be required to detect differences using criteria based on explicit scores.
6.2.5.3.1 Training blocks

To test the hypothesis that metrical and non-metrical patterns were implicitly learned, RTE decreases over training blocks were examined. There was a main effect of Block \[ F(2.45, 63.65) = 22.29, p < .001, \eta_p^2 = 0.46 \], no main effect of Metricality \[ F(1, 26) = 0.58, p = .45, \eta_p^2 = 0.02 \], and a significant interaction between Block and Metricality \[ F(2.45, 63.65) = 2.99, p = .047, \eta_p^2 = 0.10 \]. Linear trend analyses demonstrated that there were significant decreases in RTE over blocks for the metrical condition \[ F(1, 14) = 31.37, p < .001, \eta_p^2 = 0.69 \] and the non-metrical condition \[ F(1, 11) = 11.06, p = .007, \eta_p^2 = 0.50 \] (see Appendix P, Table P2). Although RTE significantly improved over training blocks for metrical \[ t(15) = 6.14, p < .001 \] and non-metrical \[ t(11) = 3.36, p = .006 \] conditions, a half-tailed ANOVA on improvement revealed that the metrical condition demonstrated significantly greater improvement than the non-metrical condition \[ F(1, 11) = 4.90, p = .018, \eta_p^2 = 0.16 \]. As shown in Figure 6.6a, this significant main effect of Metricality reflects that improvement in RTE was greater for the metrical group compared to the non-metrical group.

6.2.5.3.2 Test blocks

To ensure that RTE decreases in training blocks are attributable to learning of the temporal pattern, RTE increases in temporal tests 1 and 2 were examined. As shown in Figure 6b, significant RTE increases were demonstrated for the temporal test 1 \[ t(26) = 4.21, p < .001 \] and temporal test 2 \[ t(26) = 4.97, p < .001 \]. This indicates that the temporal patterns were, indeed, learned.
To test the hypothesis that the metrical framework was abstracted in the metrical condition, a 2 x 2 mixed models ANOVA was conducted on RTE increases in test blocks for Test Block Type (temporal test 1, temporal test 2; *within-subjects*) and Metricality (metrical, non-metrical; *between-subjects*). For the metrical condition, test 1 was SM and test 2 was WM. For the non-metrical condition, tests 1 and 2 were non-metrical versions of the metrical tests. If RTE increases in the metrical condition are larger for test 2 (WM) than test 1 (SM), then this indicates that the metrical framework was abstracted, as per the dynamic attending theory and the metric binding hypothesis. Furthermore, if there are no differences between tests 1 and 2 in the non-metrical condition, then differences between the SM and WM tests in the metrical condition cannot be attributed to differences in temporal pattern complexity.

In the temporal test blocks, there was a significant main effect of Test Block Type \( [F (1, 26) = 5.80, p = .02, \eta_p^2 = 0.19] \), but no main effect of Metricality or interaction between Test Block Type and Metricality \( (ps > .15) \). Although the interaction was not significant, we proceeded with half-tailed ANOVAs due to the *a priori* hypothesis that, for the metrical condition, there are larger RTE increases for temporal test 2 (WM) than temporal test 1 (SM). In the metrical condition, half-tailed ANOVAs revealed that RTE increases were larger for temporal test 2 (WM) compared to temporal test 1 (SM) \( [F (1, 15) = 4.00, p = .035, \eta_p^2 = 0.27] \). In the non-metrical condition, there was no different between RTE increases in temporal tests 1 and 2 \( [F (1, 11) = 2.09, p = .17, \eta_p^2 = 0.13] \). These results suggest that the metrical framework was abstracted in the metrical
condition. Furthermore, differences between SM and WM tests in the metrical condition cannot be attributed to differences in temporal pattern complexity because no differences occurred between non-metrical tests 1 and 2. However, these results must be treated with caution as the interaction between Test Block Type and Metricality was not significant.

*Figure 6.6.* Relative timing error in Experiment 3a for participants who did not report awareness of the rhythmic pattern (unaware). Training blocks are presented in Figure 6.6a and test blocks are presented in Figure 6.6b. Error bars represent standard error of the mean.

For participants who did not report awareness of the temporal pattern, the generation task indicated that learning of temporal patterns occurred implicitly. This implicit learning group demonstrated two differences in the context of metrical and non-metrical patterns in the IRT: 1) metrical patterns were learned more readily than non-metrical patterns, and 2) in the metrical condition, there was some evidence that the temporal test 2 (WM) elicited a larger RTE increase than the temporal test 1 (SM). In light of dynamic attending theory (Jones & Boltz, 1989), these results suggest that attention was guided to periodic points in time and aided the development of temporal expectancies for events
that aligned with the metrical framework. Thus, the timing of events could be reproduced more effectively when the temporal pattern conformed to a periodic metrical structure. Furthermore, in line with metric binding hypothesis, differences between SM and WM temporal tests were evident for RTE in the metrical condition, but not the non-metrical condition. However, the interaction between Metricality and Test Block Type was not significant so the interpretation of these results should be viewed as speculative. Regardless, it is possible that the differences between metrical and non-metrical conditions could be related to the abstraction of a metrical framework in the metrical condition. This result is consistent with the dynamic attending theory: in the metrical condition, attentional oscillators adapted and synchronized with the metrical framework and guided attention to periodic events; in the non-metrical condition, attentional oscillators were perturbed by non-metrical timing deviations and attention was not guided to points in time where events occurred.

Overall, Experiment 3a provided evidence that metrical and non-metrical patterns can be implicitly learned in the presence of an ordinal pattern. Furthermore, the IRT indicates that temporal patterns may have been learned independently of the ordinal pattern. However, to ensure that temporal patterns can be learned despite uncertainty of the ordinal sequence (i.e. without the possibility of integration of the temporal and ordinal patterns) the IL of temporal patterns must be explored in the absence of a repeating ordinal structure.
6.3 Experiment 3b

The aim of Experiment 3b was to examine IL of metrical and non-metrical temporal patterns in the absence of a correlated ordinal pattern. Hypotheses were the same as those in Experiment 3a: Implicit learning of metrical and non-metrical patterns can occur; Metrical patterns are learned better than non-metrical patterns; Larger RTE increases are expected for SM test patterns compared to WM test patterns.

6.3.1 Method

6.3.1.1 Participants

Participants ($N = 76$) were first year Psychology students from the University of Western Sydney who did not participate in Experiment 3a. Thirteen were male and 63 were female. Ages ranged from 17 to 57 years, with a mean age of 22.9 years ($SD = 8.5$). No participants reported a hearing impairment. Twelve participants were excluded for producing consistently high ordinal and temporal error scores in the IRT across blocks. Data from the remaining 64 participants were subjected to analyses.

6.3.1.2 Materials and Procedure

The materials and procedures used in Experiment 3b were the same as those used in Experiment 3a, except for the following. Firstly, the ordinal sequence was randomized from trial to trial. The frequency distribution of the tone locations was maintained at three per location, thus there were nine events per trial. Secondly, in place of the ordinal test block, a second temporal test block was used. One temporal test block consisted of SM patterns (and non-metrical versions of the SM patterns), and the other temporal test
block consisted of WM patterns (and non-metrical versions of the WM patterns). The order of test blocks was counterbalanced across participants.

6.3.2 Results and Discussion

6.3.2.1 Serial Reaction-time Task

6.3.2.1.1 Training blocks

To test whether temporal pattern learning occurs in an SRT when the ordinal pattern is random, RT decreases over training blocks, and increases in test blocks were analyzed. For RT in the training blocks, there were no significant main effects or interaction effects \((ps > .15)\). In linear trend analyses, the main effect of Block approached significance \(F(1, 62) = 4.01, p = .05, \eta_p^2 = 0.02\) (see Appendix P, Table P3). However, as shown in Figure 6.7a, RT did not significantly decrease over training blocks \(t(63) = 1.73, p = .26\) regardless of Metricality \(F(1, 63) = 0.01, p = .92, \eta_p^2 = 0.00\)\(^{21}\). This indicates that the learning of temporal patterns is not revealed in an SRT when the ordinal pattern is random. The result is congruent with previous SRT experiments that have not found temporal learning in the absence of an ordinal pattern (O’Reilly et al., 2008; Schultz et al., 2012; but see Brandon et al., 2012).

\(^{21}\) Linear trend analyses did not reveal significant RT decreases over blocks for the metrical condition \(t(32) = 1.16, p = .26\) or the non-metrical condition \(t(30) = 1.33, p = .19\).
Figure 6.7. Results of Experiment 3b. Panels 6.7a and 6.7b show RT over training blocks and RT increases in test blocks, respectively (for the serial reaction-time task). Panels 6.7c and 6.7d show ordinal error over training blocks and accuracy decreases in test blocks, respectively (for the IRT). Panels 6.7e and 6.7f show relative error (temporal) over training blocks and error increases in test blocks, respectively (for the IRT). Error bars represent standard error of the mean.
6.3.2.1.2 Test blocks

For RT increases in test blocks, there was no significant main effect of Test Block Type \([F (1, 63) = 1.92, p = .17, \eta^2_p = 0.03]\), a near significant main effect of Metricality \([F (1, 63) = 3.83, p = .06, \eta^2_p = 0.06]\), and no significant interaction between Test Block Type and Metricality \([F (1, 63) = 0.80, p = .38, \eta^2_p = 0.01]\). As shown in Figure 6.7b, the near significant main effect of Metricality was driven by a larger RT increase in the nonmetrical condition, specifically for temporal test 1. Results of the SRT indicate that the temporal pattern was not learned. However, previous studies (Karabanov & Ullén, 2008; Schultz et al., 2012; Ullén & Bengtsson, 2003) have suggested that the SRT obscures or underestimates temporal learning when a correlated ordinal pattern is not present. Thus, it is possible that learning of the temporal pattern still occurred even if behavioral data do not indicate learning. If learning of the temporal pattern is indicated in the IRT, then it is likely that the SRT is insensitive to temporal learning when the ordinal pattern is unpredictable.

6.3.2.2 Immediate Recall Task Ordinal Error

As the ordinal pattern was randomized from trial to trial, decreases in ordinal error over training blocks and increases in ordinal error in test blocks were not expected. Ordinal error in training blocks and test blocks was analyzed to ensure that no systematic changes in performance occurred over blocks.
6.3.2.2.1 Training blocks

For ordinal error in training blocks, there were no significant effects of Block, Metricality, or an interaction between Block and Metricality (ps > .30). Linear trend analyses corroborated these results, and there was no significant main effect of Block for the metrical condition \( F(1, 32) = 0.73, p = .40, \eta_p^2 = 0.02 \) or the non-metrical conditions \( F(1, 30) = 1.26, p = .27, \eta_p^2 = 0.04 \) (see Appendix P, Table P3). As shown in Figure 6.7c, ordinal error did not significantly decrease for metrical \( t(32) = 1.36, p = .18 \) and non-metrical \( t(30) = 1.39, p = .18 \) conditions over training blocks, and there was no significant main effect of Metricality \( F(1, 63) = 0.00, p = .98, \eta_p^2 = 0.00 \). This indicates that no systematic changes in ordinal error occurred over training blocks. Comparing the results for ordinal error in Experiments 3a and 3b, it is evident that a decrease in ordinal error in training blocks only occurs when the ordinal pattern is predictable (i.e. in Experiment 3a) but not in Experiment 3b, where the ordinal sequence was not predictable. These results indicate that decreases in ordinal error in training blocks do not occur as a result of learning the method and task but, instead, reflect the learning of the ordinal pattern.

6.3.2.2.2 Test blocks

For test blocks (see Figure 6.7d), there were no significant effects of Test Block Type, Metricality, or interaction between Test block Metre and Metricality (ps > .30). Decreases in ordinal error did not occur in temporal test 1 (SM) or 2 (WM) for metrical or non-metrical conditions (ps > .40). These results indicate no differences between
metrical and non-metrical conditions for ordinal error when the ordinal pattern is random.

6.3.2.3 Immediate Recall Task Relative Timing Error

6.3.2.3.1 Training blocks

To test the hypothesis that the temporal pattern was learned in the IRT, decreases in RTE over training blocks, and increases in the temporal test blocks were examined. For RTE in training blocks, there was a main effect of Block \( [F (2.80, 173.43) = 8.51, p < .001, \eta_p^2 = 0.12] \), but no significant main effect of Metricality or interaction between Block and Metricality \( (ps > .80) \). Linear trend analyses demonstrated significant main effects of Block for the metrical condition \( [F (1, 32) = 7.80, p = .009, \eta_p^2 = 0.20] \) or the non-metrical conditions \( [F (1, 30) = 4.62, p = .04, \eta_p^2 = 0.13] \) (see Appendix P, Table P3). As shown in Figure 6.7e, the main effect of block indicates that RTE significantly decreased over training blocks (specifically, blocks 1 to 3) for metrical and non-metrical conditions.

To test the hypothesis that metrical patterns were learned more readily than non-metrical patterns, overall improvement between the first and last training blocks was analyzed. RTE significantly decreased over training blocks for metrical \( [t (32) = 3.05, p = .005] \) and non-metrical \( [t (30) = 2.20, p = .04] \) conditions regardless of Metricality \( [F (1, 63) = 0.004, p = .95, \eta_p^2 = 0.00]. \)
6.3.2.3.2 Test blocks

To test the hypothesis that performance decrements are greater for the WM test block compared to the SM test block for the metrical condition, RTE increases in test blocks were analyzed. For test blocks, there was no significant main effect of Test Block Type \[F (1, 63) = 0.01, p = .94, \eta_p^2 = 0.00\], no significant main effect of Metricality \[F (1, 63) = 0.46, p = .50, \eta_p^2 = 0.01\], and no interaction between Test Block Type and Metricality \[F (1, 63) = 0.05, p = .82, \eta_p^2 = 0.001\]. As shown in Figure 6.7f, there were significant increases in RTE for temporal tests 1 (SM) \[t (63) = 6.12, p < .001\] and 2 (WM) \[t (63) = 7.62, p < .001\] regardless of Metricality.

Results of the IRT indicate that metrical and non-metrical patterns were learned in the absence of an ordinal regularity. In contrast, the SRT did not provide evidence of temporal pattern learning. This supports the hypothesis that the SRT is insensitive to temporal learning when the ordinal pattern is unpredictable. These results support the theory of a generalized motor program (Heuer, 1988, 1991; Schmidt, 1980, 1985), that is, the timing of actions can be learned separately from the type of action (e.g. responses to the ordinal stimuli). As the action sequence (i.e. the ordinal pattern) was different in each trial, a flexible motor program, such as the generalized motor program, was necessary to learn the timing sequence independently of the action sequence. Indeed, results of the IRT indicate that the timing sequence was learned independently.

Previous studies on the IL of temporal patterns (Schultz et al., 2012; Ullén & Bengtsson, 2003) have suggested that temporal learning may be underestimated in the SRT in the
face of probabilistic uncertainty of the upcoming stimulus identities. In other words, when the identity of the upcoming stimulus is uncertain, participants are unable to prepare the correct response even if they have knowledge of when the stimulus will occur. Thus, learning of the temporal pattern may be obscured in the SRT if the upcoming stimulus identity cannot be predicted. However, it is evident that learning of the temporal pattern occurred in the IRT and, therefore, it is likely that the SRT is insensitive to temporal learning when the ordinal pattern is unknown or random.

**6.3.5 Learning Temporal Patterns without Explicit Knowledge**

**6.3.5.1 Verbal Reports**

As in Experiment 3a, verbal reports of awareness of the rhythmic pattern were obtained by the experimenter explaining that the temporal pattern in the first five blocks was always the same and participants were then asked whether they noticed that the timing was always the same. Of the 64 participants, 13 participants in the metrical condition and 14 participants in the non-metrical condition were unaware that the temporal pattern was the same and 20 participants in the metrical condition and 17 participants in the non-metrical condition were aware of the temporal pattern.

**6.3.5.2 Generation Task**

To test the hypothesis that learning of temporal patterns can be implicit, explicit scores were analyzed in a 2 (Metricality; metrical, non-metrical) x 2 (Awareness; unaware, aware) *between-subjects* ANOVA. Explicit scores for RTE were not significantly greater than zero for unaware participants in the metrical condition [$t (12) = 0.23, p = .82$] but
were significantly different from zero for the aware participants in the metrical condition \([t (18) = 2.22, p = .04]\). Similarly, in the non-metrical condition explicit RTE scores were not significantly greater than zero for unaware participants \([t (13) = 0.04, p = .97]\), but were significantly greater than zero for aware participants \([t (16) = 2.41, p = .03]\) (see Figure 8). There was no significant main effect of Metricality \([F (1, 63) = 0.29, p = .59, \eta_p^2 = 0.01]\), a significant main effect of Awareness of rhythm \([F (1, 63) = 6.99, p = .01 \eta_p^2 = 0.11]\), and no interaction between Metricality and Awareness \([F (1, 63) = 0.12, p = .73, \eta_p^2 = 0.002]\). Participants who reported they were unaware of the temporal pattern did not demonstrate RTE explicit scores that were significantly greater than zero. This supports our hypothesis that temporal patterns can be learned implicitly.

*Figure 6.8.* Relative error explicit scores in Experiment 3b for the metrical and non-metrical conditions for participants who did (aware) or did not (unaware) report awareness of a temporal pattern in verbal reports. Error bars represent standard error of the mean.
6.3.5.3 Immediate Recall Relative Timing Error in the Unaware Group

As in Experiment 3a, results of the generation task suggest that learning of temporal patterns was implicit for participants who did not report awareness of a temporal pattern. To more exclusively examine IL of temporal patterns, RTE of participants who did not report awareness of the temporal pattern were analysed.22

6.3.5.3.1 Training blocks

To test the hypothesis that metrical and non-metrical patterns were implicitly learned, RTE decreases over training blocks were examined. For RTE in training blocks, there was a main effect of Block \(F(2.14, 53.58) = 4.15, p = .02, \eta_p^2 = 0.14\), no main effect of Metricality \(F(1, 25) = 0.004, p = .95, \eta_p^2 = 0.00\), and no significant interaction between Block and Metricality \(F(2.14, 53.58) = 0.88, p = .43, \eta_p^2 = 0.03\). Linear trend analyses showed significant main effect of Block \(F(1, 25) = 5.30, p = .03, \eta_p^2 = 0.18\) (see Appendix P, Table P2).23 As shown in Figure 6.9a, RTE near significantly improved over training blocks for metrical condition \(t(12) = 1.98, p = .07\) and significantly improved for the non-metrical condition \(t(14) = 3.61, p < .01\). No significant main effect of Metricality was evident \(F(1, 25) = 0.01, p = .94, \eta_p^2 = 0.00\). These results support the hypothesis that metrical and non-metrical patterns were both learned, but do not support the hypothesis that metrical patterns are learned more readily.

22 Analyses on RTE were also conducted for participants who produced explicit scores of zero or less (see Appendix Q, Table Q4). There was evidence of learning in metrical and non-metrical conditions in training blocks \(F(4, 80) = 8.00, p < .001 \eta_p^2 = 0.29\). No other effects were significant \((ps > .26)\). These results indicate that metrical and non-metrical patterns were learned with similar efficacy, and do not indicate that the metrical structure was abstracted.

23 Linear trend analyses did not reveal significant RTE decreases over blocks for the metrical condition \(t(12) = 2.18, p = .17\) or the non-metrical condition \(t(13) = 3.18, p = .10\). However, metrical and non-metrical conditions approached significance at the order 4 \(F(1, 12) = 3.95, p = .07, \eta_p^2 = .25\) and quadratic \(F(1, 13) = 5.07, p = .04, \eta_p^2 = .28\) levels, respectively. This indicates that learning did not occur in a linear fashion, although learning still occurred.
than non-metrical patterns. In contrast to predictions derived from the dynamic attending theory (Jones & Boltz, 1989), results suggest that the presence of meter did not aid the learning the temporal patterns when the ordinal sequence is unpredictable.

6.3.5.3.2 Test blocks

To test the hypothesis that the metrical framework was abstracted in the metrical condition, a 2 x 2 mixed models ANOVA was conducted on RTE increases for Test Block Type (temporal test 1, temporal test 2; within-subjects) and Metricality (metrical, non-metrical; between-subjects). There were no significant main effects of Test Block Type \([F (1, 25) = 1.88, p = .18, partial \eta^2 = 0.07]\) or Metricality \([F (1, 25) = 0.002, p = .96, partial \eta^2 = 0.00]\), but there was a near significant interaction between Test Block Type and Metricality \([F (1, 25) = 3.66, p = .07, partial \eta^2 = 0.13]\). As the interaction was near-significant, planned comparisons were conducted between test 1 and test 2 for metrical and non-metrical conditions to test the hypothesis that the metrical framework was learned in the metrical condition. A half-tailed planned comparison between the test 1 and test 2 revealed that, in the metrical condition, there was a significant difference between test 1 (SM) and test 2 (WM) \([F (1, 12) = 3.90, p = .04, partial \eta^2 = 0.25]\). As shown in Figure 6.9b, this indicated that RTE increases were greater in the WM test than the SM test for the metrical condition. Although the interaction between Test Block Type and Metricality was near significant, results of the planned comparisons support the hypothesis that the metrical framework was abstracted in the metrical condition. In the non-metrical condition, no significant difference was demonstrated between tests 1 and 2 \([F (1, 13) = 0.22, p = .65, partial \eta^2 = 0.02]\). As the non-metrical patterns were
matched to the metrical patterns in all aspects other than meter, this indicates that differences between tests 1 and 2 cannot be attributed to differences in temporal pattern complexity. For the metrical condition, significant RTE increases were not demonstrated for the SM test block \( t(12) = 1.10, p = .30 \) but were demonstrated in the WM test block \( t(12) = 4.05, p = .002 \). In the non-metrical condition, significant RTE increases were evident for both temporal test 1 \( t(13) = 2.73, p = .02 \) and 2 \( t(13) = 3.08, p = .01 \). For the metrical condition, a possible explanation for the lack of an RTE increase in the SM test block might be that the metrical framework aided responses to the SM test pattern, even though the temporal pattern was novel.

Figure 6.9. Relative timing error in Experiment 3b for the participant who did not report awareness of the rhythmic pattern (unaware). Training blocks are presented in Figure 6.9a and test blocks are presented in Figure 6.9b. Error bars represent standard error of the mean.

Greater increases in RTE for WM tests compared to SM tests in the metrical condition are in accordance with metric binding hypothesis (Jones, 2009): in the metrical condition metric binding occurred, thus strengthening expectancies for events occurring in
metrical (i.e. periodic) locations. When the novel rhythm conformed to the metrical framework, attention was guided to points in time where events occurred. Thus, performance decrements were not as large, compared with those for novel WM patterns, because the metrical framework could be utilized for novel SM patterns. When the novel rhythm violated the metrical framework, performance decrements were greater as events did not consistently occur at moments of high expectancy. However, the interaction was between Test Block Type and Metricality was only near significant and the interpretation of these results must be considered with that in mind.

In Experiment 3b, metrical and non-metrical patterns were implicitly learned when the ordinal sequence was random and uncorrelated with the temporal patterns. Differences between metrical and non-metrical conditions were only evident for participants who did not report awareness of the temporal pattern. In the metrical condition, RTE increases were greater for the WM test compared to the SM test, indicating that the metrical framework might have been abstracted in the metrical condition. However, decreases in RTE in training blocks were not greater for metrical patterns than for non-metrical patterns, indicating that meter did not provide a benefit for temporal pattern learning.

6.4 General Discussion

Two experiments demonstrated the learning of metrical and non-metrical patterns, and provided evidence that this learning can be implicit. Experiment 3a examined IL of temporal patterns in the presence of an ordinal pattern. Metrical patterns were learned more effectively than non-metrical patterns, and there was some
speculative evidence that a hierarchical metrical structure was abstracted in test blocks. Interpreted through the dynamic attending theory (Jones & Boltz, 1989), this indicates that the abstraction of an underlying isochronous pulse (or beat) may have facilitated in-the-moment expectancies. However, there was only weak evidence that periodic expectancies at multiple periodicities were formed, as proposed by the metric binding hypothesis (Jones, 2009). Specifically, although RT increases were greater for WM test blocks than for SM test blocks in the metrical condition, differences between non-metrical versions of these test blocks produced a similar (but non-significant) trend.

Experiment 3b examined IL of temporal patterns in the absence of an ordinal pattern. In contrast to the results of Experiment 3a and the dynamic attending theory (Jones & Boltz, 1989), there were no differences between metrical and non-metrical conditions in Experiment 3b in regards to learning efficacy over training blocks. However, there was some weak evidence that the unaware metrical group had abstracted the metrical framework, as per the metric binding hypothesis (Jones, 2009), as the introduction of patterns with a weaker metrical strength resulted in increased error in temporal reproductions compared to patterns with the same metrical strength.

It is possible that a benefit of meter was not evident in Experiment 3b due to the lack of predictability of the ordinal pattern and, subsequently, differences in the amount of cognitive resources allocated to the temporal pattern. In Experiment 3a, the ordinal pattern was predictable and, after a number of trials, cognitive resources may have been reallocated from the ordinal pattern to the temporal pattern. Thus, temporal expectancies
and temporal learning may have benefited from the knowledge of the ordinal pattern, and the benefit of meter surfaced. Conversely, in Experiment 3b, the ordinal pattern was ever-changing and more cognitive resources were required to successfully reproduce the ordinal pattern. In turn, the temporal pattern did not receive the cognitive resources necessary for the benefits of meter to occur (although there was evidence of metric binding in test blocks).

### 6.4.1 Influences of Implicit Learning on Beat and Meter Abstraction

Differences between metrical and non-metrical patterns were only evident in the IRT for participants who were unaware of the temporal pattern. It is possible that beat and meter abstraction may be closely related to unconscious processes. For example, there is evidence (e.g. Drake, Penel & Bigand, 2000b) that tapping or moving in response to the meter of a rhythm can occur spontaneously (i.e. spontaneous synchronization). One could speculate that this is an unconscious process but no research has addressed this issue in human adults (but see Zentner & Eerola, 2010 for an infant study).

There is also evidence that the more declarative knowledge (or musical training) an individual has, the better they are at discriminating tempo changes (Drake, Jones, & Baruch, 2000a) and the higher level of metrical abstraction that occurs (Drake et al., 2000b). Taken together, these results may suggest differences in the mechanisms involved in responding to meter: There may be a mechanism where responses to meter are implicit (or possibly innate, see Patel, Iverson, Bregman, & Schulz, 2009), and a mechanism where explicit control of responses is activated, possibly via metric binding.
(Drake et al., 2000b). In the present study, participants who were unaware of the temporal pattern may have been unable to exert control over their temporal responses. In this way, relatively automatic responses may have occurred for events that conformed to a metrical framework, thus facilitating performance. It is also possible that participants who had explicit control over responses may not have demonstrated differences between metrical and non-metrical conditions due to a greater ability to discriminate and reproduce timing deviations that were present in the non-metrical condition. In the present study, however, there were no significant differences in performance between aware and unaware groups. Future studies could investigate the role musical training plays in the perception of metrical and non-metrical patterns.

6.4.2 Independent Learning of Temporal Patterns

In line with previous experiments using the IRT (Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003), results of the present study indicate that temporal patterns can be learned independently of an ordinal pattern (Experiment 3a) and random ordinal sequences (Experiment 3b). These results indicate that the learning of temporal patterns does not need to occur in relation to a correlated action sequence, as suggested by previous SRT experiments (Buchner & Steffens, 2001; O’Reilly et al., 2008; Shin & Ivry, 2002). The discrepancy between the present results (see also Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003) and other experiments on the IL of temporal patterns (Buchner & Steffens, 2001; O’Reilly et al., 2008; Shin & Ivry, 2002) could be explained by four methodological differences.
First, the present study uses auditory stimuli whereas some other studies have used visual stimuli (O’Reilly et al., 2008; Shin & Ivry, 2002; but see Buchner & Steffens, 2001, who used auditory stimuli). There is some evidence that responses to auditory temporal patterns (specifically, rhythms) are more precise than to visual temporal patterns (e.g. Patel, Iverson, Chen, & Repp, 2005). It is possible that the independent learning of the temporal pattern is more prominent when auditory stimuli are used due to specialization of the auditory cortex for temporal processing (e.g. Carney, 1999), and/or because of strong coupling between auditory stimuli and motor actions (e.g. Repp & Penel, 2002; 2004). Thus, it might be the case that the processing of temporal patterns is better when auditory stimuli are used compared to visual stimuli. This would have consequences for theories relating to motor programs of timing and action; perhaps the learning of temporal and ordinal patterns occurs differently for visual and auditory modalities. Previous studies (O’Reilly et al., 2008; Shin & Ivry, 2002) may have found reduced learning of temporal patterns due to the use of visual stimuli.

Second, the present study used patterned IOIs whereas some previous studies used response-stimulus intervals (Buchner & Steffens, 2001; Shin & Ivry, 2002, Experiment 1). As discussed in the introduction, it should be easier to develop temporal expectancies for temporal patterns using IOIs as the timing between event onsets do not vary as a function of RT. Thus, previous experiments may not have demonstrated independent learning of temporal patterns due to the use of response-stimulus intervals.
Third, the present study used test patterns that match the simple frequency information (Reed & Johnstone, 1994) of the training patterns whereas previous studies used random ordinal and/or temporal sequences in test blocks (Buchner & Steffens, 2001; O’Reilly et al., 2008; Shin & Ivry, 2002). Changes in the simple frequency information may have a greater influence on RT increases when the ordinal sequence is random for two reasons: 1) It has been shown that participants have difficulty storing a series of intervals in memory (Povel, 1981; Povel, 1984; Sternberg & Knoll, 1984), so it is possible that people are less sensitive to changes in simple frequency information of IOIs, and 2) In the multiple alternative SRT, when the identity of an upcoming stimulus is unknown (i.e. random), participants are unable to prepare the appropriate action for the next response (Schultz et al., 2012). It is possible that, in studies using temporal and ordinal patterns (O’Reilly et al., 2008; Shin & Ivry, 2002), larger RT increases for changes in the ordinal pattern were a result of greater sensitivity to changes in simple frequency information for ordinal patterns. In the present study, simple frequency information were maintained, which might explain why the present study showed similar RT increases for ordinal and temporal test blocks in the SRT.

Fourth, the present study used an IRT to enable measurement of ordinal error and relative timing error; in the SRT, RT reflects the learning of both dimensions simultaneously with a primary focus on the correct identification of ordinal stimuli. Thus, differences between the results in the present study and previous experiments (Buchner & Steffens, 2001; O’Reilly et al., 2008; Shin & Ivry, 2002) may reflect differences in the types of measurements used. Specifically, RT in the SRT might be
more sensitive to changes in the ordinal pattern than to changes in the temporal pattern under certain circumstances. While the first three explanations are outside the scope of the present paper, this fourth explanation was explored in Experiment 3b by examining learning in the SRT and IRT in the absence of an ordinal pattern. Importantly, in Experiment 3b, temporal pattern learning was indicated in the IRT but not the SRT, suggesting that the SRT underestimates temporal learning when the ordinal sequence is unpredictable (as suggested by Schultz et al., 2012; Ullén & Bengtsson, 2003).

Results of previous experiments have suggested that the SRT might underestimate temporal pattern learning when learned with a random or uncorrelated ordinal pattern (Karabanov & Ullén, 2008; Schultz et al., 2012; Ullén & Bengtsson, 2003). Indeed, results of the present study indicate that the SRT underestimates temporal learning when the ordinal pattern is random. In Experiment 3a, where the ordinal pattern correlated with the temporal pattern, the SRT and IRT both indicated learning of the temporal pattern, that is, decreases in RT and RTE occurred over training blocks, and RT and RTE increased in test blocks. In Experiment 3b, where the ordinal pattern was random and uncorrelated with the temporal pattern, the IRT demonstrated RTE decreases over training blocks and increases in test blocks, indicative of temporal pattern learning. Conversely, the SRT did not indicate temporal pattern learning as RT did not decrease over training blocks and systematically increase in test blocks. Thus, the SRT may not have been sensitive to temporal learning when the ordinal and temporal patterns are not correlated. This might explain the lack of evidence for independent temporal learning in
previous SRT studies under conditions where the ordinal and temporal patterns were not correlated (e.g. O’Reilly et al., 2008; Shin & Ivry, 2002).

6.5 Conclusion

The present study suggests that IL of temporal patterns can occur independently of a correlated and uncorrelated ordinal pattern. Results indicate that the timing of actions can be learned and reproduced when the type of action is uncorrelated, thus, results support the theory of a generalized motor program (Heuer, 1988, 1991; Schmidt, 1980, 1985). Furthermore, there appears to be a benefit of meter regarding in-the-moment expectancies in Experiment 3a, as is predicted by the dynamic attending theory (Jones & Boltz, 1989). There was also weak evidence for metric binding (Jones, 2009) in Experiment 3a, and stronger evidence in Experiment 3b. These results indicate that meter may aid expectancies differently depending on the situation in which the temporal patterns are learned, that is, depending on the predictability of the ordinal sequence. It is important to examine the effects of meter on IL of temporal patterns when the ordinal sequence is always predictable or constant (see Schultz et al., 2012) to gain a better understanding of temporal learning in isolation of ordinal learning. Results of the present study give an impetus to the investigation of implicit learning of more complex meters (see Tillmann, Stevens, & Keller, 2010) and the perception of non-metrical timing deviations.
Chapter 7

General Discussion
The implicit learning (IL) of temporal patterns is a relatively under-investigated field of inquiry that has produced inconclusive results. On the one hand, some studies have shown that temporal patterns cannot be implicitly learned unless a concurrent ordinal structure is also available (Buchner & Steffens, 2001; O’Reilly et al., 2008; Shin & Ivry, 2002). On the other hand, some studies have demonstrated the IL of temporal patterns without an ordinal sequence (Salidis, 2001) or when the ordinal sequence is unpredictable (Brandon et al., 2012; Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003). To expose possible explanations for such differences in results and to explore further the IL of temporal patterns, the present program of research investigated the IL of auditory temporal patterns that are characteristic of musical rhythms.

With an aim to investigate how aspects of musical rhythm (e.g. meter) may facilitate the IL of temporal patterns, two types of temporal patterns were used, that is, auditory metrical and non-metrical patterns. The construction of these metrical and non-metrical pattern stimuli was based on research and theories of rhythm perception (Essens & Povel, 1985; Grahn & Brett, 2007; Jones, 2009; Povel & Essens, 1985). While research on rhythm reproduction indicates that metrical and non-metrical patterns can be learned (Essens & Povel, 1985; Grahn & Brett, 2007), extant results concerning whether temporal (i.e. metrical or non-metrical) patterns can be learned implicitly are mixed (Brandon et al., 2012; Buchner & Steffens, 2001; Karabanov & Ullén, 2008; O’Reilly et al., 2008; Salidis, 2001; Shin & Ivry, 2002; Ullén & Bengtsson, 2003).
There were three broad aims of the experimental work. The first aim was to examine the IL of temporal patterns and to investigate the conditions under which implicit learning of temporal patterns is observed. More specifically, three different methods were compared to examine whether mixed results for the IL of temporal patterns can be explained by methodological differences: the multiple response SRT (as used by Brandon et al., 2012; Buchner & Steffens, 2001; O’Reilly et al., 2008; Shin & Ivry, 2002), the single response SRT (as used by Salidis, 2001), and the IRT (as used by Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003).

Second, four experiments (Experiments 1, 2b, 3a, and 3b) investigated how temporal expectancies are acquired in the presence and absence of meter by comparing the learning of metrical and non-metrical patterns. Hypotheses regarding how metrical and non-metrical patterns are learned were derived from the music cognition research on rhythm perception (Essens & Povel, 1985; Grahn & Brett, 2007) and theories on temporal perception, namely the dynamic attending theory and the metric binding hypothesis (Jones, 2009). Hypotheses were that: 1) metrical and non-metrical patterns can be implicitly learned, 2) metrical patterns are learned more readily than non-metrical patterns, and 3) the metrical framework is abstracted for metrical patterns, and facilitates responses to novel metrical patterns with the same metrical strength as the learned metrical pattern. Third, a statistical model was implemented with the aim of disentangling conscious and unconscious processes for the IL of metrical and non-metrical patterns. This chapter discusses these three aims and interprets the findings in light of theories of temporal perception and implicit learning; the broader implications of
the research are discussed. Future directions for research on the IL of temporal patterns are then proposed.

7.1 Summary of Findings

7.1.1 Comparing the Methods of Measuring the Implicit Learning of Temporal Patterns

The implicit learning of temporal patterns was examined in five experiments and a model-based analysis. The Syllable Identification Task (Experiment 1) did not demonstrate learning of metrical and non-metrical patterns in a multiple response SRT, and results did not support the hypothesis that temporal patterns can be learned. Based on the results of Experiment 1 and suggestions by Ullén and Bengtsson (2003), it was hypothesized that the learning of temporal patterns is underestimated in the multiple response SRT. In contrast, the single response SRT (Salidis, 2001) and the IRT (Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003) are hypothesized to be more sensitive methods for investigating the IL of temporal patterns in the absence of an ordinal pattern; responses to the temporal pattern in the single response SRT and IRT are less dependent on knowledge of the ordinal sequence.

To examine the hypothesis that learning of temporal patterns is underestimated in the multiple response SRT when the ordinal sequence is unpredictable, Experiments 2a and 3b compared the learning of temporal patterns in the multiple response SRT with learning in a single response SRT (Experiment 2a) or an IRT (Experiment 3b). In line with this hypothesis, results of Experiments 2a and 3b suggest that measures of temporal
pattern learning underestimate temporal learning in a multiple response SRT when the identity of the upcoming stimulus is uncertain. Interpreted through the concept of probabilistic uncertainty, results suggest that temporal pattern learning is obscured when the upcoming stimulus is uncertain because a response to the ordinal stimulus cannot be prepared even if information about the temporal pattern has been acquired.

7.1.2 The Independent Learning of Temporal Patterns from Ordinal Sequences

The present results have implications for learning temporal patterns that occurs independently of ordinal patterns. Studies that have used the multiple response SRT to examine independent learning of temporal and ordinal patterns (Buchner & Steffens, 2001; O’Reilly et al., 2008; Shin & Ivry, 2002) have indicated that temporal patterns are only learned with a concurrent ordinal pattern. In other words, knowledge of the temporal pattern is not shown in the absence of the ordinal pattern. Thus, previous studies have concluded that temporal patterns are not learned independently of ordinal patterns (Buchner & Steffens, 2001; O’Reilly et al., 2008; Shin & Ivry, 2002). By contrast, studies that have used metrical patterns in a multiple response SRT (Brandon et al., 2012) or IRT (Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003) have demonstrated that temporal patterns can be learned when the ordinal sequence is unpredictable.

In accordance with previous findings, the results of Experiments 2a, 3a, and 3b indicate that the independent learning of temporal patterns is observed in the IRT or the single
response SRT but not the multiple response SRT. Thus, the present results are in accordance with previous results of studies that have used single response SRT (Salidis, 2001), multiple response SRT (Buchner & Steffens, 2001; O’Reilly et al., 2008; Shin & Ivry, 2002; but not Brandon et al., 2012), and the IRT (Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003). There were, however, some notable differences between the present experiments and previous multiple response SRT paradigms that did not demonstrate independent learning of temporal patterns. These differences, and their implications, are now discussed.

In a multiple response SRT, Buchner and Steffens (2001) trained participants on a temporal pattern of response-stimulus intervals concurrently with an ordinal pattern of pitches where each pitch could have i) an exclusive one-to-one relationship with the temporal intervals (i.e. perfectly correlated) or, ii) a more ambiguous relationship. In test blocks containing a random temporal sequence, RT increases were observed for the perfectly correlated condition (i), but not the ambiguous condition (ii). In Experiment 3a of the thesis, temporal intervals and spatial locations had an ambiguous relationship to one another (i.e. temporal and ordinal patterns were correlated), that is, a given temporal interval could be associated with any of three spatial locations. In contrast with the results of Buchner and Steffens, Experiment 3a indicated that temporal patterns were learned independently of the ordinal pattern: test blocks containing a novel temporal pattern demonstrated RT increases in the multiple response SRT and increases in temporal error in the IRT.
The main difference between the experiment by Buchner and Steffens (2001) and Experiment 3a in the present thesis is that Buchner and Steffens used temporal patterns of response-stimulus intervals, whereas Experiment 3a used temporal patterns of IOIs. It is likely that it is easier to form temporal expectancies for temporal patterns of IOIs than for response-stimulus intervals because the intervals between event onsets for response-stimulus intervals vary as a function of RT. Thus, Buchner and Steffens may not have demonstrated independent learning of temporal patterns due to the use of response-stimulus intervals. As shown in Experiment 3a, it appears possible to learn temporal patterns independently of ordinal patterns if the temporal pattern is constructed from IOIs.

O’Reilly et al. (2008) used a multiple response SRT to examine temporal pattern learning where, in training blocks, the ordinal sequence was either predictable or random. Learning of the temporal pattern (IOIs) was only observed in conditions where the ordinal pattern was predictable in training blocks, but not when the ordinal sequence was random; results were interpreted as evidence that temporal patterns can only be learned in the presence of ordinal patterns. The results of the multiple response SRT in Experiments 2a, 3a, and 3b were in line with the results of O’Reilly et al.: learning of the temporal pattern was not demonstrated in the multiple response SRT when the ordinal sequence was random (Experiments 2a and 3b). However, the two tasks that are less affected by probabilistic uncertainty of the stimulus identity (i.e. the single response SRT and the IRT) indicated that the temporal pattern was still learned when the ordinal sequence was random. Thus, it is possible that learning of the temporal pattern was
underestimated in O’Reilly et al. (2008) due to probabilistic uncertainty in the condition where the ordinal sequence was random and that, subsequently, independent learning of the temporal pattern was not observed.

In Shin and Ivry (2002), learning of the temporal pattern was examined in an SRT by comparing the RT increases in different test blocks where: i) the ordinal sequence could be random while the temporal pattern remained, ii) the temporal sequence could be random while the ordinal pattern remained, or iii) both the ordinal and temporal sequences were random. Results showed that RT increases were greater when the ordinal sequence was random than when the temporal sequence was random, and was viewed as evidence that temporal patterns cannot be learned independently of an ordinal pattern. However, it is possible that larger RT increases in response to a random ordinal sequence compared to a random temporal sequence are elicited by probabilistic uncertainty. Participants were unable to prepare responses when the ordinal sequence was unpredictable, resulting in larger RT increases when the ordinal sequence was random; participants could still prepare responses when the ordinal pattern was predictable, even if the timing of the stimulus was unpredictable. The fact that RT is more affected by changes in the ordinal pattern compared to changes in the temporal pattern indicates that the multiple response SRT is more sensitive to ordinal pattern learning than to temporal pattern learning. Thus, it is likely that independent learning of temporal patterns has not been observed in a multiple response SRT due to the primary focus of the task, that is, identification of the ordinal stimuli²₄.
7.1.3 Comparing the Implicit Learning of Metrical and Non-metrical Patterns

The IL of metrical and non-metrical patterns was demonstrated in a single response SRT (as used by Salidis, 2001) in Experiment 2b, and in an IRT in Experiments 3a and 3b (as used by Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003). Results supported the hypothesis that metrical and non-metrical patterns can be implicitly learned: In Experiment 2b, RT decreased over training blocks and increased in test blocks for metrical and non-metrical conditions; in Experiments 3a and 3b, timing error decreased over training blocks and increased in test blocks for metrical and non-metrical conditions.

7.1.3.1 Was Learning Implicit?

The generation task was used to assess the contribution of implicit and explicit learning of temporal pattern in Experiment Sets 2 and 3. Similarity between the generated sequences and the training pattern was not significantly greater under the inclusion instruction than under the exclusion instruction. Results suggest that participants could not explicitly reproduce the temporal pattern (in the inclusion instruction) any better than they implicitly reproduced the temporal pattern under instruction to produce new patterns (in the exclusion instruction). Thus, the generation task indicated that learning of the temporal pattern was implicit for metrical and non-metrical patterns. However,

24 In the SRT of Experiment 3a, where the ordinal pattern was predictable, RT increases were comparable for temporal and ordinal test blocks, where test blocks contained novel patterns that matched the training patterns with respect to simple frequency information (Reed & Johnson, 1994). It is possible that RT increases were larger when the ordinal sequence was random than when the temporal sequence was random due to the use of random test blocks. It is also possible that the use of auditory stimuli in experiments reported here facilitated learning of the temporal pattern (Carney, 1999).
based on responses in the recognition task, the SIMM indicated that learning of the metrical pattern was implicit in Experiment 2a, but not in Experiment 2b\textsuperscript{25}. In the SIMM, it is assumed that IL and unconscious processes are reflected by perceptual fluency. As there was a difference between the results of the generation task and the recognition task as analysed by the SIMM, it is possible that perceptual fluency is not necessary for learning to be implicit and that perceptual fluency may reflect a different process or component of IL (see section 7.4).

7.1.3.2 Did Meter Facilitate Temporal Learning?

The hypothesis that metrical patterns are learned more readily than non-metrical patterns was only supported in the IRT for implicit learners in Experiment 3a, but not in the single response SRT in Experiment 2b, or the IRT in Experiment 3b. In Experiment 2b, metrical and non-metrical patterns were learned at similar rates and similar RT decreases occurred over training blocks for metrical and non-metrical conditions. Similarly, in Experiment 3b, timing error decreased over training blocks at comparable rates for metrical and non-metrical conditions. In Experiment 3a, where there was a concurrent ordinal pattern, metrical patterns were learned more readily than non-metrical patterns for implicit learners in the IRT. Furthermore, there was a tendency for ordinal patterns to be learned more readily in the metrical condition compared to the non-metrical condition. These results are in line with the dynamic attending theory (Jones & Boltz, 1989) and the concept of attentional oscillators: in the metrical condition, attention was

\textsuperscript{25}As the duration of experimental sessions was long (i.e. 60 minutes) and potentially fatiguing, the recognition task and SIMM were not used in Experiment Set 3.
guided to periodic points in time and facilitated the encoding of the temporal pattern and also the ordinal pattern.

7.1.3.3 Was the Metrical Framework Abstracted?

To assess whether the metrical framework was abstracted, performance decrements were compared in response to novel SM patterns and novel WM patterns. If performance decrements (i.e. RT increases in the SRT, timing error increases in the IRT) are greater in the WM test block compared to the SM test block, then the metrical framework has been abstracted. Furthermore, to ensure that these differences are due to changes in the metrical strength and not due to differences in rhythmic complexity, a non-metrical condition was also included. The rationale is as follows: Non-metrical test blocks were identical to the metrical test blocks (SM and WM) with regard to figural groupings and simple frequency information, and differed only in terms of the non-metrical timing deviations (i.e. deviations from a metrical framework) in the non-metrical condition. If differences between the two test blocks occur in the metrical condition, but not the non-metrical condition, then the differences between SM and WM test blocks in the metrical condition cannot be attributed to differences in rhythmic complexity. Instead, differences between SM and WM test blocks would indicate that the metrical framework was abstracted.

Results supported the hypothesis that the metrical framework was abstracted and learned in the metrical condition for Experiment Set 2, and speculative evidence was revealed in Experiment Set 3. In Experiment 2b, abstraction of the metrical framework was evident:
in the metrical condition, greater RT increases occurred for novel WM test patterns than for novel SM test patterns; in the non-metrical condition, there were no differences between non-metrical test blocks with matched figural groupings. Thus, differences between RT increases in SM and WM test blocks can only be attributed to differences in metrical strength and not to differences in pattern complexity. Similarly, for metrical patterns in Experiments 3a and 3b, learning of the metrical framework was suggested in the IRT for implicit learners through greater increases in temporal error for novel WM test patterns than for SM test patterns (although these results are based on a non-significant interaction in Experiment 3a, and a near-significant interaction in Experiment 3b). Moreover, in Experiments 3a and 3b, there were no differences between non-metrical test blocks that were identical to metrical test patterns with regard to simple event frequency and figural groupings, a result in line with those of Experiment 2b.

Taken together, results of Experiment Sets 2 and 3 indicate that entrainment to a metric structure occurred when events occurred periodically (i.e. in the metrical condition), a result in line with the metric binding hypothesis that posits that multiple attentional oscillators adapt to the periodicity of a temporal pattern at multiple levels (Jones, 2009). More specifically, in the metrical condition, attentional oscillators entrained to the beat (i.e. the smallest IOI) and to strong beats that occurred every four beats. Thus, when the novel SM pattern was introduced, attention was guided to strong beats that contained an event. When the WM pattern was introduced, where events did not occur every four beats, attention was sometimes guided to points in time that did not contain an event and expectancies were violated, thus leading to larger performance decrements in test blocks.
Overall, results of Experiment Sets 2 and 3 indicated a benefit of meter concerning either the rate of learning in training blocks (Experiment 3a) or the utilization of the metrical framework for novel rhythms with the same metrical strength in test blocks (Experiment Sets 2 and 3). The hypothesis that metrical patterns are learned more readily than non-metrical patterns was supported in Experiment 3a, where decreases in temporal error and ordinal error over training blocks were greater when a metrical framework was present, than when the pattern was non-metrical. In Experiments 2a (single response SRT), 2b, 3a, and 3b, there was a benefit of meter in test blocks when the strength of the metrical framework was maintained (in the SM test block): although the temporal pattern was novel, the persistence of the metrical framework facilitated responses to events that conformed to the metrical framework. These results are consistent with the dynamic attending theory (Jones & Boltz, 1989) and the metric binding hypothesis (Jones, 2009). The implications of the present findings are now discussed.

7.2 The Impact of Method and Task on the Implicit Learning of Temporal Patterns

The experiments in the present thesis have brought to light the way in which methodological differences can result in the underestimation of temporal pattern learning. Most of the previous experiments on the IL of temporal patterns that have used a multiple response SRT have been unable to demonstrate learning of the temporal pattern that is independent of the ordinal pattern (Buchner & Steffens, 2001; O'Reilly et al. 2008; Shin & Ivry, 2002; but see Brandon et al., 2012). The present results indicate
that the multiple response SRT underestimates temporal learning when the ordinal pattern is unpredictable, a finding in line with the suggestions of Ullén and Bengtsson (2003). It is proposed that the underestimation of temporal learning in the multiple response SRT is due to probabilistic uncertainty of the stimulus identity; that is, participants were unable to prepare responses to the unpredictable ordinal stimuli (e.g. spatial location), even if they have acquired knowledge of the timing of the events or the temporal pattern.

The present thesis indicates that the single response SRT (Salidis, 2001) and the IRT (Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003) are more sensitive methods for examining temporal learning and are less affected by probabilistic uncertainty of the stimulus identity. This is not to say that temporal pattern learning cannot occur in a multiple response SRT; the results of Brandon et al. (submitted) indicate that temporal patterns can be learned in a multiple response SRT when the ordinal sequence is random. Instead, it is argued that the exhibition of temporal learning is underestimated in the multiple response SRT, and is underrepresented relative to the learning of ordinal patterns. Thus, future research on the independent learning of ordinal and temporal patterns warrants the use of the IRT to ensure that the measure of learning is sensitive to temporal learning.

7.2.1 Implicitly Learning Patterns of Inter-onset Intervals

Experiments in the present thesis differed from previous studies on the IL of temporal patterns regarding the type of temporal intervals used and the stimulus modality. The
present experiments (see also Brandon et al., 2012; Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003) used patterns of IOIs, whereas previous studies used patterns of response-stimulus intervals (Buchner & Steffens, 2001; Salidis, 2001; Shin & Ivry, 2002, Experiment 1). The hypothesis was that it would be more difficult to learn temporal patterns that consist of response-stimulus intervals because the intervals between event onsets vary as a function of RT. Furthermore, temporal patterns that consist of response-stimulus intervals are inherently non-metrical (Salidis, 2001) and even more non-metrical than the temporal patterns used in the present thesis: Intervals between the onsets of consecutive events are modulated by RT for response-stimulus intervals, and it is unlikely that intervals between events could be conceived in terms of a metrical framework. If metrical patterns are learned more readily than non-metrical patterns, and IOIs facilitate learning relative to response-stimulus intervals, then metrical patterns that are constructed from IOIs should be learned even more readily than non-metrical patterns that are constructed from response-stimulus intervals.

Results of the present experiments indicate that IOI patterns can be learned, but a direct comparison of IOI patterns and response-stimulus interval patterns is required to test whether IOI patterns are learned more readily than response-stimulus interval patterns. Handel (1998, pp. 1546) stated that any rhythm or temporal pattern consisting of IOIs “… is metric to some degree, depending on the strength of the meter interpretation it evokes.” Thus, future research could compare the IL of metrical (IOI) patterns and non-metrical (response-stimulus interval) patterns to examine how temporal expectancies are formed in the presence and full absence of meter. Such research would have
implications for how people learn and are taught skills that could be considered non-metrical in a musical sense, such as sport and language. It is an open empirical question whether such skills are learned faster or more effectively if metrical timings were introduced, at least during preliminary training sessions.

7.2.2 Implicitly Learning Auditory Temporal Patterns

Regarding stimulus modality, some of the previous studies that have not shown temporal learning using the multiple response SRT have used visual stimuli (O'Reilly et al., 2008; Shin & Ivry, 2002; but Buchner & Steffens, 2001 used auditory pitch stimuli). Conversely, studies using auditory stimuli (Brandon et al., 2012; Salidis, 2001) or auditory-visual stimuli (Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003) have demonstrated temporal pattern learning. There is some research that indicates that audition dominates vision for temporal processing of complex rhythms in sensorimotor synchronization tasks when discrete visual stimuli are used (Patel et al., 2005; Repp & Penel, 2002; 2004). There is also some evidence that, for isochronous patterns, synchronization to dynamic visual displays is comparable to that of auditory patterns (Hove, Spivey & Krumhansl, 2010). The results of the present experiments provide some support to the hypothesis that the auditory pathway specializes in temporal perception (Carney, 1999). However, a comparison between the IL of temporal patterns in the auditory modality and those in the visual modality has not yet been conducted. Such a comparison could use dynamic visual displays (see, for example, Gobel, Sanchez, & P. Reber, 2011) to examine whether temporal expectancies can be formed implicitly for visual and auditory temporal patterns.
Research in neuroscience (e.g. Baumann, Koeneke, Meyer, Lutz, & Jäncke, 2005) and sensorimotor perception (e.g. Lahav, Boulanger, Schlaug, & Saltzman, 2005; Loehr & Palmer, 2009) has suggested a close relationship between auditory cortex and motor cortex. Tasks such as the SRT and IRT both have a strong motor component associated with learning, where learning is shown through speeded reaction times or more accurate reproductions over blocks. Thus, it is likely that the IL of auditory temporal patterns would occur more readily than the IL of visual temporal patterns. Future experiments could compare how auditory and visual temporal patterns are learned, and whether auditory temporal patterns are learned more effectively than visual temporal patterns. As there is some evidence that it is more difficult to abstract a beat for visual temporal patterns (Grahn, Henry, & McAuley, 2011; Patel et al., 2005), future research could explore whether metrical frameworks are abstracted for visual temporal patterns as well as auditory temporal patterns as indicated in the present experiments.

7.3 Differences in the Learning of Metrical and Non-metrical Patterns

The learning of metrical and non-metrical patterns was demonstrated in Experiment 2b (Chapter 4), and Experiments 3a and 3b (Chapter 6). Metrical patterns were only learned more readily than non-metrical patterns in the IRT of Experiment 3a, and only for participants who learned implicitly. However, there was evidence that the metrical framework was abstracted in Experiments 2b, and speculative evidence in Experiments 3a and 3b, even though the hypothesis that metrical patterns are learned more readily than non-metrical patterns was not supported in Experiment 2b and 3b. Taken together,
these results suggest that, even if the metrical framework is abstracted, the metrical framework does not always facilitate the learning of the temporal pattern. Specifically, metrical patterns were only learned more readily than non-metrical rhythms when 1) learning is implicit, 2) temporal patterns are learned concurrently with an ordinal pattern, and 3) learning occurs in a reproduction task such as the IRT, but not in an online task such as the single response SRT. These three points and their implications are now discussed.

7.3.1 A Benefit of Meter for Implicit Learning

Meter only facilitated learning in Experiment 3a for participants who learned implicitly. This result conflicts with previous research that has indicated that meter facilitates the learning of temporal patterns under explicit instruction (e.g. Essens & Povel, 1985; Grahn & Brett, 2007). However, constraints in the construction of the temporal patterns distinguish the present experiments from previous experiments. Previous experiments have compared metrical and non-metrical patterns using patterns that are not matched with regard to simple frequency information (Reed & Johnson, 1994) or figural and rhythmic groupings (Bamberger, 1980). Simple frequency information concerns the statistical properties of a pattern: item frequency, the number of times each item occurs in a sequence; transition frequency, the number of times each pair of items occurs in a sequence; rate of reversal, the frequency with which the first and third item of a group of three are identical; rate of full coverage, the number of items that need to be viewed in a sequence for each item to be presented at least once, and; the rate of full transition usage, the number of pairs that need to be presented for each unique pair of items to be
perceived at least once. Figural groupings refer to the size and frequency of groups of temporally proximal events (Bamberger, 1980).

In the present experiments, metrical and non-metrical patterns had identical conditional probabilities and figural groupings, and, therefore, identical rhythmic complexity (e.g. Lempel & Ziv, 1976; Tanguiane, 1993). It is possible that differences between metrical and non-metrical patterns in previous experiments were elicited by differences in surface statistical structures of the patterns or differences in rhythmic complexity (Essens & Povel, 1985; Grahn & Brett, 2007). Future experiments could use similar constraints to those applied here (i.e. matched simple frequency information and rhythmic groupings) to examine whether differences between metrical and non-metrical patterns are elicited under explicit instruction when patterns have identical rhythmic complexity (at least, insofar as figural groupings are concerned). A comparison of metrical and non-metrical patterns constructed so as to have matched simple frequency information and matched figural groupings could reveal that previous observed differences between the reproduction of metrical and non-metrical patterns are due to differences in rhythmic complexity as opposed to differences in the presence or absence of meter. The results of Experiments 2b and 3b indicate that metrical and non-metrical patterns are learned similarly when matched for simple event frequency and figural grouping.

Some measures of rhythmic complexity (e.g. Povel & Essens, 1985; Shmulevich & Povel, 2000) have also included components that account for metrical interpretation, and the interplay between metrical accents and rhythmic accents (see Essens, 1995 for a review).
7.3.2 The Relationship between Ordinal Patterns and Metrical Structures

Concerning the predictability of the ordinal pattern, metrical patterns were only learned more readily than non-metrical patterns when learned with a concurrent ordinal pattern (i.e. in Experiment 3a), but not when the ordinal sequence was random (i.e. in Experiments 2b and 3b). These results suggest that meter only facilitates learning when the pattern of ordinal stimuli is predictable. It is possible that there was interplay between the predictability of the ordinal structure and predictability based on the metrical framework, due to heightened expectancies at metrical locations as suggested by the metric binding hypothesis (Jones, 2009). In other words, the metrical structure may have facilitated learning of the ordinal pattern and, simultaneously, the ordinal pattern may have aided learning of the temporal structure. In a functional magnetic resonance imaging experiment, Bengtsson, Ehrsson, Forssberg, and Ullén (2004) demonstrated that there were specific areas associated with temporal control (e.g. presupplementary motor area, right inferior frontal gyrus and precentral sulcus, and bilateral superior temporal gyri) and ordinal control (e.g. lateral fronto-parietal areas, basil ganglia, and cerebellum). However, Bengtsson et al. (2004) also demonstrated that, when a combined ordinal-temporal pattern was presented, there were additional subcortical areas that were activated that may reflect the integration of temporal and ordinal patterns (e.g. vermis and superior colliculi of mesencephalon). Thus, there may be several interrelated mechanisms that are activated when temporal and ordinal patterns are learned concurrently, as well as separate mechanisms for the independent learning of ordinal and temporal patterns. Future research could examine patterns of activation when temporal patterns are metrical and non-metrical to test whether metrical
frameworks play a role in the integrated learning of ordinal and temporal structures. If, when learned with ordinal patterns, metrical patterns elicit greater activation than non-metrical patterns in the subcortical areas that have been hypothesized to be related to integration, then it is possible that meter aids in the integration of ordinal and temporal information.

Previous experiments that have compared the reproduction of metrical and non-metrical patterns have used a constant stimulus, that is, the ordinal dimension was constant and did not introduce changes in pitch, intensity, or timbre (Essens & Povel, 1985; Grahn & Brett, 2007). Other experiments have investigated the effect of metrical frameworks on pitch discrimination (Ellis & Jones, 2009; Jones, Boltz, & Kidd, 1982) and have indicated that responses to ordinal (pitch) stimuli are facilitated if the stimuli align with a metrical framework. Similarly, studies on joint accent structure (Ellis & Jones, 2009; Jones & Pfordresher, 1997) have investigated the relationship between metrical accents and phenomenal accents. Joint accent structure is a theoretical construct that derives measures of pattern complexity from the relationship between metrical accents and phenomenal accents (Jones & Pfordresher, 1997). Phenomenal accents are accents that arise from changes in the properties of the stimulus relative to surrounding stimuli, such as pitch, intensity, and duration (Lerdahl & Jackendoff, 1983). Similar to Povel and Essens’ (1985) clock model, joint accent structure measures rhythmic complexity based on how often phenomenal accents occur periodically, that is, on theorized strong beats. Research into joint accent structure has demonstrated that phenomenal accents can affect the metrical interpretation and perceived complexity of a temporal pattern (Ellis &
Jones, 2009; Jones & Pfordresher, 1997), indicating that there is a complex relationship between ordinal patterns and metrical temporal patterns (and possible non-metrical patterns). However, there have been no systematic studies on the interaction between metrical frameworks and the predictability of a newly learned ordinal pattern.

Results of the present experiments indicate that metrical patterns are only learned more readily than non-metrical patterns when an ordinal pattern is predictable. Future research could examine how metrical and non-metrical patterns are learned in the presence of an ordinal pattern that does or does not conform to newly acquired expectancies, both under explicit instruction and when learning is implicit. Such research would provide greater insights into the independent and integrated learning of temporal and ordinal structures. Furthermore, future experiments could exploit other expectancies to ordinal patterns (e.g. tonal expectancies) and how these relate to metrical expectancies (Chen, Penhune, & Zatorre, 2008; Janata, 2005). Experiments of this nature would bring to light how musical sequences are learned, and how musical expectancies are acquired through exposure to various musical styles.

7.3.3 Meter Facilitates Learning in Offline Tasks

Comparing the results of the IRT and the multiple response SRT, metrical patterns were only learned more readily than non-metrical patterns in Experiment 3a in the IRT, but not the multiple response SRT. In Experiment 2b, it was suggested that differences between metrical and non-metrical patterns were not evident due to the use of an online task, and that tasks that involve the encoding and retrieval of temporal patterns may
elicit larger differences between metrical and non-metrical patterns. In support of this suggestion, previous studies that have found differences between metrical and non-metrical patterns have used reproduction tasks (Essens & Povel, 1985; Grahn & Brett, 2007).

Differences between metrical and non-metrical patterns have also been observed in online tasks, but only when the temporal structure of the non-metrical pattern was unpredictable (Large & Jones, 1999). Large and Jones used sequences of IOIs where the order of IOIs was not predictable and, subsequently, temporal expectancies could only be derived from the metrical framework but could not be based on any systematic pattern of IOIs. For non-metrical conditions, non-metrical timing deviations were introduced at various points in the temporal sequence. Thus, learning of a temporal regularity was impossible for non-metrical patterns; there was no metrical framework or systematicity on which to base expectancies in the non-metrical condition. It follows that differences between metrical and non-metrical patterns in Large and Jones (1999) were driven by a lack of any learnable structure in non-metrical conditions. However, Large and Jones did not aim to investigate how metrical and non-metrical patterns are learned; the aim of the experiments in Large and Jones was examine how internal oscillations can entrain and adapted to metrical time structures.

The present results indicate that the learning of metrical and non-metrical patterns does not differ in an online task (i.e. the single response SRT in Experiment 2b), with the exception that metric binding occurs for metrical patterns (as indicated by larger RT
increases in the WM test block compared to the SM test block). To the knowledge of the author, Experiment 2b was the first comparison between the learning of predictable metrical and non-metrical patterns in an online task. Further research on the learning of predictable metrical and non-metrical patterns in online and offline tasks may bring to light differences between metrical expectancies and expectancies based on the probabilistic structure of IOIs. Such research could reveal that the benefit of meter that is theorized in clock models and the dynamic attending theory is essentially a global benefit of expectancy that can be realized with any predictable structure, that is, metrical structures or probabilistic structures (e.g. second order conditional probabilities).

7.4 The Implicit Learning of Temporal Patterns: Motor Fluency and Perceptual Fluency

Experiments 2a and 2b used generation and recognition post-test tasks based on the process dissociation procedure (Jacoby, 1991) to examine the degree to which temporal patterns were learned implicitly (see Chapter 4 and Chapter 5). While the generation task reflects IL based on the assumption that motor fluency is related to unconscious processes, the recognition task (and the SIMM) reflects IL based on the assumption that perceptual fluency indicates unconscious processes. However, there were differences between the results of the generation task and the results of the recognition task as evaluated by the SIMM: in Experiment 2a, the generation task and SIMM both indicated that learning of the metrical pattern was implicit; in Experiment 2b where the procedure was identical to Experiment 2a, the generation task indicated that learning of the metrical pattern was implicit, but the SIMM indicated that learning was equally implicit.
and explicit. As discussed in Chapter 5, these results could indicate that 1) perceptual fluency does not represent unconscious processes, and instead reflects another component of conscious processes (as per Shanks & Johnstone, 1999), 2) perceptual fluency represents the amount of control one has over the use of implicitly learned information (as per Fu, Dienes, & Fu, 2008), or 3) that motor fluency and perceptual fluency are dissociable processes that capture different aspects of implicit learning, as suggested by previous experiments on the relationship between perceptual and motor fluency (Gaillard & Cleeremans, submitted; Yang, Gallo, & Beilock, 2009).

The discrepancy between the generation task and the SIMM in Experiment 2b, but not Experiment 2a, has revealed that there may be differences between the processes captured by generation tasks and recognition tasks. The present thesis did not aim to investigate which processes are captured by the generation and recognition task and, subsequently, no conclusions can be reached regarding what process the recognition task measures (i.e. implicit learning or control over implicitly acquired information). Rather, we rely on to the generation task as a measure of IL because it has been shown to be a sensitive measure of implicit and explicit sequence knowledge (Perruchet & Amorim, 1992). Furthermore, the generation task has been used to examine the IL of temporal patterns (Karabanov & Ullén, 2008) and ordinal patterns (Destrebecqz & Cleeremans, 2001; 2003). However, the disagreement between the results of the generation task and the recognition task indicates that these two measures may capture qualitatively different processes, and warrants further investigation. In particular, future experiments could investigate whether the differences between the generation task and the recognition task
occur under conditions of increased attentional load. For example, a motor task (e.g. a tapping task) and a perceptual task (e.g. a tone counting task) could each be performed during the generation and recognition tasks. If the motor task only interferes with performance in the generation task, and the perception task only interferes with the recognition task, then motor fluency and perceptual fluency are dissociable processes. Alternatively, if the motor task interferes with the recognition task, and the perceptual task interferes with the generation task, then motor fluency and perceptual fluency may reflect similar and related processes.

7.5 Limitations of the Thesis

A limitation of the present thesis is that the temporal patterns used could be considered too slow to be interpreted as musical rhythms. While previous rhythm perception studies have used IOIs ranging from 200ms to 800ms (e.g. Essens & Povel, 1985; Povel & Essens, 1985), IOIs in the present study ranged from 500ms to 2000ms (Experiment Set 2) and 400ms to 1600ms (Experiment Set 3). The tempi of the temporal patterns used here were chosen to ensure that participants were able to respond to, and/or identify, stimuli that were presented continuously and sequentially. Results indicated that participants were still able to abstract the metrical framework for metrical patterns. However, to make ecologically valid conclusions regarding how people learn musical rhythms, temporal patterns with faster tempi would have to be used. Future experiments could use the single response SRT or the IRT to investigate temporal learning of temporal patterns with faster tempi.
Similarly, ordinal stimuli would have to consist of series of pitches (or timbres) to be considered musical. In the present experiments, auditory spatial stimuli were used to create stimuli that were less likely to produce phenomenal accents (Lerdahl & Jackendoff, 1983). Patterns that change along the dimension of pitch could be conceived as musical melodies. The present thesis avoided the use of musical melodies under the assumption that a continuously cycling melody of three or four pitches would likely be learned explicitly (as in Buchner & Steffens, 2001). Furthermore, such stimuli may have resulted in auditory stream segregation, that is, the perceptual grouping of sounds from a single source into separate elements based on pitch cues (Bregman, 1990). However, it is possible that melodies consisting of a temporal pattern and an ordinal pattern of pitches could be implicitly learned. An investigation of the IL of melodies would provide a more ecologically valid approach for how musical patterns are learned and whether this can occur implicitly.

Another limitation is that the present thesis only investigated metrical patterns that have a quadruple meter, a common meter in Western music. It is possible that participants had a predisposition to the quadruple meter, that is, participants were acculturated to the quadruple meter. Hannon and Trehub (2005) demonstrated that infants learn foreign rhythms more readily than adults, indicating that acculturation to certain rhythms and meters occurs during development. In turn, acculturation could preclude the abstraction of novel meters and/or strengthen expectancies for meters that are more commonly experienced. Thus, the typically Western listeners in the present experiments may have had a cultural predilection for the quadruple meter. To further examine how people
attune to novel meters, the learning of temporal patterns with meters that are less common in Western music could be investigated. For example, the meters of music from the Balkan regions could provide insights into how attending oscillators may entrain to periodicities that have not often been encountered (Tillmann, Stevens, & Keller, 2011). Investigations and comparisons between Western meters and meters from other cultures would reveal whether the findings of the present study that corroborate metric binding can be generalised to other metrical frameworks (e.g. uneven meters). Paradigms such as the single response SRT or IRT could be used to examine the formation of temporal expectancies for Western meters and for more culturally diverse meters.

7.6 Conclusions

The five experiments and model-based analysis have broad implications for temporal perception, music cognition, and implicit learning. By exploiting the implicit learning of rhythmic patterns, the present project has brought into relief how temporal expectancies are acquired, and how temporal patterns might be cognitively organized into meaningful groups or units (e.g. via the abstraction of meter). By using methods designed to elicit IL (and methods to assess IL), the acquisition of new temporal expectancies occurred in a manner analogous to mere exposure (Reber, 1989), that is, without explicit awareness or intention. The present research paves the way for future research that could investigate how musical grammars are learned, such as metrical and tonal hierarchies (e.g. Lerdahl & Jackendoff, 1981; 1983). Artificial grammar learning paradigms (Reber, 1969) using rhythmic and melodic grammars could provide insights into how music is learned via
acculturation, that is, exposure to a particular cultural context (e.g. Hannon & Trehub, 2005).

As previous research has indicated that implicitly learned information can be better retained and implemented than information that is learned explicitly (Lewicki, 1986; Reber, 1969; 1976; Reber & Allen, 1978), the present results have implications for music education and also clinical applications (e.g. Campbell, 1991; Casey, 1991; Young, 1971). The present experiments implemented a “Computer Game for the Blind” in which participants implicitly acquired information about rhythmic structures. A computer game paradigm could be used for teaching purposes, where students implicitly learn how to perform complex sequences of actions that consist of temporal and ordinal structures, such as playing a musical instrument (e.g. Baumann et al., 2005; Clarke, 1993). Take, for example, the computer game Guitar Hero (Activision Publishing Inc., 2005-2010) where players synchronize responses to a continuous stream of ordinal stimuli that correspond to buttons on a faux guitar. If such a game paradigm could be transferred to real musical instruments, then it would be possible to teach people novel and diverse ordinal and temporal patterns in an engaging context. Furthermore, such learning might be implicit: players could learn sequences of musical actions (i.e. temporal and ordinal patterns) without intention to learn, or awareness regarding the structures that have been learned.

Implicit learning could be a powerful tool for rehabilitation programs for populations who exhibit difficulties in temporal processes, such as stroke patients (Pohl, McDowd,
Filion, Richards, & Stiers, 2005). Boyd and Weinstein (2003) showed that explicit instruction interferes with motor learning for adult stroke patients. In contrast, Pohl et al. (2005) demonstrated that stroke patients can implicitly learn ordinal sequences. In a direct comparison of implicit and explicit learning of sequences for basil ganglia stroke patients, Boyd and Weinstein (2004) found that learning was impaired for participants who were provided explicit sequence information but not for participants who received no additional information. Taken together, these results (Boyd & Weinstein, 2003; 2004; Pohl et al., 2005) suggest that IL a potentially effective mode of learning for stroke patients that may aid in rehabilitation for performing motor actions. In relation to IL of temporal patterns, a treatment entitled melodic intonation therapy (Schlaug, Marchina, & Norton, 2008) has been suggested for speech rehabilitation for stroke patients. Melodic intonation therapy involves a melodic (i.e. singing) and a temporal (i.e. tapping) component and, importantly, the temporal component involves moving and singing to an isochronous beat, that is, the timing is metrical. In fact, a study by Stahl, Kotz, Henseler, Turner, and Geyer (2011) demonstrated that rhythm plays a crucial role in the rehabilitation of stroke patients, and may even be the driving force behind the benefits of melodic intonation therapy for stroke patients. Thus, implicitly learning motor movements in a rhythmic or metrical context may be one of the mechanisms that play a crucial role for the rehabilitation of stroke patients. IL of temporal structure is an important theoretical explanation for the success of melodic intonation therapy and awaits further investigation.
Lastly, a possible dissociation between IL and perceptual fluency has been revealed using the SIMM and a generation task based on the process dissociation procedure. While the generation task indicated that learning was implicit in Experiments 2a and 2b, the SIMM indicated that learning was implicit in Experiment 2a, but not Experiment 2b. The discrepancy between the results of the generation task and the SIMM may reflect differences between the recognition of patterns and the reproduction of patterns in terms of which processes are captured. For example, the recognition task may reflect perceptual fluency whereas the generation may reflect motor fluency. These results have implications for IL research that uses familiarity (i.e. perceptual fluency) as a measure of IL, and further research is necessary to understand the, somewhat controversial, relationship between perceptual fluency and IL (Shanks & Johnstone, 1999). Furthermore, future research on perceptual and motor fluency is important for understanding how implicit and automatic mechanisms may contribute to perception and action for ordinal and temporal sequences in a range of domains, from music cognition to language acquisition.
References


Schultz\(^b\), B. G., Stevens, C. J., Keller, P., & Tillmann, B. A sequence identification measurement model to investigate the implicit learning of metrical and non–metrical temporal patterns. Submitted (see Chapter 5).

Schultz\(^c\), B. G., Stevens, C. J., Keller, P., & Tillmann, B. The implicit learning of auditory metrical and non–metrical rhythms in an immediate recall task. In preparation (see Chapter 6).


Appendix A: Detailed Report of Experiment 1

The Syllable Identification Task

The purpose of Experiment 1 was to investigate whether metrical and non-metrical patterns can be learned in an SRT when the ordinal sequence is random, and to examine whether metrical patterns are learned more readily than non-metrical patterns. Experiment 1 closely followed the methods of Brandon et al. (submitted), and used auditory stimuli consisting of three different spoken syllables. Previous studies have demonstrated the IL of metrical patterns (Brandon et al., 2012; Karabanov & Ullén, 2008; Ullén & Bengtsson, 2003) and non-metrical patterns (Salidis, 2001). Thus, it was hypothesized that metrical and non-metrical patterns can be learned, as shown through RT decreases in training blocks, and RT increases in a test block. Based on music cognition research (Essens & Povel, 1985; Grahn & Brett, 2007; Keller & Burnham, 2005), and the dynamic attending theory and metric binding hypothesis (Jones, 2009), it was hypothesized that metrical patterns are learned more readily than non-metrical patterns. If RT decreases over training blocks are greater for metrical patterns than non-metrical patterns, then this indicates that metrical patterns were learned more readily.

It was also hypothesized that the learning of metrical and non-metrical patterns can be implicit, as indicated by the generation and recognition tasks based on the process dissociation procedure. In the generation task, IL is indicated if similarity scores in the exclusion instruction condition are greater than or equal to similarity scores in the inclusion instruction condition. In the recognition task, IL is indicated if participants are
able to recognize the pattern from the training blocks (i.e. the acquisition pattern), and reject novel patterns that have the same systematicity as the acquisition pattern (i.e. systematic patterns) or no systematicity (i.e. distracter patterns).

**A1 Experiment 1 Design**

In the SRT, the independent variables were Metricality (metrical, non-metrical; between-subjects) and Block (1-6; within-subjects), where blocks 1-4 and 6 contained the acquisition pattern, and block 5 was the test block. Syllable (/PA/, /KA/, /TA/; within-subjects) was also included as an independent variable to ensure that accuracy and RT for the different spoken syllables were comparable. For RT, IOI (metrical = 500ms, 1000ms, 1500ms, 2000ms, and 3000ms; non-metrical = 500ms, 1000ms, 1250ms, 2250ms, 3000ms) was also analyzed following Salidis (2001) to examine whether groups of proximal events may have been learned. Dependent variables were response accuracy, RT for correct responses, and overall improvement defined as the difference in RT between the first training block and the last training block (block 4). In the generation task, independent variables were Metricality (metrical, non-metrical; between-subjects) and Instruction (inclusion, exclusion; within-subjects); the dependent variable was similarity score which was defined as the correspondence between the generated sequences (in inclusion and exclusion conditions) and the training sequence from the SRT (see Appendix L). In the recognition task, independent variables were Metricality (metrical, non-metrical; between-subjects), Instruction (inclusion, exclusion; within-subjects), and Pattern (acquisition, systematic, distracter; within-subjects); the dependent variable was proportion of ‘Yes’ responses.
A2 Method

A2.1 Participants

Participants (N = 48) were first year Psychology students from the University of Western Sydney. Ages ranged from 18 to 43 years, with a mean age of 21.1 (SD = 5.5), and 34 were female. There was a large spread of nationalities, but the majority were Australian (N = 26), followed by Vietnamese (N = 6), Iraqi (N = 2), and Chinese (N = 2). Another 11 individual cases of different nationalities made up the rest of the sample (N = 11). No participants suffered a hearing impairment. Forty-three participants were right-handed and five were left-handed.

A2.1 Ordinal Sequences

Ordinal sequences consisted of the spoken syllables /KA/, /PA/, and /TA/ (see Appendix R), chosen because of comparable voice onset times (Brandon et al., 2012), that were created with MBROLA speech synthesizer software using a male voice. All syllables were of identical duration (218ms), fundamental frequency (120Hz), and maximum amplitude (approximately 1.0 Pascal), although they differed slightly in intensity (/KA/ = 81.62dB, /PA/ = 82.19dB, /TA/ = 82.68dB). These constraints were imposed to reduce the likelihood of the perception of phenomenal accents. Figure A1 shows the waveforms of the syllable stimuli. The order in which syllables occurred was pseudo-random, under the constraints that a syllable cannot occur twice consecutively and that each syllable occurred an equal number of times per block (3 Syllables x 67 occurrences = 201 event onsets).
Figure A1. Waveforms of stimuli (/KA/, /PA/, and /TA/) used to construct syllable sequences. Duration (.218 secs) and maximum amplitude (approximately 1 Pascal) were constant between stimuli. Minimum amplitude in Pascals (/KA/ = -.688, /PA/ = -.765, /TA/ = -.771) and intensity (/KA/ = 81.62dB, /PA/ = 82.19dB, /TA/ = 82.68dB) differed slightly between stimuli.
A2.2 Temporal patterns

The temporal patterns used in training and test blocks of the SRT, and the systematic and distracter patterns, are shown in Figure A2. Both metrical and non-metrical temporal patterns are based on the following interval patterns, where item identities A-E correspond with temporal intervals presented in Table A1. The assumed beat and metrical framework of the training pattern and test pattern (the SRT), and the novel systematic and distracter patterns (recognition task) for metrical and non-metrical conditions are presented in Figure 4. In the non-metrical condition, IOIs contained timing deviations from the theorized metrical framework. Timing deviations were larger than the just noticeable difference for timing deviations from the beat, that is, larger than 2.5% of the minimum IOI (i.e. 500ms), as per the results of Friberg and Sundberg (1995). Patterns had durations of 16,000 ms per presentation.

Training Pattern


Test Pattern


Novel Systematic Pattern

**Novel Distracter Pattern**


Table A1.

*Item identities for metrical and non-metrical patterns.*

<table>
<thead>
<tr>
<th>Item</th>
<th>Metrical</th>
<th>Non-metrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>500ms</td>
<td>500ms</td>
</tr>
<tr>
<td>B</td>
<td>1000ms</td>
<td>1000ms</td>
</tr>
<tr>
<td>C</td>
<td>1500ms</td>
<td>1250ms</td>
</tr>
<tr>
<td>D</td>
<td>2000ms</td>
<td>2250ms</td>
</tr>
<tr>
<td>E</td>
<td>3000ms</td>
<td>3000ms</td>
</tr>
</tbody>
</table>

Note: Items A, B, and E are kept constant for metrical and non-metrical patterns at 500ms, 1000ms, and 3000ms, respectively.
Figure A2. Metrical and non-metrical patterns in the training blocks and test block of the SRT, and the systematic and distracter patterns of the recognition task. Assumed beats are indicated by short vertical lines, strong beats are indicated by dashed vertical lines, and events of the rhythm are indicated by crosses. The stimuli only consist of the events in the rhythm; beats and strong beats are hypothesized to be cognitively abstracted by the perceiver.
As can be seen in Table A2, all simple frequency information (as per Reed & Johnson, 1994) is equal for the training and test patterns (item frequency has been omitted from the table, as this remains constant at .2 for all patterns). Simple frequency information also matches the training and test sequences for the systematic recognition pattern in all regards except for the rate of full coverage (FC).

Table A2.

*Transition frequency, rate of full coverage (FC), and rate of full transition usage (FTU) for training and test patterns in the serial reaction-time task, and systematic and distracter patterns in the recognition task.*

<table>
<thead>
<tr>
<th>Sequence</th>
<th>Transition Frequency</th>
<th>FC</th>
<th>FTU</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AB</td>
<td>AC</td>
<td>AD</td>
</tr>
<tr>
<td>Training</td>
<td>.1</td>
<td>0</td>
<td>.1</td>
</tr>
<tr>
<td>Test</td>
<td>.1</td>
<td>0</td>
<td>.1</td>
</tr>
<tr>
<td>Systematic*</td>
<td>.1</td>
<td>0</td>
<td>.1</td>
</tr>
<tr>
<td>Distracter</td>
<td>0</td>
<td>.1</td>
<td>0</td>
</tr>
</tbody>
</table>

*Note: The systematic pattern had a rate of full coverage that differed slightly from the training pattern. This could not be avoided with the current constraints on the training pattern.*

**A2.3 Apparatus**

Auditory stimuli were presented through Sennheiser headphones using Edirol UA-25EX sound drivers. PsyScope (Cohen, MacWhinney, Flatt, & Provost, 1993) software (installed on Macbook Pros) was used to present the instructions and auditory
stimuli, and to collect responses. A custom-made MatLab script was used to extract the data prior to analysis.

**A2.4 Procedure**

Participants were welcomed and they were advised that they will be performing a task in which they are to identify a series of syllables using keys “1”, “2”, and “3” on the number pad. The relationship between the syllable and the key corresponding to the syllable was counterbalanced across participants. Keys were labeled as /PA/, /KA/, and /TA/ according to their key correspondence and participants were able to view these labels at all times. Participants were then given an information sheet (see APPENDIX B) that provided the cover story of the importance of being able to understand spoken syllables and to quickly and accurately identify them. Participants were not informed that the timing of stimuli would follow a repeating pattern. After reading the information sheet and signing the consent form (as per APPENDIX B; ethics approval number H7764), participants were seated in front of the computer on which instructions were presented. Prior to the blocks, participants were given a practice block that contained a random temporal sequence (with duration of 1.07 seconds). Following the practice, the SRT commenced.

The SRT consisted of four blocks that each contained 20 repetitions of the training pattern (block duration 5.36 minutes) outlined above followed by the test pattern in the fifth block. The training pattern was then reintroduced for the sixth and final block. A 30 second break was enforced between blocks. Following the SRT, participants were asked three questions: “Did you notice anything peculiar in the syllable identification task?”,
“Did you notice any regularities in the syllable identification task?”, and “Did you notice the temporal pattern in the syllable identification task?” Prior to the third question participants were informed of the presence of the rhythmic pattern. Then the generation and recognition tasks were administered. The order of generation and recognition tasks was counterbalanced and, within each task, the order of instructions (inclusion and exclusion) was counterbalanced.

In the generation task, participants were asked to generate patterns using the “1”, “2”, and “3” keys. In the inclusion instruction, participants are required to reproduce the temporal pattern they heard most often in the syllable identification task, and to reproduce the pattern twice in a row. In the exclusion instruction, participants are required to create new temporal patterns that are different from those in the syllable identification task, but use the same number of syllables and the same rhythmic groupings of syllables. For example, participants were told that if they heard groups of two, three, or four syllables close together, then try to include the same temporal groups in their pattern. Participants were asked to generate the pattern twice in a row. Participants were given 20 seconds for each attempt, and five attempts overall. Participants received auditory feedback for each key-press (i.e. pressing keys 1 – 3 resulted in a /PA/, /KA/, or /TA/ depending on the key correspondence).

In the recognition task, participants were asked to listen to a number of patterns, some of which were in the syllable identification task, some of which had a similar structure to patterns in the syllable identification task, and some of which had a different structure.
In the inclusion instruction condition, participants were asked to respond “Yes” when the temporal pattern was identical to, or had a similar structure to, that of the pattern in the syllable identification task. Participants were asked to respond “No” if the pattern did not seem structured, or appeared to be random. In the exclusion instruction condition, participants were required to only respond “Yes” if the sequence was structured similarly, but was NOT identical to the one presented in the syllable identification task. If the participant recognizes the pattern from the syllable identification task, or if the pattern appeared to be unstructured or random, then they were to respond “No”.

In the recognition task, patterns (training, systematic, and distracter) were presented three times each, with each using only a single syllable (/PA/, /KA/, or /TA/) Single syllables were used in the recognition task to reduce confusion that may arise due to “recognition” of the syllable sequences from the SRT, even though the ordinal sequences were random. Thus, the inclusion and exclusion instructions each consisted of nine trials (duration of 10 to 15 minutes). Trials were presented in a random order. In regards to simple frequency information (Reed & Johnson, 1994), distracter patterns still contained three of the same transitions, but the pattern did not align metrically at any hierarchical level. The systematic pattern matched all simple frequency information except for the rate of full coverage. The systematic pattern was weakly metrical, but nonetheless aligned three times with the strong beats (see Figure A3).
Upon completion of all tasks, participants were presented with a questionnaire ascertaining formal music and dance training and a demographic survey (APPENDIX C). Participants were then debriefed and thanked for their participation. Experiment sessions did not exceed 60 minutes.

A3 Results and Discussion

Accuracy was analyzed using a 3 (Syllable) x 6 (Block) repeated measures analysis of variance (ANOVA), with Metricality as a *between-subjects* factor. RT was analyzed using a 6 (Block) x 3 (Syllable) x 5 (IOI) repeated measures RT improvement over training blocks (i.e. the difference between blocks 1 and 4) was analyzed in a univariate ANOVA with Metricality as a *between-subjects* factor. To ensure that decreases in RT in training blocks are attributable to the learning of the temporal patterns and not task learning, RT increases in the test block were analyzed with Metricality as a *between-subjects* factor.

A3.1 The Serial Reaction-time Task

Responses were considered accurate if the syllable was identified correctly, and if the response was made between 100-850ms after the stimulus onset. The lower threshold of 100ms was chosen as a cut-off for early responses as up to 100ms is too short a time to hear, identify, and give a motor response to the event. Under these criteria, 23% of responses were excluded. RT reported here reflect RT from the onset the stimulus.
A3.1.1 Accuracy

Accuracy was analyzed with a 6 (Block) x 3 (Syllable) repeated measures ANOVA with Metricality as a *between-subjects* factor. There was a significant main effect for Block \( [F (5, 230) = 3.05, p = .01, \eta^2_p = .06] \), no significant main effect of Syllable \( [F (2, 92) = 2.14, p = .12, \eta^2_p = .04] \), and no significant main effect for Metricality \( [F (1, 46) = 2.06, p = .16, \eta^2_p = .04] \). There was a significant interaction between Block and Syllable \( [F (10, 460) = 2.04, p = .03, \eta^2_p = .04] \), but no other interactions approached significance \( (ps > .20) \). As shown in Table 3.3, the significant main effect of Block indicates that accuracy decreased over blocks, a result that is not in line with our hypotheses. The significant interaction between Block and Syllable indicated that while accuracy for syllable /PA/ \( (M = .64, SEM = .02) \) and /TA/ \( (M = .64, SEM = .02) \) started high and then decreased over blocks, accuracy for /KA/ \( (M = .63, SEM = .02) \) remained low over all blocks. Overall, the results for accuracy indicate that accuracy decreased over training blocks. It is possible that the decreases in accuracy occurred due to fatigue or boredom.

Table A3.

*Mean accuracy (proportion) and standard error of the mean (SEM) for responses in blocks 1 to 6 for metrical and non-metrical conditions.*

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Metrical</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>.69</td>
<td>.65</td>
<td>.67</td>
<td>.66</td>
<td>.66</td>
<td>.65</td>
<td></td>
</tr>
<tr>
<td>SEM</td>
<td>.03</td>
<td>.03</td>
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<td></td>
</tr>
<tr>
<td><strong>Non-Metrical</strong></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Mean</td>
<td>.66</td>
<td>.64</td>
<td>.61</td>
<td>.59</td>
<td>.58</td>
<td>.58</td>
<td></td>
</tr>
<tr>
<td>SEM</td>
<td>.03</td>
<td>.04</td>
<td>.03</td>
<td>.03</td>
<td>.03</td>
<td>.04</td>
<td></td>
</tr>
</tbody>
</table>

*Note. Chance level is 33% for response accuracy to the three syllables.*
A3.1.2 Reaction time

As a result of the response criteria, some cells contained no data. Thus, a full 6 (Block) x 3 (Syllable) x 5 (IOI) repeated measures ANOVA could not be implemented. Instead, data were first analyzed in a 6 (Block) x 5 (IOI) repeated measures ANOVA with Metricality as a *between-subjects* factor. Then, to test whether there are RT differences between syllables, a 6 (Block) x 3 (Syllable) repeated measures ANOVA was conducted with Metricality as a *between-subjects* factor. This meant that interactions between Syllable and IOI could not be assessed.

To test the hypothesis that metrical and non-metrical patterns can be learned, RT was analyzed with a 6 (Block) x 5 (IOI) repeated measures ANOVA with Metricality as a *between-subjects* factor. There was no main effect of Block \([F(5, 225) = .71, \, p = .61, \, \eta^2_p = .02]\), a significant main effect of IOI \([F(4, 180) = 79.78, \, p < .001, \, \eta^2_p = .64]\), and no main effect of Metricality \([F(1, 45) = 2.36, \, p = .13, \, \eta^2_p = .05]\). There were significant interactions between Metricality and IOI \([F(4, 180) = 5.39, \, p < .001, \, \eta^2_p = .11]\), and between Block and IOI \([F(20, 900) = 2.37, \, p = .001, \, \eta^2_p = .05]\), but no other interactions were significant \((ps > .16)\). The lack of a significant main effect of Block indicates that RT did not decrease over training blocks or increase in test blocks. Thus, the hypothesis that metrical and non-metrical patterns can be learned was not supported. Furthermore, the lack of a significant main effect of Metricality indicates that there were no performance differences between metrical and non-metrical patterns. Thus, the hypothesis that metrical patterns are learned more readily than non-metrical patterns was
not supported. Post-hoc comparisons between IOIs indicated that all IOIs were significantly different from one another (ps < .01) with the exception of the 1000ms IOI and the 1500ms/1250ms IOI. The interaction between Metricality and IOI shows that RT for IOIs greater than 500ms (particularly intervals 2000ms/2250 and 3000ms) were larger for non-metrical patterns compared with metrical patterns (see Figure 3.3). As shown in Figure 3.3, the interaction between Block and IOI does not reflect that RT decreased over training blocks, and increased in test blocks, for any IOI; RT changes in blocks did not occur systematically, nor as a result of the experimental manipulations.

*Figure A3.* Mean correct reaction times over blocks 1-6 in the metrical and non-metrical conditions for the five inter-onset intervals. IOI 1-5 represent intervals of: 500ms, 1000ms, 1500ms, 2000ms, and 3000ms in the metrical condition and 500ms, 1000ms, 1250ms, 2250ms, and 3000ms in the non-metrical condition. The test block was introduced in Block 5. Error bars represent standard error of the mean.
To examine if there were any differences between metrical and non-metrical patterns in regards to RT decreases over training blocks, RT improvement (defined as the difference between blocks 1 and 4) was analyzed in a univariate ANOVA with Metricality as a between-subjects variable. There was no main effect of Metricality [$F (1, 47) = 0.07, p = .79, \eta_p^2 = .002$], and RT decreases were not significantly greater than zero for the metrical [$t (24) = -.37, p = .72$] or non-metrical [$t (22) = -.71, p = .49$] conditions. These results mean that the hypothesis that metrical and non-metrical patterns can be learned was not supported. To examine whether test blocks elicited RT increases for metrical and non-metrical patterns, RT increase (defined as the difference between RTs in the test block, and the mean RT of adjacent blocks) was analyzed in a univariate ANOVA with Metricality as a between-subjects variable. There was no main effect of Metricality [$F (1, 47) = 0.70, p = .41, \eta_p^2 = .02$], and RT decreases were not significantly greater than zero for the metrical [$t (24) = .10, p = .92$] or non-metrical [$t (22) = 1.20, p = .24$] conditions. Overall, results of the SRT do not support the hypothesis that metrical and non-metrical patterns can be learned, or that metrical patterns are learned more readily than non-metrical patterns.

To examine whether RT varied between syllables, RT was analyzed with a 6 (Block) x 3 (Syllable) repeated measures ANOVA with Metricality as a between-subjects factor. As main effects for Block and Metricality were reported above, only Syllable and interactions with Syllable are reported here. There was a significant main effect of Syllable [$F (2, 90) = 3.53, p = .03, \eta_p^2 = .07$], a significant interaction of Syllable with Block [$F (10, 450) = 2.17, p = .02, \eta_p^2 = .05$], but no other interactions were significant.
Post-hoc comparisons between syllables indicated that RT for /KA/ ($M = 591.06$, $SEM = 7.01$) was significantly greater than RT for /PA/ ($M = 578.76$, $SEM = 8.10$) ($p = .006$) and near-significantly greater than RT for /TA/ ($M = 580.06$, $SEM = 8.39$) ($p = .06$), but RT for /PA/ and /TA/ did not differ ($p = .75$). The interaction between Block and Syllable did not indicate that RT decreased over training blocks, and increased in test blocks, for any syllable. These results suggest that participants may have had more difficulty perceiving and responding to the syllable /PA/ compared to /KA/ and /TA/. As shown in Figure A1, this may be due to differences in the onsets of the stimuli; /KA/ and /TA/ have subtly louder onsets than /PA/, although such differences are likely negligible, and were not observed by Brandon et al. (submitted).

A3.2 Verbal Reports

In the questions following the SRT, 12 participants reported that they did not notice “anything peculiar” in the SRT task and 36 participants did notice something. Similarly, 34 participants claimed to have been aware of a regularity in the SRT, with 14 participants claiming they were not aware of a pattern. When informed that there was, in fact, a rhythmic pattern in the SRT, 29 participants reported that they noticed the rhythmic pattern and 19 participants reported that they were not aware of a rhythmic pattern. These responses did not differ as a result of Metricality (metrical, non-metrical).
A3.3 The Generation Task

Of the 48 participants who completed the SRT, data for 47 participants were included for the generation task. The one participant who was excluded did not produce any sequences during the generation task. Similarity scores representing the correspondence between the generated sequence and the training sequence (see Appendix L) were analyzed in a repeated measures ANOVA with Instruction (inclusion, exclusion) as a within-subjects factor and Metricality as a between-subjects factor. There was a near-significant main effect of Instruction \([F (1, 46) = 3.57, p = .07, \eta_p^2 = .07]\), no significant main effect of Metricality \([F (1, 46) = 1.10, p = .30, \eta_p^2 = .02]\), and no significant interaction between Instruction and Metricality \([F (1, 46) = 1.61, p = .21, \eta_p^2 = .04]\). As shown in Figure A4, the near-significant main effect of Instruction indicates that similarity scores tended to be greater in the exclusion instruction than in the inclusion instruction condition. These results indicate that, if temporal patterns were learned in the SRT, then this learning was implicit. However, there was no evidence that temporal patterns were learned in the SRT.

To examine if any knowledge of the temporal pattern was demonstrated in the generation task, similarity scores were compared to chance levels, estimated at 0.4 as determined by a random number generator (see Appendix L). Similarity scores were calculated by comparing the produced sequence of intervals in inclusion and exclusion conditions with the sequence of intervals in the pattern from the training block. In the metrical condition, similarity scores were significantly greater than chance in the inclusion \([t (23) = 2.28, p = .03]\) and exclusion \([t (23) = 5.52, p < .001]\) instructions. In
the non-metrical condition, similarity scores were significantly greater than chance in the inclusion \( t (22) = 2.14, p = .04 \) and exclusion \( t (22) = 2.42, p = .02 \) instruction conditions. These results indicate that participants were able to reproduce at least part of the temporal pattern in inclusion and exclusion instructions. The results of the generation task, that indicate that some learning of the temporal pattern occurred, are in contrast with the results of the SRT that indicated that temporal patterns were not learned. It is possible that, as the ordinal sequence in Experiment 1 was random, the SRT underestimated the learning of temporal patterns due to probabilistic uncertainty of the stimulus identity.

*Figure A4.* Mean similarity scores in the generation task for inclusion and exclusion instructions for metrical and non-metrical conditions. Error bars represent standard error of the mean. The dashed line indicates chance levels, as indicated by a random number generator (see Appendix L).
A3.4 The Recognition Task

Of the 48 participants who completed the SRT, data were retained for 42 participants for the recognition task. Data for the other six participants were not obtained due to experimental error (i.e. responses were not recorded in PsyScope). Mean proportions of “Yes” responses in the recognition task are shown in Figure A5. Mean proportion of “Yes” responses were analyzed in a 2 (Instruction; inclusion, exclusion) x 3 (Pattern; training, systematic, distracter) repeated measures ANOVA with Metricality as a between-subjects factor.

There was no main effect of Instruction \[F(1, 41) = 0.13, p = .72, \eta_p^2 = .003\], a main effect of Pattern \[F(2, 82) = 5.67, p = .005, \eta_p^2 = .12\], and no main effect of Metricality \[F(1, 41) = 2.63, p = .11, \eta_p^2 = .06\]. No interactions were significant \((ps > .15)\). As shown in Figure 3.5, the main effect of Pattern indicated that there were more “Yes” responses for the distracter sequence than to the training sequence \((p = .002)\) or to the systematic distracter pattern \((p = .067)\). This result is in direct contrast with our hypotheses, but is in line with the results of the SRT that indicated that metrical and non-metrical patterns were not learned. One-sample \(t\)-tests were conducted to examine if the proportion for “Yes” responses differed from chance (0.5). “Yes” responses occurred significantly less than chance (i.e. participants more often responded “No”) for the training pattern in the inclusion instruction \(t(41) = -2.54, p = .02\), and near-significantly greater than chance for the distracter pattern in the exclusion instruction \(t(41) = 1.90, p = .06\). No other responses significantly differed from chance \((ps > .10)\). Overall, results
of the recognition task do not indicate that participants could detect the training pattern, or reject the systematic and distracter patterns at levels greater than that predicted by chance. As learning was not demonstrated in the SRT, results of the recognition task may reflect that participants did not learn the temporal patterns, or abstract metrical or statistical features from the temporal patterns.

Figure A5. Mean proportion of “Yes” responses for training, systematic, and distracter sequences in inclusion and exclusion instructions for metrical and non-metrical conditions in the recognition task. Error bars show standard error of the mean.

A4 General Discussion
The results of Experiment 1 do not support the hypothesis that metrical and non-metrical patterns can be learned in an SRT when the ordinal sequence is unpredictable. These results are in line with the previous experiments that have not demonstrated the learning
of temporal patterns when the ordinal structure in unpredictable (O’Reilly et al., 2008; Shin & Ivry, 2002). Furthermore, these results are in contrast with previous studies that have found that learning of temporal patterns constructed from IOIs (Ullén & Bengtsson, 2003; Karabanov & Ullén, 2008) and response-stimulus intervals (Salidis, 2001) can be learned. Although results of the generation and recognition tasks may indicate that learning was implicit, this finding is without merit if learning was not demonstrated \textit{a priori}, that is, in the SRT.

Interestingly, although the SRT provided no evidence that the temporal pattern was learned, the generation task indicated that at least some aspect of the temporal was learned as reproductions of the learned sequence were all generated above levels predicted by chance. It has been proposed that temporal learning might be underestimated in the SRT in situations where the ordinal sequence is unpredictable, that is, under conditions of probabilistic uncertainty (Ullén & Bengtsson, 2003). Probabilistic uncertainty may have obscured learning because participants were not able to prepare for the next response to the ordinal items, even if they could anticipate the timing of the next stimulus. For this reason, Experiment 2a (see Chapter 5) was designed to compare temporal learning in a multiple-alternative forced choice task (similar to that used here in Experiment 1) with a stimulus-detection task as used by Salidis (2001). Results of Experiment 1 also showed that accuracy decreased over the course of the SRT blocks. It is possible that these decreases in accuracy indicated that participants became disinterested in the experimental task. Similarly, participants may have become fatigued
due to the length of the experiment. To remedy such issues, subsequent experiments adopted a more engaging cover story of a computer game (see Chapter 4).

Regarding the manipulations of metrical and non-metrical patterns, there were no differences in response to metrical and non-metrical patterns. While the lack of a difference between metrical and non-metrical patterns could be due to probabilistic uncertainty, it is also possible that the timing deviations in non-metrical patterns were not large enough to elicit differences. Another possibility is that the temporal patterns were too slow to elicit a sense of beat and meter. Specifically, the use of long IOIs (up to 3000ms) may have prevented participants from abstracting a metrical framework. For this reason, subsequent experiments in the present thesis used temporal patterns that contained shorter intervals and contained more occurrences of the shortest IOIs (e.g. 500ms and 1000ms). Perceptual tests of the temporal patterns were also conducted to ensure that both the beat and a meter could be abstracted (see Chapter 3).

Significant RT differences were found in response to the spoken syllables. Specifically, responses to /PA/ were slower than responses to /KA/ or /TA/. As the syllables-to-key correspondences were distributed across participants, this cannot be attributed to differences in motor performance associated with key location. As it was preferable that stimuli, and responses to the stimuli, were equivalent, the stimuli used for Experiment 1 may not have been ideal. For this reason, sets of stimuli that may not elicit RT differences were considered and trialed (see Chapter 3). Chapter 3 describes the stimuli
that were used in Experiment Sets 2 and 3, and reports three pilot experiments that were used to ensure that the stimuli were suitable.
Appendix B:
Experiment 1 Information Sheet, Consent Form, and Questionnaire
Information Sheet – Syllable Identification Experiment

Dear Participant,

Thank you for signing up for this experiment. This research project investigates speed and accuracy in responding to various syllables. The experiment will be conducted on a computer and the computer will record your accuracy and speed of responding. Syllables such as /PA/, /KA/, and /TA/ will be presented continuously and we ask that you respond as quickly and as accurately as possible. The series of tasks will take about 45 minutes to complete.

If the task raises any concerns for you, please do not hesitate to contact the student researcher, Ben Schultz (phone: 02 9772 6660), or A/Prof Kate Stevens of the School of Psychology, UWS Bankstown campus (phone: 02 9772 6324).

The results of these experiments will be presented as conference papers and in the form of a journal article, e.g., in the *Journal of Experimental Psychology*. As a participant you are welcome to view the results as they become available.

Your participation in this study is voluntary. You are free to withdraw consent and discontinue participation in the activity at any time without penalty. Any questions concerning this project can be directed to student researcher Ben Schultz or A/Prof Kate Stevens of the School of Psychology, UWS Bankstown campus.

Catherine Stevens, PhD
Principal Researcher

**NOTE:** This study has been approved by the University of Western Sydney Human Research Ethics Committee or Panel (indicate Committee or Panel). The Approval Number is HREC07/006. If you have any complaints or reservations about the ethical conduct of this research, you may contact the Ethics Committee/Panel through the Research Ethics Officers (ph: 02 4736 0883 or 4736 0884). Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.
Research Project – Syllable Identification Experiment

Consent Form

I __________________________ have read the information provided and any questions I have asked have been answered to my satisfaction. I agree to participate in this activity, realising that I may withdraw at any time. I agree that research data gathered for the study may be published.

____________________________________  ________________________
Participant’s signature                  Date

____________________________________  ________________________
Investigator                           Date
Appendix C:
Participants: Music and Dance Training and Demographic Questionnaires

College of Arts

Benjamin G. Schultz
MARCS Auditory Laboratories
Bldg 5, Bankstown
Phone: (+612) 9772 6660
Fax: (+612) 9772 6326
Email: b.schultz@uws.edu.au

September 2009

Syllable Identification Experiment

Questionnaire

Music Training

1. Have you received any formal musical training?

☐ YES
☐ NO (Go to question 5)
2. If yes, what kinds of musical training have you received (i.e. classical, jazz, etc.)?

_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________

3. How many years (of each AND in total) of musical training have you received?

_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________

4. On which musical instruments have you received training in, and how many years of each?

_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________

Dance Training

5. Have you received any formal dance training?

[ ] YES [ ] NO (Go to question 8)
6. If yes, what kinds of dance training have you received (i.e. ballet, jazz, etc.)?
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________

7. How many years (of each AND in total) of dance training have you received?
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________

8. Thank you for participating.
Syllable Identification Experiment

Questionnaire

Condition (for experimenter only): ____________________

Student Number: ____________________

1. Age? ____________

2. Gender?

[ ] Male  [ ] Female
3. What is your nationality? ___________________

4. Are you left-handed or right-handed?

☐ Left-handed  ☐ Right-handed

5. Do you suffer from any hearing disability or impairment?

☐ Yes  ☐ No
Appendix D: Intensity Recordings of Stimuli

Table D1.

Measurements (dB SPL) from the artificial ear at 400Hz, 1kHz, 1.25kHz, and 2kHz for Level differences of 0dB, -2dB, -4dB, and -6dB.

<table>
<thead>
<tr>
<th>Sound Type</th>
<th>Level difference</th>
<th>400 Hz</th>
<th>1 kHz</th>
<th>1.25 kHz</th>
<th>2 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bursts</td>
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<td>94.5</td>
<td>72.7</td>
<td>84.4</td>
<td>75.5</td>
</tr>
<tr>
<td></td>
<td>2dB</td>
<td>92.5</td>
<td>70.7</td>
<td>82.4</td>
<td>73.5</td>
</tr>
<tr>
<td></td>
<td>4dB</td>
<td>90.5</td>
<td>68.7</td>
<td>80.4</td>
<td>71.5</td>
</tr>
<tr>
<td></td>
<td>6dB</td>
<td>88.5</td>
<td>66.7</td>
<td>78.4</td>
<td>69.5</td>
</tr>
<tr>
<td>Continuous</td>
<td>0dB</td>
<td>95.5</td>
<td>73.7</td>
<td>85.5</td>
<td>76.6</td>
</tr>
<tr>
<td></td>
<td>2dB</td>
<td>93.5</td>
<td>71.7</td>
<td>83.5</td>
<td>74.6</td>
</tr>
<tr>
<td></td>
<td>4dB</td>
<td>91.5</td>
<td>69.7</td>
<td>81.5</td>
<td>72.6</td>
</tr>
<tr>
<td></td>
<td>6dB</td>
<td>89.5</td>
<td>67.7</td>
<td>79.5</td>
<td>70.6</td>
</tr>
</tbody>
</table>

Note. Measurements at 1 kHz were taken under the advisement of Dr. Matt Petoe who stated this level was of a high standard for measurement of dB SPL. Measurements at 1.25 kHz, and 2 kHz were included as these were the next two highest dB peaks after the 400Hz dB levels. Measurements were obtained using a Brüel and Kjær artificial ear with a 1” microphone of type 4144.
Appendix E:
Information Sheet and Consent Form for the Binaural
Summation Experiment
Participant Information Sheet

Loudness Test

You are invited to participate in a study coordinated by A/Prof Kate Stevens from the School of Psychology and MARCS Auditory Laboratories at the University of Western Sydney. The experiment is part of a three-year research project that has been funded by the Australian Research Council Discovery Project scheme. Researchers are A/Prof Kate Stevens and PhD Student Ben Schultz at the University of Western Sydney, and Prof Barbara Tillmann and PhD Student Ben Schultz at the University of Lyon 1.

The purpose of the study is to investigate how people perceive loudness differently between monaural presentations (e.g. left or right ear) and binaural presentations (both ears) of sound. This study aims to investigate auditory perception in the absence of visual cues.

The experiment is computer-based. You will be presented with pairs of sounds and asked to indicate whether the sounds were the same or different in terms of loudness. Please respond as quickly and accurately as possible. Sounds will be presented through either the left headphone speaker, the right headphone speaker, or both headphone speakers.

The experiment will take 15 minutes to complete leading to 15 minutes of participation credit (for first-year psychology students). The sounds will be presented at comfortable listening levels and there should be no discomfort.

All aspects of the study, including results, will be confidential and only the researchers will have access to information on participants. Results of the experiment will be reported in student theses and in journal articles and conference papers. A copy of these can be obtained from the researcher and School of Psychology.

Your participation in this study is entirely voluntary: you are not obliged to be involved and – if you do participate – you can withdraw at any time without giving any reason and without any consequences.

When you have read this information, Ben Schultz will discuss it with you further and answer any questions you may have. If you would like to know more at any stage, please feel free to contact Kate Stevens by email kj.stevens@uws.edu.au or on 9772 6324.

Catherine (Kate) Stevens PhD
Chief Investigator and Associate Professor in Psychology
NOTE: This study has been approved by the University of Western Sydney Human Research Ethics Committee. The Approval number is H7764. If you have any complaints or reservations about the ethical conduct of this research, you may contact the Ethics Committee through the Office of Research Services on Tel 02-4736 0883, Fax 02-4736 0013 or email humanethics@uws.edu.au. Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.
Loudness Test

Consent Form

I, __________________________________ , consent to participate in the research project titled Loudness Test.

I acknowledge that:

I have read the participant information sheet and have been given the opportunity to discuss the information and my involvement in the project with the researcher.

The procedures required for the project and the time involved have been explained to me, and any questions I have about the project have been answered to my satisfaction.

I consent to the computer-based auditory perception task.

I understand that my involvement is confidential and that the information gained during the study may be published but no information about me will be used in any way that reveals my identity.

I understand that I can withdraw from the study at any time, without affecting my relationship with the researcher/s now or in the future.

Signed: ___________________________________________

Name: ___________________________________________

Date: ___________________________________________
Appendix F:  
Computer Game for the Blind Cover Story

Story for the Computer Game for the Blind in Experiments 2a and 2b

Welcome to the Computer Game for the Blind. This game follows the story of Marie O. and Louis G., two mechanics who live in a far off land. Only a moment ago, Princess Daisy was kidnapped by the evil dragon Trogdor, and taken to his lair in Magma-land. It is your mission to save Princess Daisy and restore peace to the land.

Marie O. and Louis G. have constructed a flying go-cart so they can reach Princess Daisy in time. Unfortunately, Magma-land is so hot that no windows can be used and our heroes are 'Flying Blind'. Luckily for you, they have designed a special sonar system!

Single Response Conditions (Experiment 2a: Single response, and Experiment 2b)

The sonar system will BEEP from different locations every time you need to dodge, weave, and jump to avoid an obstacle. To avoid these obstacles, you will need to press the ‘0’ key every time you hear a beep.

Multiple Response Condition (Experiment 2a)

The sonar system will BEEP from different locations every time you need to dodge, weave, and jump to avoid an obstacle. To avoid these obstacles, you will need to press:

'1' if you hear the sound from the LEFT headphone
'2' if you hear the sound from BOTH headphones, and
'3' if you hear the sound from the RIGHT headphone.

First, we'll give you a bit of practice. In this task you will hear BEEPS from the LEFT headphone, the RIGHT headphone, or BOTH headphones. Please try to respond as quickly and as accurately as possible and pay attention to the location of the BEEPS.

(Following the Practice Round)
Now that you have had a practice, let's begin. Again, please try to respond as quickly and as accurately as possible.

(Following Block 1)
Not bad, but you will have to try harder if you want to save Princess Daisy in time!

(Following Block 2)
You've made progress, but the Princess is still a long way off!

(Following Block 3)
Whew! That was a close one! You'll need to stay alert to dodge those volcanic rocks.

(Following Block 4)
You've arrived at the castle. Let's sneak through the back entrance through the caves.
You can see a light at the end of the tunnel. We're getting closer now.

We've made it out of the caves. Now to find the Princess!

Just as you reach the princess, Trogdor takes flight with the Princess in his grasp! We will have to chase him!

We've almost caught up to Trogdor! Just a little further...

Trogdor dropped the Princess and, thanks to your fancy flying, we caught her in our ship. Trogdor has run away and the Princess is finally safe. Well done!

Congratulations! You have rescued the Princess and brought peace to the kingdom.

**Story for the Computer Game for the Blind in Experiments 3a and 3b**

Welcome to the Computer Game for the Blind. This game follows the story of Marie O. and Louis G., two mechanics who live in a far off land. Only a moment ago, Princess
Daisy was kidnapped by the evil dragon Trogdor, and taken to his lair in Magma-land. It is your mission to save Princess Daisy and restore peace to the land.

Marie O. and Louis G. have constructed a flying go-cart so they can reach Princess Daisy in time. Unfortunately, Magma-land is so hot that no windows can be used and our heroes are 'Flying Blind'. Luckily for you, they have designed a special sonar system!

The sonar system will BEEP from different locations every time you need to dodge, weave, and jump to avoid an obstacle. To avoid these obstacles, you will need to press:

'1' if you hear the sound from the LEFT headphone
'2' if you hear the sound from BOTH headphones, and
'3' if you hear the sound from the RIGHT headphone.

The heat has damaged the equipment so you will need to perform two tasks to avoid the obstacles. In the first task, you will need to identify to each BEEP as quickly and accurately as possible. In the second task, you will need to reproduce the sequence of BEEPS in the correct order. Both tasks must be completed successfully to navigate the landscape.

First, we'll give you a bit of practice. In this task you will hear BEEPS from the LEFT headphone, the RIGHT headphone, or BOTH headphones. You will need to press '1' for
LEFT, '2' for BOTH, and '3' for RIGHT. We will now teach you how the sounds relate to the three keys.

(Following the Practice Round)

Now that you have had a practice, let's begin. Again, please try to reproduce the sequence to the best of your ability.

(Following Block 1)

Not bad, but you will have to try harder if you want to save Princess Daisy in time!

(Following Block 2)

You've made progress, but the Princess is still a long way off!

(Following Block 3)

Whew! That was a close one! You'll need to stay alert to dodge those volcanic rocks.

(Following Block 4)

I hope Trogdor hasn't hurt the Princess. We'll need to do better!

(Following Block 5)

You're getting pretty good at this! Don't get cocky though!

(Following Block 6)

You've arrived at the castle. Let's sneak through the back entrance through the caves.
You can see a light at the end of the tunnel. We're getting closer now.

We've made it out of the caves. Now to find the Princess!

Just as you reach the princess, Trogdor takes flight with the Princess in his grasp! We will have to chase him!

We've almost caught up to Trogdor! Just a little further...

Trogdor dropped the Princess and, thanks to your fancy flying, we caught her in our ship. Trogdor has run away and the Princess is finally safe. Well done!

Congratulations! You have rescued the Princess and brought peace to the kingdom.
Appendix G:
Information Sheet and Consent Form for the Music Notation Experiment
Participant Information Sheet

Rhythm Notation Test

You are invited to participate in a study coordinated by A/Prof Kate Stevens from the School of Psychology and MARCS Auditory Laboratories at the University of Western Sydney. The experiment is part of a three-year research project that has been funded by the Australian Research Council Discovery Project scheme. Researchers are A/Prof Kate Stevens and PhD Student Ben Schultz at the University of Western Sydney, and Prof Barbara Tillmann and PhD Student Ben Schultz at the University of Lyon 2.

The purpose of this study is to investigate how people perceive different types of musical rhythms. You will be presented with a number of different rhythms, and you are to listen to the rhythm until you think you can notate the rhythm on the musical stave provided (i.e. the manuscript paper). You can notate the rhythm as many times as you like, and you can choose which attempt you are most satisfied. After you have notated each rhythm, you will be asked some questions regarding the rhythm.

The experiment will take 20 minutes to complete. The sounds will be presented at comfortable listening levels and there should be no discomfort.

All aspects of the study, including results, will be confidential and only the researchers will have access to information on participants. Results of the experiment will be reported in student theses and in journal articles and conference papers. A copy of these can be obtained from the researcher and School of Psychology.

Your participation in this study is entirely voluntary: you are not obliged to be involved and – if you do participate – you can withdraw at any time without giving any reason and without any consequences.

When you have read this information, Ben Schultz will discuss it with you further and answer any questions you may have. If you would like to know more at any stage, please feel free to contact Kate Stevens by email kj.stevens@uws.edu.au or on 9772 6324.

Catherine (Kate) Stevens PhD
Chief Investigator and Associate Professor in Psychology

NOTE: This study has been approved by the University of Western Sydney Human Research Ethics Committee. The Approval number is H7764. If you have any complaints or reservations about the ethical conduct of this research, you may contact the Ethics Committee through the Office of Research Services on Tel 02-4736 0883, Fax 02-4736 0013 or email kj.stevens@uws.edu.au.
humanethics@uws.edu.au. Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.
Rhythm Notation Test

Consent Form

I, ____________________________________________________ , consent to participate in the research project titled Rhythm Notation Test.

I acknowledge that:

I have read the participant information sheet and have been given the opportunity to discuss the information and my involvement in the project with the researcher.

The procedures required for the project and the time involved have been explained to me, and any questions I have about the project have been answered to my satisfaction.

I consent to the computer-based auditory perception task.

I understand that my involvement is confidential and that the information gained during the study may be published but no information about me will be used in any way that reveals my identity.

I understand that I can withdraw from the study at any time, without affecting my relationship with the researcher/s now or in the future.

Signed: __________________________________________

Name: ___________________________________________

Date: __________________________________________
Appendix H:
Musical Scores and Response Sheets for the Notation Experiment

The documents given here are only the musical staves and response sheet for Item 1. There were four item sheets (one for each of the four rhythms) that were identical to those here, except for the numbering, that is, there was Item 1, Item 2, Item 3, and Item 4.
1. How many times did you listen to the Item? _______

2. Which attempt were you most satisfied with? ________

3. On a scale of 1 to 10 (where 1 = very easy and 10 = very difficult), how difficult was it to notate the rhythm of this Item? ________

4. Would you say this pattern is metrical? (Please circle)
   
   Yes  
   No

5. Please provide a few reasons why.
   
   __________________________________________________________
   __________________________________________________________
   __________________________________________________________
   __________________________________________________________
   __________________________________________________________
Appendix I:
Information Sheet and Consent Form for the Tapping Experiment
Participant Information Sheet

Beat Tapping Test

You are invited to participate in a study coordinated by A/Prof Kate Stevens from the School of Psychology and MARCS Auditory Laboratories at the University of Western Sydney. The experiment is part of a three-year research project that has been funded by the Australian Research Council Discovery Project scheme. Researchers are A/Prof Kate Stevens and PhD Student Ben Schultz at the University of Western Sydney, and Prof Barbara Tillmann and PhD Student Ben Schultz at the University of Lyon 2.

The purpose of this study is to investigate how people perceive different types of musical rhythms. You will be presented with a number of different rhythms, and you are to listen to the rhythm until you feel comfortable that you can tap the beat of the rhythm on the drum pad. The experimenter will give you some examples of a beat if you are unsure. You are asked to continue tapping until you hear a wood block sound.

The experiment will take up to 60 minutes to complete. The sounds will be presented at comfortable listening levels through headphones and there should be no discomfort.

All aspects of the study, including results, will be confidential and only the researchers will have access to information on participants. Results of the experiment will be reported in student theses and in journal articles and conference papers. A copy of these can be obtained from the researcher and School of Psychology.

Your participation in this study is entirely voluntary: you are not obliged to be involved and – if you do participate – you can withdraw at any time without giving any reason and without any consequences.

When you have read this information, Ben Schultz will discuss it with you further and answer any questions you may have. If you would like to know more at any stage, please feel free to contact Kate Stevens by email kj.stevens@uws.edu.au or on 9772 6324.

Catherine (Kate) Stevens PhD
Chief Investigator and Associate Professor in Psychology

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humanethics@uws.edu.au. Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.
Beat Tapping Test

Consent Form

I, ________________________________________________, consent to participate in the research project titled Beat Tapping Test.

I acknowledge that:

I have read the participant information sheet and have been given the opportunity to discuss the information and my involvement in the project with the researcher.

The procedures required for the project and the time involved have been explained to me, and any questions I have about the project have been answered to my satisfaction.

I consent to the computer-based auditory perception and tapping task.

I understand that my involvement is confidential and that the information gained during the study may be published but no information about me will be used in any way that reveals my identity.

I understand that I can withdraw from the study at any time, without affecting my relationship with the researcher/s now or in the future.

Signed: __________________________________________

Name: ___________________________________________

Date: ___________________________________________
Appendix J:
Information Sheet and Consent Form for Experiments 2a and 2b

In Experiment 2a, two different information sheets were used: one for the multiple response serial reaction-time task, and another for the single response serial reaction-time task. The first information sheet presented here describes the multiple response serial reaction-time task. The second information sheet describes the single response serial reaction-time task.
Participant Information Sheet

Computer Game for the Blind

You are invited to participate in a study coordinated by A/Prof Kate Stevens from the School of Psychology and MARCS Auditory Laboratories at the University of Western Sydney. The experiment is part of a three-year research project that has been funded by the Australian Research Council Discovery Project scheme. Researchers are A/Prof Kate Stevens and PhD Student Ben Schultz at the University of Western Sydney, and Prof Barbara Tillmann and PhD Student Ben Schultz at the University of Lyon 1.

The purpose of the study is to investigate how quickly and accurately people are able to react to a range of Computer Game-like sounds. This study aims to investigate auditory perception in the absence of visual cues.

The experiment is computer-based. You will be presented with different sounds and asked to respond as quickly and accurately as possible. Sounds will be presented through either the left headphone speaker, the right headphone speaker, or both headphone speakers. Your task is to respond with the labeled “L”, “M”, and “R” keys according to whether you thought the sound came from the left, middle (both) or right speaker.

The experiment will take 45 minutes to complete leading to 45 minutes of participation credit. The sounds will be presented at comfortable listening levels and there should be no discomfort.

All aspects of the study, including results, will be confidential and only the researchers will have access to information on participants. Results of the experiment will be reported in student theses and in journal articles and conference papers. A copy of these can be obtained from the researcher and School of Psychology.

Your participation in this study is entirely voluntary: you are not obliged to be involved and – if you do participate – you can withdraw at any time without giving any reason and without any consequences.

When you have read this information, Ben Schultz will discuss it with you further and answer any questions you may have. If you would like to know more at any stage, please feel free to contact Kate Stevens by email kj.stevens@uws.edu.au or on 9772 6324.

Catherine (Kate) Stevens PhD
Chief Investigator and Associate Professor in Psychology

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Participant Information Sheet

Computer Game for the Blind

You are invited to participate in a study coordinated by A/Prof Kate Stevens from the School of Psychology and MARCS Auditory Laboratories at the University of Western Sydney. The experiment is part of a three-year research project that has been funded by the Australian Research Council Discovery Project scheme. Researchers are A/Prof Kate Stevens and PhD Student Ben Schultz at the University of Western Sydney, and Prof Barbara Tillmann and PhD Student Ben Schultz at the University of Lyon 1.

The purpose of the study is to investigate how quickly and accurately people are able to react to a range of Computer Game-like sounds. This study aims to investigate auditory perception in the absence of visual cues.

The experiment is computer-based. You will be presented with three sounds and asked to respond as quickly and accurately as possible. Sounds will be presented through either the left headphone speaker, the right headphone speaker, or both headphone speakers. Your task is to respond with the labeled “PUSH ME” key as quickly as possible.

The experiment will take 45 minutes to complete leading to 45 minutes of participation credit. The sounds will be presented at comfortable listening levels and there should be no discomfort.

All aspects of the study, including results, will be confidential and only the researchers will have access to information on participants. Results of the experiment will be reported in student theses and in journal articles and conference papers. A copy of these can be obtained from the researcher and School of Psychology.

Your participation in this study is entirely voluntary: you are not obliged to be involved and – if you do participate – you can withdraw at any time without giving any reason and without any consequences.

When you have read this information, Ben Schultz will discuss it with you further and answer any questions you may have. If you would like to know more at any stage, please feel free to contact Kate Stevens by email kj.stevens@uws.edu.au or on 9772 6324.

March 2010
Catherine (Kate) Stevens PhD  
Chief Investigator and Associate Professor in Psychology  

NOTE: This study has been approved by the University of Western Sydney Human Research Ethics Committee. The Approval number is H7764. If you have any complaints or reservations about the ethical conduct of this research, you may contact the Ethics Committee through the Office of Research Services on Tel 02-4736 0883, Fax 02-4736 0013 or email humanethics@uws.edu.au. Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.
Computer Game for the Blind

Consent Form

I, ____________________________________________________ , consent to participate in the research project titled Computer Game for the Blind.

I acknowledge that:

I have read the participant information sheet and have been given the opportunity to discuss the information and my involvement in the project with the researcher.

The procedures required for the project and the time involved have been explained to me, and any questions I have about the project have been answered to my satisfaction.

I consent to the computer-based auditory perception task.

I understand that my involvement is confidential and that the information gained during the study may be published but no information about me will be used in any way that reveals my identity.

I understand that I can withdraw from the study at any time, without affecting my relationship with the researcher/s now or in the future.

Signed: __________________________________________

Name: ___________________________________________

Date: ____________________________________________
Appendix K: Post-test Questionnaires for Experiments 2a, 2b, 3a, and 3b

Computer Game for the Blind Experiment

Questionnaire

Demographic Information

STUDENT ID: __________________________

1. Do you suffer from any hearing disability or impairment?
   
   □ YES   □ NO

2. Native language? __________________________
Music Training

3. Have you ever studied any kind of music on a regular and individual or group basis?

☐ YES ☐ NO (Go to question 6)

4. If yes, for each age period, please specify:

<table>
<thead>
<tr>
<th>AGE PERIOD</th>
<th>INSTRUMENT and/or SPECIFICATION</th>
<th>AVERAGE NO. HRS/WK</th>
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<tbody>
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<td>(e.g. Ages 10-12)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>__________</td>
<td>_____________________________</td>
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<tr>
<td>__________</td>
<td>_____________________________</td>
<td>__________</td>
</tr>
</tbody>
</table>

5. Have you ever studied music theory? If so, how extensively? (i.e. levels achieved or courses taken)

_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________
_______________________________________________________________________
### Dance Training

6. Have you undertaken any **dance** training?

- [ ] YES  
- [ ] NO (Go to question 8)

7. If yes, for each age period, please specify:

<table>
<thead>
<tr>
<th>AGE PERIOD</th>
<th>DANCE TYPE and/or SPECIFICATION</th>
<th>AVERAGE NO. HRS/WK</th>
</tr>
</thead>
<tbody>
<tr>
<td>(e.g. Ages 10-12)</td>
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</table>
Video Game Experience

8. Do you have any experience playing video games?

☐ YES  ☐ NO (Go to question 15)

9. If yes, what kinds of video games do you play (tick as necessary) and how many hours a week would you spend playing each type? (If unsure, please ask the experimenter for a definition of these).

☐ Role-playing: _____ hours per week  ☐ Platform: _____ hours p/w

☐ Driving/Racing: _______ hours p/w  ☐ Sports: _______ hours p/w

☐ First-person shooter: _____ hours p/w  ☐ Strategy: _______ hours p/w

☐ Other (Please define)__________________________ : ______ hours p/w

10. At what age period(s) did you play these videogames (please specify):

<table>
<thead>
<tr>
<th>AGE PERIOD</th>
<th>VIDEOGAME TYPE</th>
<th>AVERAGE NO.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(e.g. Ages 10-12)</td>
<td>and/or SPECIFICATION</td>
<td>HRS/WK</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age Period</th>
<th>Video Game Type and/or Specification</th>
<th>Average No. Hrs/Wk</th>
</tr>
</thead>
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<tr>
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</tbody>
</table>

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Please answer these questions about the video games you play
(Note: These questions do not refer to the computer game for the blind)

11. On a scale of 1 to 5 (where 1 = “Very Unsuccessful” and 5 = “Very Successful”), how successful do you think you are at these games (please circle)?

1 2 3 4 5
(Very Unsuccessful) (Moderately Successful) (Very Successful)

12. On a scale of 1 to 5 (where 1 = “Very Slow” and 5 = “Very Fast”), how quick do you think your reaction times are in these games (please circle)?

1 2 3 4 5
(Very Slow) (Moderately Fast) (Very Fast)

13. On a scale of 1 to 5 (where 1 = “Very Bad” and 5 = “Very Good”), how good are you at predicting WHAT will occur next in these games (please circle)?

1 2 3 4 5
(Very Bad) (Moderately Good) (Very Good)

14. On a scale of 1 to 5 (where 1 = “Very Bad” and 5 = “Very Good”), how good are you at predicting WHEN things will occur next in these games (please circle)?

1 2 3 4 5
(Very Bad) (Moderately Good) (Very Good)

15. Thank you for participating!
Appendix L: Description of Data Extraction in the Generation Task

Data for the generation task were analyzed in MatLab using a method based on the serial-recall task used by Bengtsson and Ullén (2003) and adapted for examining the production of repeating patterns. First, for each trial (five inclusion and five exclusion trials) the time series of responses were extracted for each trial. Next, IOIs were calculated by treating the first button press as the starting point and calculating the time between the onsets of each tap. Then all intervals were divided by the smallest interval and multiplied by 500ms, the smallest interval of the training pattern. In this way, the smallest interval was used as the referent for the smallest IOI (i.e. the smallest IOI became 500ms, and all other IOIs were standardized to this value). In Experiment 1, the metrical pattern was analyzed as (in ms) [1500-1000-1500-500-3000-500-2000-2000-1000-3000] and the non-metrical pattern was [1250-1000-1250-500-3000-500-2250-2250-1000-3000]. In Experiment Sets 2 and 3, the metrical training pattern was analyzed as (in ms) [500-1500-1000-500-500-1000-2000] and the non-metrical training pattern was [500-1350-1100-1100-500-500-1100-1850].

The response IOI sequences were then compared to the actual patterns. No indication of a starting or ending point of the pattern was given in blocks because the pattern cycled (20 times per block in Experiment 1; 24 times per block in Experiment Sets 2 and 3). Furthermore, different starting points were used for each block. As participants might reproduce the training pattern using any starting point of the pattern, the training pattern was compared to the produced sequence starting from every possible point of the pattern.
produced sequence. For example, if the participant produced a sequence of 16 intervals, the training pattern would be compared to the produced sequence 16 times, and the 16 item sequence would be concatenated with itself. For each starting position, the training pattern was compared with the produced sequence for each of the eight intervals of the training pattern. If the produced interval was equal to the training interval (with a tolerance of +/-30% of the base pulse), the response was counted as correct. Each sequence comparison produced a similarity score (from 0 to 1). Then, the maximum similarity values were extracted from all sequence comparisons. The maximum values were used to ensure that a correct pattern reproduction was reflected regardless of the starting point selected by the participant.

To estimate chance levels, a pseudo-random number generator was used to create sequences. The constraints of the sequences were that: 1) they could not be longer than 32s in Experiment 1, or 20s in Experiment Sets 2 and 3, that is, the amount of time allowed for sequence production, 2) inter-onset intervals were only able to be between 200ms and 3200ms (Experiment 1), or 200ms and 2800ms (Experiment Sets 2 and 3), that is, within the approximate range of intervals produced by participants, and 3) they could contain a maximum of 20 intervals (Experiment 1) or 16 intervals (Experiment Sets 2 and 3). Simulations calculated the mean similarity scores for 25 “participants” (with five “attempts” each) for both the metrical and non-metrical patterns. For Experiment 1, the results of the simulations produced a mean similarity score of .4 (SD = .01) for both metrical and non-metrical patterns. For Experiment Sets 2 and 3, the results of the simulations produced a mean similarity score .27 (SD = .01) for both the metrical
and non-metrical patterns. Thus, this value was used as an indication of chance performance in the generation task.
Appendix M: Description of the Unrestricted Sequence Identification Measurement Model

The unrestricted model was run for metrical conditions in Experiments 1 (M1) and 2 (M2) following the procedures of Buchner and colleagues (Buchner et al., 1997; 1998; Buchner & Steffens, 2001). Parameters indicating the probability of guessing under inclusion (M1 $g_i = .46$, M2 $g_i = .37$) and exclusion (M1 $g_e = .53$, M2 $g_e = .55$) instructions were not different from 0.5 (as would be expected according to chance levels in a binary choice task). The parameters representing the probability of detecting systematicity ($s$) based on simple frequency information were not different from zero (M1 $s = .00$, M2 $s = .11$) as found by Buchner et al. (1997; 1998; 2001). This suggests that the conscious recognition of the statistical regularities of the acquisition pattern did not occur. The parameters representing the conscious detection of metrical strength ($m$) were not different from zero (M1 $m = .08$, M2 $m = .17$). This suggests that the conscious recognition of the metrical strength of the acquisition pattern of metrical patterns did not occur.

The parameters representing the probability of detecting a lack of metrical or statistical structure ($d$) were not different from zero (M1 $d = .05$, M2 $d = .00$). This suggests that participants may not have consciously recognized a lack of structure when patterns did not have the same statistical regularity or strong metrical structure as the acquisition pattern. The parameters representing conscious recognition of the acquisition pattern were different from zero (M1 $c = .30$, M2 $c = .29$). The parameter representing
unconscious recognition of the acquisition pattern was only different from zero for M1 (uc- = .55), but not for M2 (uc- = .16). Regarding the relative contributions of conscious and unconscious processes to recognition judgments, in M1, conscious processes (c) were slightly different from unconscious processes (uc-), but in M2, conscious and unconscious processes were not different.
Appendix N:
Information Sheet and Consent Form for Experiments 3a and 3b
Patient Information Sheet

Computer Game for the Blind

You are invited to participate in a study coordinated by A/Prof Kate Stevens from the School of Psychology and MARCS Auditory Laboratories at the University of Western Sydney. The experiment is part of a three-year research project that has been funded by the Australian Research Council Discovery Project scheme. Researchers are A/Prof Kate Stevens and PhD Student Ben Schultz at the University of Western Sydney, and Prof Barbara Tillmann and PhD Student Ben Schultz at the University of Lyon.

The purpose of the study is to investigate how quickly and accurately people are able to react to a range of computer game-like sounds, and then reproduce the sequence of sounds shortly after. This study aims to investigate auditory perception in the absence of visual cues.

The experiment is computer-based. You will be presented with different sounds and asked to respond as quickly and accurately as possible. Sounds will be presented through the left headphone, or the right headphone, or both headphones. In each round you have two tasks. The first task is to identify to each sound as quickly as possible. We would like to respond with the keys labeled “1”, “2”, and “3” according to whether you thought the sound came from the left, both, or right headphone. The second task is to reproduce the sequence as accurately as possible.

The experiment will take 45 minutes to complete leading to 45 minutes of participation credit. The sounds will be presented at comfortable listening levels and there should be no discomfort.

All aspects of the study, including results, will be confidential and only the researchers will have access to information on participants. Results of the experiment will be reported in student theses and in journal articles and conference papers. A copy of these can be obtained from the researcher and School of Psychology.

Your participation in this study is entirely voluntary: you are not obliged to be involved and – if you do participate – you can withdraw at any time without giving any reason and without any consequences.

When you have read this information, Ben Schultz will discuss it with you further and answer any questions you may have. If you would like to know more at any stage, please feel free to contact Kate Stevens by email kj.stevens@uws.edu.au or on 9772 6324.

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Computer Game for the Blind

Consent Form

I, ________________________________________________, consent to participate in the research project titled Computer Game for the Blind.

I acknowledge that:

I have read the participant information sheet and have been given the opportunity to discuss the information and my involvement in the project with the researcher.

The procedures required for the project and the time involved have been explained to me, and any questions I have about the project have been answered to my satisfaction.

I consent to the computer-based auditory perception task.

I understand that my involvement is confidential and that the information gained during the study may be published but no information about me will be used in any way that reveals my identity.

I understand that I can withdraw from the study at any time, without affecting my relationship with the researcher/s now or in the future.

Signed: __________________________________________

Name: __________________________________________

Date: ___________________________________________
Appendix O:
Summary of Analysis of Variance Output

Table O1.

Summary of F statistics in Experiment 1.

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Effect</th>
<th>F</th>
<th>df1</th>
<th>df2</th>
<th>p-value</th>
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<td>RT</td>
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<td>5</td>
<td>230</td>
<td>.38</td>
<td>.02</td>
</tr>
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<td>184</td>
<td>&lt;.001</td>
<td>.64</td>
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<td>.12</td>
<td>.05</td>
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<td>.05</td>
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<td>920</td>
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<td>.05</td>
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<td>.004</td>
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<tr>
<td></td>
<td>IOI x Metricality</td>
<td>5.39</td>
<td>4</td>
<td>184</td>
<td>&lt;.001</td>
<td>.11</td>
</tr>
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<td>20</td>
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*Summary of F statistics in Experiment 2b.*

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*Summary of F statistics in Experiment 2b.*

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Table O4.

Summary of F statistics in the serial reaction-time task (SRT) of Experiment 3a.

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*Summary of F statistics in the immediate recall task (IRT) of Experiment 3a.*

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Summary of F statistics in the serial reaction-time task (SRT) of Experiment 3b.

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*Summary of F statistics in the immediate recall task (IRT) of Experiment 3b.*

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Table O8.

*Summary of F statistics in Pilot Experiment 1: The Binaural Summation Experiment.*

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Effect</th>
<th>F</th>
<th>df1</th>
<th>df2</th>
<th>p-value</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion of “Different” Judgments</td>
<td>Level</td>
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<td>33</td>
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<td>.81</td>
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<tr>
<td></td>
<td>Side</td>
<td>3.11</td>
<td>1</td>
<td>11</td>
<td>.11</td>
<td>.22</td>
</tr>
<tr>
<td></td>
<td>Level x Side</td>
<td>0.41</td>
<td>3</td>
<td>33</td>
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<td>.04</td>
</tr>
</tbody>
</table>

Table O9.

*Summary of F statistics in Pilot Experiment 2: The Music Notation Experiment.*

<table>
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<th>F</th>
<th>df1</th>
<th>df2</th>
<th>p-value</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Notated Timing Deviations</td>
<td>Metricality</td>
<td>30.00</td>
<td>1</td>
<td>4</td>
<td>.005</td>
<td>.88</td>
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<tr>
<td></td>
<td>Pattern</td>
<td>0.12</td>
<td>1</td>
<td>4</td>
<td>.75</td>
<td>.03</td>
</tr>
<tr>
<td></td>
<td>Metricality x Pattern</td>
<td>1.39</td>
<td>1</td>
<td>4</td>
<td>.31</td>
<td>.26</td>
</tr>
<tr>
<td>Difficulty Ratings</td>
<td>Metricality</td>
<td>62.30</td>
<td>1</td>
<td>4</td>
<td>.001</td>
<td>.94</td>
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<tr>
<td></td>
<td>Pattern</td>
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<td>4</td>
<td>.46</td>
<td>.14</td>
</tr>
<tr>
<td></td>
<td>Metricality x Pattern</td>
<td>1.29</td>
<td>1</td>
<td>4</td>
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</tbody>
</table>
Table O10.

Summary of $F$ statistics in Pilot Experiment 3: The Beat Tapping Experiment.

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Effect</th>
<th>$F$</th>
<th>df1</th>
<th>df2</th>
<th>$p$-value</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient of Variation</td>
<td>Metricality</td>
<td>43.37</td>
<td>1</td>
<td>13</td>
<td>&lt;.001</td>
<td>.78</td>
</tr>
<tr>
<td></td>
<td>Pattern</td>
<td>2.69</td>
<td>2</td>
<td>24</td>
<td>.09</td>
<td>.18</td>
</tr>
<tr>
<td></td>
<td>Musical Training</td>
<td>0.11</td>
<td>1</td>
<td>13</td>
<td>.75</td>
<td>.01</td>
</tr>
<tr>
<td></td>
<td>Metricality x Musical Training</td>
<td>9.63</td>
<td>1</td>
<td>13</td>
<td>.009</td>
<td>.45</td>
</tr>
<tr>
<td></td>
<td>Pattern x Musical Training</td>
<td>2.69</td>
<td>2</td>
<td>24</td>
<td>.09</td>
<td>.18</td>
</tr>
<tr>
<td></td>
<td>Metricality x Pattern</td>
<td>0.25</td>
<td>2</td>
<td>24</td>
<td>.78</td>
<td>.02</td>
</tr>
<tr>
<td></td>
<td>Metricality x Pattern x Musical Training</td>
<td>0.20</td>
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<td>.02</td>
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<td>Difficulty Ratings</td>
<td>Metricality</td>
<td>115.6</td>
<td>1</td>
<td>13</td>
<td>&lt;.001</td>
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<tr>
<td></td>
<td>Pattern</td>
<td>17.97</td>
<td>2</td>
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<tr>
<td></td>
<td>Musical Training</td>
<td>4.45</td>
<td>1</td>
<td>13</td>
<td>.06</td>
<td>.27</td>
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<td>Metricality x Musical Training</td>
<td>53.70</td>
<td>1</td>
<td>13</td>
<td>&lt;.001</td>
<td>.82</td>
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<td></td>
<td>Metricality x Pattern</td>
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<td>24</td>
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<td>.14</td>
</tr>
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<td>Metricality x Pattern x Musical Training</td>
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<td>.49</td>
<td>.06</td>
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<td>Metricality Ratings</td>
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<td>1</td>
<td>13</td>
<td>&lt;.001</td>
<td>.92</td>
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<td></td>
<td>Pattern</td>
<td>14.79</td>
<td>2</td>
<td>24</td>
<td>&lt;.001</td>
<td>.55</td>
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<tr>
<td></td>
<td>Musical Training</td>
<td>0.48</td>
<td>1</td>
<td>13</td>
<td>.50</td>
<td>.04</td>
</tr>
<tr>
<td></td>
<td>Metricality x Musical Training</td>
<td>97.37</td>
<td>1</td>
<td>13</td>
<td>&lt;.001</td>
<td>.89</td>
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<tr>
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<td>Pattern x Musical Training</td>
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<td>24</td>
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<td>.11</td>
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<td>Metricality x Pattern</td>
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<td>24</td>
<td>.12</td>
<td>.16</td>
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<tr>
<td></td>
<td>Metricality x Pattern x Musical Training</td>
<td>0.17</td>
<td>2</td>
<td>24</td>
<td>.85</td>
<td>.01</td>
</tr>
</tbody>
</table>
**Appendix P:**
Linear Trend Analyses for Training Blocks in Experiments 2a, 2b, 3a, and 3b

Table P1.

*Summary of Linear Trend Analyses in Experiments 2a and 2b.*

<table>
<thead>
<tr>
<th>Condition</th>
<th>F</th>
<th>df1,df2</th>
<th>p-value</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Experiment 2a</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Both</td>
<td>25.49</td>
<td>1, 47</td>
<td>&lt;.001</td>
<td>.35</td>
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<tr>
<td>Single Response</td>
<td>18.08</td>
<td>1, 18</td>
<td>&lt;.001</td>
<td>.50</td>
</tr>
<tr>
<td>Multiple Response</td>
<td>1.64</td>
<td>1, 29</td>
<td>.21</td>
<td>.05</td>
</tr>
<tr>
<td><strong>Experiment 2b</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Both</td>
<td>23.31</td>
<td>1, 36</td>
<td>&lt;.001</td>
<td>.39</td>
</tr>
<tr>
<td>Metrical</td>
<td>13.59</td>
<td>1, 17</td>
<td>.002</td>
<td>.44</td>
</tr>
<tr>
<td>Non-metrical</td>
<td>9.73</td>
<td>1, 19</td>
<td>.006</td>
<td>.34</td>
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</tbody>
</table>
Table P2.

*Summary of Linear Trend Analyses in Experiment 3a.*

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Condition</th>
<th>F</th>
<th>df1,df2</th>
<th>p-value</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaction Time</td>
<td>Both</td>
<td>85.01</td>
<td>1, 54</td>
<td>&lt;.001</td>
<td>.61</td>
</tr>
<tr>
<td></td>
<td>Metrical</td>
<td>81.13</td>
<td>1, 25</td>
<td>&lt;.001</td>
<td>.76</td>
</tr>
<tr>
<td></td>
<td>Non-metrical</td>
<td>28.39</td>
<td>1, 29</td>
<td>&lt;.001</td>
<td>.50</td>
</tr>
<tr>
<td>Ordinal Error</td>
<td>Both</td>
<td>259.21</td>
<td>1, 62</td>
<td>&lt;.001</td>
<td>.81</td>
</tr>
<tr>
<td></td>
<td>Metrical</td>
<td>159.29</td>
<td>1, 31</td>
<td>&lt;.001</td>
<td>.84</td>
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<td></td>
<td>Non-metrical</td>
<td>102.65</td>
<td>1, 31</td>
<td>&lt;.001</td>
<td>.77</td>
</tr>
<tr>
<td>Relative Timing</td>
<td>Both</td>
<td>63.47</td>
<td>1, 62</td>
<td>&lt;.001</td>
<td>.51</td>
</tr>
<tr>
<td>Error (Immediate</td>
<td>Metrical</td>
<td>32.44</td>
<td>1, 31</td>
<td>&lt;.001</td>
<td>.51</td>
</tr>
<tr>
<td>Recall Task)</td>
<td>Non-metrical</td>
<td>32.03</td>
<td>1, 31</td>
<td>&lt;.001</td>
<td>.51</td>
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<tr>
<td>Relative Timing</td>
<td>Both</td>
<td>38.63</td>
<td>1, 25</td>
<td>&lt;.001</td>
<td>.61</td>
</tr>
<tr>
<td>Error (Implicit)</td>
<td>Metrical</td>
<td>31.37</td>
<td>1, 14</td>
<td>&lt;.001</td>
<td>.69</td>
</tr>
<tr>
<td></td>
<td>Non-metrical</td>
<td>11.06</td>
<td>1, 11</td>
<td>.007</td>
<td>.50</td>
</tr>
</tbody>
</table>
Table P3.

Summary of Linear Trend Analyses in Experiment 3b.

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Condition</th>
<th>F</th>
<th>df1,df2</th>
<th>p-value</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaction Time (Serial Reaction-time Task)</td>
<td>Both</td>
<td>4.01</td>
<td>1, 62</td>
<td>.05</td>
<td>.06</td>
</tr>
<tr>
<td></td>
<td>Metrical</td>
<td>2.76</td>
<td>1, 32</td>
<td>.11</td>
<td>.08</td>
</tr>
<tr>
<td></td>
<td>Non-metrical</td>
<td>1.33</td>
<td>1, 30</td>
<td>.26</td>
<td>.04</td>
</tr>
<tr>
<td>Ordinal Error (Immediate Recall Task)</td>
<td>Both</td>
<td>1.88</td>
<td>1, 62</td>
<td>.18</td>
<td>.03</td>
</tr>
<tr>
<td></td>
<td>Metrical</td>
<td>0.73</td>
<td>1, 32</td>
<td>.40</td>
<td>.02</td>
</tr>
<tr>
<td></td>
<td>Non-metrical</td>
<td>1.26</td>
<td>1, 30</td>
<td>.27</td>
<td>.04</td>
</tr>
<tr>
<td>Relative Timing Error (Immediate Recall Task)</td>
<td>Both</td>
<td>11.68</td>
<td>1, 62</td>
<td>.001</td>
<td>.16</td>
</tr>
<tr>
<td></td>
<td>Metrical</td>
<td>7.80</td>
<td>1, 31</td>
<td>.009</td>
<td>.20</td>
</tr>
<tr>
<td></td>
<td>Non-metrical</td>
<td>4.62</td>
<td>1, 30</td>
<td>.04</td>
<td>.13</td>
</tr>
<tr>
<td>Relative Timing Error (Implicit)</td>
<td>Both</td>
<td>5.30</td>
<td>1, 25</td>
<td>.03</td>
<td>.18</td>
</tr>
<tr>
<td></td>
<td>Metrical*</td>
<td>2.18</td>
<td>1, 12</td>
<td>.17</td>
<td>.15</td>
</tr>
<tr>
<td></td>
<td>Non-metrical*</td>
<td>3.18</td>
<td>1, 13</td>
<td>.10</td>
<td>.20</td>
</tr>
</tbody>
</table>

* Metrical and non-metrical conditions approached significance at the order 4 \(F(1, 12) = 3.95, p = .07, \eta_p^2 = .25\) and quadratic \(F(1, 13) = 5.07, p = .04, \eta_p^2 = .28\), respectively. This indicates that learning did not occur in a linear fashion, although learning still occurred.
Appendix Q:
Results for Implicit Learners as Determined by Explicit Scores from the Generation Task

Table Q1.

F statistics for participants with explicit scores of zero or less in Experiment 2a.

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Effect</th>
<th>F</th>
<th>df1, df2</th>
<th>p-value</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaction Time</td>
<td>Training Blocks (1 to 5)</td>
<td>6.40</td>
<td>4, 100</td>
<td>&lt;.001</td>
<td>.20</td>
</tr>
<tr>
<td></td>
<td>Task (Training Blocks)</td>
<td>136.41</td>
<td>1, 25</td>
<td>&lt;.001</td>
<td>.85</td>
</tr>
<tr>
<td></td>
<td>Training Blocks x Task</td>
<td>3.26</td>
<td>4, 100</td>
<td>.015</td>
<td>.12</td>
</tr>
<tr>
<td>Improvement</td>
<td>Task</td>
<td>3.50</td>
<td>1, 25</td>
<td>.074</td>
<td>.13</td>
</tr>
<tr>
<td>Damage</td>
<td>Test Block</td>
<td>9.63</td>
<td>1, 25</td>
<td>.009</td>
<td>.45</td>
</tr>
<tr>
<td></td>
<td>Task (Test Blocks)</td>
<td>2.69</td>
<td>1, 25</td>
<td>.09</td>
<td>.18</td>
</tr>
<tr>
<td></td>
<td>Test Block x Task</td>
<td>0.25</td>
<td>1, 25</td>
<td>.78</td>
<td>.02</td>
</tr>
<tr>
<td></td>
<td>Test Block (Single response only)</td>
<td>8.07</td>
<td>1, 11</td>
<td>.016</td>
<td>.42</td>
</tr>
<tr>
<td></td>
<td>Test Block (Multiple response only)</td>
<td>1.82</td>
<td>1, 14</td>
<td>.20</td>
<td>.12</td>
</tr>
</tbody>
</table>

There were 12 (of 25) participants in the single response condition and 15 (of 35) participants in the multiple response condition who produced explicit scores of zero or less.
Figure Q1. Results from the SRT in Experiment 2a excluding participants with explicit scores of zero or greater. Q1a) Mean RT (correct responses only) for the single response and multiple response conditions over blocks. Blocks 1-5 contain the training pattern. Error bars represent standard error of the mean. Q1b) Mean RT increases between the test block and the mean of the adjacent blocks for strongly metrical and weakly metrical test blocks in the single response and multiple response conditions. Error bars represent standard error of the mean.
Table Q2.

*F* statistics for participants with explicit scores of zero or less in Experiment 2b.

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Effect</th>
<th>F</th>
<th>df1, df2</th>
<th>p-value</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reaction Time</td>
<td>Training Blocks (1 to 5)</td>
<td>10.20</td>
<td>4, 92</td>
<td>&lt;.001</td>
<td>.31</td>
</tr>
<tr>
<td></td>
<td>Metricality (Training Blocks)</td>
<td>0.21</td>
<td>1, 23</td>
<td>.65</td>
<td>.01</td>
</tr>
<tr>
<td></td>
<td>Training Blocks x Metricality</td>
<td>0.68</td>
<td>4, 92</td>
<td>.61</td>
<td>.03</td>
</tr>
<tr>
<td>Improvement</td>
<td>Metricality</td>
<td>0.06</td>
<td>1, 23</td>
<td>.81</td>
<td>.003</td>
</tr>
<tr>
<td>Damage</td>
<td>Test Block</td>
<td>3.10</td>
<td>1, 23</td>
<td>.09</td>
<td>.12</td>
</tr>
<tr>
<td></td>
<td>Metricality (Test Blocks)</td>
<td>1.22</td>
<td>1, 23</td>
<td>.28</td>
<td>.05</td>
</tr>
<tr>
<td></td>
<td>Test Block x Metricality</td>
<td>0.25</td>
<td>1, 23</td>
<td>.78</td>
<td>.02</td>
</tr>
<tr>
<td></td>
<td>Test Block (Metrical only)</td>
<td>2.46</td>
<td>1, 10</td>
<td>.15</td>
<td>.20</td>
</tr>
<tr>
<td></td>
<td>Test Block (Non-metrical only)</td>
<td>0.86</td>
<td>1, 13</td>
<td>.37</td>
<td>.06</td>
</tr>
</tbody>
</table>

There were 11 (of 25) participants in the metrical condition and 14 (of 26) participants in the non-metrical condition who produced explicit scores of zero or less.
Figure Q2. Results from the SRT in Experiment 2b excluding participants with explicit scores of zero or greater. Q2a) Mean RT (correct responses only) for the metrical and non-metrical conditions over blocks. Blocks 1-5 contain the training pattern. Error bars represent standard error of the mean. Q2b) Mean RT increases between the test block and the mean of the adjacent blocks for test blocks 1 and 2. In the metrical condition, test 1 was strongly metrical and test 2 was weakly metrical. Error bars represent standard error of the mean.
Table Q3.

*F* statistics for participants with explicit scores of zero or less in Experiment 3a.

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Effect</th>
<th>F</th>
<th>df1, df2</th>
<th>p-value</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative Timing Error</td>
<td>Training Blocks (1 to 5)</td>
<td>5.87</td>
<td>4, 64</td>
<td>&lt;.001</td>
<td>.27</td>
</tr>
<tr>
<td></td>
<td>Metricality (Training Blocks)</td>
<td>0.00</td>
<td>1, 17</td>
<td>.99</td>
<td>.00</td>
</tr>
<tr>
<td></td>
<td>Training Blocks x Metricality</td>
<td>0.88</td>
<td>4, 64</td>
<td>.48</td>
<td>.05</td>
</tr>
<tr>
<td>Improvement</td>
<td>Metricality</td>
<td>0.66</td>
<td>1, 17</td>
<td>.43</td>
<td>.04</td>
</tr>
<tr>
<td>Damage</td>
<td>Test Block</td>
<td>0.99</td>
<td>1, 17</td>
<td>.34</td>
<td>.06</td>
</tr>
<tr>
<td></td>
<td>Metricality (Test Blocks)</td>
<td>0.55</td>
<td>1, 17</td>
<td>.93</td>
<td>.03</td>
</tr>
<tr>
<td></td>
<td>Test Block x Metricality</td>
<td>0.01</td>
<td>1, 17</td>
<td>.93</td>
<td>.00</td>
</tr>
<tr>
<td></td>
<td>Test Block (Metrical only)</td>
<td>0.34</td>
<td>1, 6</td>
<td>.58</td>
<td>.05</td>
</tr>
<tr>
<td></td>
<td>Test Block (Non-metrical only)</td>
<td>0.71</td>
<td>1, 10</td>
<td>.42</td>
<td>.07</td>
</tr>
</tbody>
</table>

There were 7 (of 33) participants in the metrical condition and 11 (of 31) participants in the non-metrical condition who produced explicit scores of zero or less.
Figure Q3. Results from the IRT in Experiment 3a excluding participants with explicit scores of zero or greater. Q3a) Mean relative timing error for the metrical and non-metrical conditions over blocks. Blocks 1-5 contain the training pattern. Q3b) Mean relative timing error increases between the test block and the mean of the adjacent blocks for test blocks 1 and 2. In the metrical condition, test 1 was strongly metrical and test 2 was weakly metrical. Error bars represent standard error of the mean.
Table Q4.

*F* statistics for participants with explicit scores of zero or less in Experiment 3b.

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Effect</th>
<th>F</th>
<th>df1, df2</th>
<th>p-value</th>
<th>Partial Eta Squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative Timing Error</td>
<td>Training Blocks (1 to 5)</td>
<td>8.00</td>
<td>4, 80</td>
<td>&lt;.001</td>
<td>.29</td>
</tr>
<tr>
<td></td>
<td>Metricality (Training Blocks)</td>
<td>1.35</td>
<td>1, 20</td>
<td>.26</td>
<td>.06</td>
</tr>
<tr>
<td></td>
<td>Training Blocks x Metricality</td>
<td>1.09</td>
<td>4, 80</td>
<td>.37</td>
<td>.05</td>
</tr>
<tr>
<td>Improvement</td>
<td>Metricality</td>
<td>0.11</td>
<td>1, 20</td>
<td>.74</td>
<td>.01</td>
</tr>
<tr>
<td>Damage</td>
<td>Test Block</td>
<td>0.28</td>
<td>1, 20</td>
<td>.60</td>
<td>.01</td>
</tr>
<tr>
<td></td>
<td>Metricality (Test Blocks)</td>
<td>0.05</td>
<td>1, 20</td>
<td>.82</td>
<td>.003</td>
</tr>
<tr>
<td></td>
<td>Test Block x Metricality</td>
<td>0.28</td>
<td>1, 20</td>
<td>.60</td>
<td>.01</td>
</tr>
<tr>
<td></td>
<td>Test Block (Metrical only)</td>
<td>0.01</td>
<td>1, 12</td>
<td>.94</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>Test Block (Non-metrical only)</td>
<td>0.56</td>
<td>1, 8</td>
<td>.56</td>
<td>.07</td>
</tr>
</tbody>
</table>

There were 13 (of 31) participants in the metrical condition and 9 (of 31) participants in the non-metrical condition who produced explicit scores of zero or less.
Figure Q4. Results from the IRT in Experiment 3b excluding participants with explicit scores of zero or greater. Q4a) Mean relative timing error for the metrical and non-metrical conditions over blocks. Blocks 1-5 contain the training pattern. Q4b) Mean relative timing error increases between the test block and the mean of the adjacent blocks for test blocks 1 and 2. In the metrical condition, test 1 was strongly metrical and test 2 was weakly metrical. Error bars represent standard error of the mean.
Appendix R:
Stimuli (DVD-ROM)