Implicit Learning of Complex Auditory Temporal Structures with Even and Uneven Meters

Josephine A. Terry
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Statement of Authentication

The work presented in this thesis is, to the best of my knowledge and belief, original except as acknowledged in the text. I hereby declare that I have not submitted this material, either in full or in part, for a degree at this or any other institution.

Josephine Terry
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Abstract

Complex auditory sequences (e.g. speech and music) unfold in time. With exposure, listeners can extract regularities in these sequences and develop expectations about the identity (ordinal dimension) and the timing (temporal dimension) of upcoming events. When upheld, these expectations permit faster, and more accurate responses to events, compared to when expectations of the ordinal and/or temporal dimensions are violated (Brandon, Terry, Stevens, & Tillmann, 2012; Buchner & Steffens, 2001; Nissen & Bullemer, 1987; Shin & Ivry, 2002). In everyday life, expectations can be acquired without an intention to do so, and without attention being directed to the regularities in the sequence (Perruchet, 2008; Shanks, 2005). That is, sequential regularities can be learned implicitly. Implicit learning (IL) research has primarily investigated learning of ordinal dimensions of visual sequences. The research presented in this thesis investigated IL of complex temporal structures in auditory sequences with rhythmic features typical of music.

Musical rhythms of many cultures have a hierarchical beat structure: meter. Meter is the perception of cyclic patterns of strong and weak beats. The more salient the strong beats, and the more regular and frequent their distribution across time, the stronger the meter is perceived to be. In most Western tonal music, strong beats are evenly spaced in time (even meters). However, in music from the Balkan region for example, strong beats can be unevenly spaced in time (uneven meters). Through a lifetime’s exposure, listeners develop expectations of meter characteristic of their musical environment. In the experiments reported in this thesis, rhythms with even and uneven meters are used to examine the flexibility of Western listeners to implicitly learn temporal structures.
According to the *Dynamic Attending Theory*, attentional energy, driven by neural oscillations, is directed to points in time that are consistent with a preceding temporal context. Events occurring at expected time points are judged more accurately and/or quickly than events occurring at misaligned points in time (Barnes & Jones, 2000; Jones, Moynihan, MacKenzie, & Puente, 2002; Large & Jones, 1999; Tillmann & Lebrun-Guillaud, 2006). These neural oscillations have also been shown to entrain to perceived meters and it has been argued that these oscillatory processes underlie temporal expectation (Grahn, 2012; Large & Snyder, 2009; Snyder & Large, 2005). In the current research project, the development of temporal expectations was examined using an auditory serial reaction time task (SRTT).

Participants with no or minimal formal musical training identified as quickly and accurately as possible sequences of auditory events (e.g. pseudo-random ordering of syllables). Unbeknownst to participants, the temporal presentation of events followed a repeating series of inter-onset intervals (IOIs). It was hypothesised that, as temporal expectations were acquired over exposure blocks, reaction time (RT) to identify the syllables would decrease. It was also hypothesised that, as temporal expectations were violated at the introduction of a new rhythm at a test block, RT would increase.

Experiment 1 demonstrated IL of a weakly metrical rhythm. In particular, the durations of intervals between auditory groups (i.e. inter-group intervals, IGIs) were learned. RT significantly decreased over exposure blocks and increased at the test block. There was no evidence of learning a second rhythm with a slightly weaker meter. In Experiment 2, the metrical structure of the rhythms presented in Experiment 1 was cued with an accented pulse and some learning of the rhythm with the slightly weaker meter was evident: RT increased significantly to controlled within-group
intervals at the test block. In Experiment 3, and with explicit instructions to learn the rhythms, only the stronger of the two weakly metrical rhythms was learned.

Experiments 4 to 6 examined IL of rhythms with even and uneven meters. The results showed that listeners of Western tonal music learned rhythms with even and uneven meters. RT to syllables following IGIs decreased significantly over exposure and increased at a test block. In all experiments with IL instructions, post-test questionnaires, and familiarity and certainty ratings to exposure, test, and novel sequences revealed that learning of the exposure rhythms was implicit.

The results of six experiments provide evidence of IL of temporal structures, or auditory rhythms, when the ordinal structure was unpredictable. Learning occurred not just of the grouping structure but also of the timing between groups of events. Furthermore, listeners of Western tonal music implicitly learned rhythms with culturally familiar and culturally less familiar meters. Together, these findings demonstrate the capacity of listeners to develop temporal expectations of musical rhythms that either uphold or violate long-term, culturally acquired expectations. The findings also highlight the efficacy of implicit learning as a means of developing temporal expectations in a single exposure session. Demonstrations of IL of temporal structures have important implications for settings where an explicit instruction to learn a rhythm may impeded learning (e.g. music education, motor skills rehabilitation, speech therapy).
Chapter 1

Introduction
1. Introduction

1.1. Preface

Music is ubiquitous, yet a listener’s experience of listening to music is highly influenced by previous exposure to culturally specific musical styles (Creel, 2011; Curtis & Bharucha, 2009; Hannon & Trehub, 2005a; Huron, 2008; Krumhansl, 2000b; Morrison, Demorest, & Stambaugh, 2008). It has been proposed that expectations, or tacit knowledge of culturally specific musical structures (e.g. tonal, melodic, temporal/rhythmic) can be acquired via unintentional and non-conscious learning (i.e. implicit learning) (Bigand & Poulin-Charronnat, 2006; Creel, 2011; Huron, 2006; Jones, 2009; Rohrmeier & Rebuschat, 2012; Rohrmeier, Rebuschat, & Cross, 2011; Tillmann, Bharucha, & Bigand, 2000; Trehub & Hannon, 2009). A substantial body of research has examined implicit learning (IL) of visual sequences but there has been considerably less research investigating IL of auditory musical structures, particularly temporal, or rhythmic structures. This thesis reports six experiments investigating IL of temporal structure, or rhythms akin to those found in music.

Musical rhythmic structures were chosen as the focus of investigation because they are encountered in everyday life and are familiar to listeners irrespective of formal musical training (Bigand & Poulin-Charronnat, 2006). Synchronising or entraining with musical rhythms is a universal human capacity that enables listeners to coordinate movement with music, or with other listeners (Brown, 2003; Brown, Merker, & Wallin, 2000; Merker, Madison, & Eckerdal, 2009). The accurate anticipation of a rhythm as it unfolds in time is crucial for the performance of music.
and dance. Temporal regularity is also important for oral traditions as it enhances memorisation of speech (e.g. poetry and prose) (Rubin, 1995), and increases the aesthetic appreciation and positive emotional appraisal of poetry (Obermeier, et al., 2013). Moreover, synchronising movements with others is an affiliative behaviour that enhances social cohesion (Hove & Risen, 2009) and infant-caregiver bonding (Malloch & Trevarthen, 2009; Phillips-Silver & Keller, 2012).

Meter, or the perception of cycling strong and weak beats (see Section 1.4 for a full description) is an important structural feature of musical rhythm that facilitates entrainment and aids in the prediction of the timing of upcoming musical events (e.g. tones, beats) (Large & Jones, 1999; Large & Kolen, 1994; Large & Palmer, 2002; Large & Snyder, 2009; Patel, Iversen, Chen, & Repp, 2005). While metrical structures are present across rhythms of all cultures, the nature of these structures varies cross-culturally (Clayton, Sager, & Will, 2004; London, 1995; Magill & Pressing, 1997; Moelants, 2006; Nettl, 1983). Therefore, an important research question concerns the ways in which temporal expectations are developed, both over a lifetime’s exposure to musical rhythms, and over the short-term with exposure to novel rhythms. The current program of research will investigate the effect of long-term expectations, acquired over a lifetime’s exposure to culturally specific rhythms, on IL of novel rhythms in a laboratory setting. Thus, six experiments reported in this thesis will examine the capacity of listeners of Western tonal music to implicitly learn rhythms with relatively familiar, and less familiar meters.

Methods used are derived from the IL research field. Specifically, an auditory adaptation of the serial reaction time task (SRTT), commonly employed to measure learning of the ordinal structure of visual sequences (e.g. Destrebecqz & Cleeremans, 2001; Nissen & Bullemer, 1987), is used to measure learning of temporal structure.
The rationale underpinning the use of this method in the current thesis is that listeners develop temporal expectations by implicitly learning a repeating sequence of inter-onset intervals (IOIs). Consequently, reaction time (RT) to identify the events used to instantiate the temporal structures decreases with exposure. Furthermore, RT increases when temporal expectations are violated by the introduction of a different sequence of IOIs. By controlling the nature of the violation, the precise features of the temporal structures that are learned can be determined.

The remainder of this chapter will review research investigations of the development of temporal expectations and temporal processing. Meter will be defined, and its relevance to the current research project will be proposed. Research into IL of visual and auditory structures, particularly temporal structures, will be summarised and the experiments conducted in this research project will be briefly described. Literature reviews and hypotheses specific to each experiment will be presented at the beginning of each subsequent experimental chapter (Chapters 2 to 5).

1.2. Development of Musical Expectations

Expectations of musical structure (e.g. tonality and rhythm) can develop as a consequence of mere exposure (Bigand & Poulin-Charronnat, 2006; Creel, 2011; Schellenberg, Bigand, Poulin-Charronnat, Garnier, & Stevens, 2005; Tillmann, et al., 2000). Listening to a specific musical work will give rise to expectations particular to that work (i.e. veridical expectations). However, a lifetime of listening to many exemplars of a particular musical style allows listeners to process unheard musical works, emblematic of the same style, using an established framework (i.e. by developing schematic expectations) (Huron, 2006; Justus & Bharucha, 2001). In other words, listeners will have an expectation of how the newly heard musical work will
most probably unfold in time. Hence, via mere listening, the regularities in musical sequences are internalised and over time become culturally familiar (Bigand & Poulin-Charronnat, 2006; Creel, 2011; Curtis & Bharucha, 2009; Demorest, Morrison, Beken, & Jungbluth, 2008; Hannon & Trainor, 2007; Morrison, et al., 2008; Stevens, 2012; Tillmann & Lebrun-Guillaud, 2006; Trehub & Hannon, 2006, 2009). Furthermore, research indicates that schematic expectations affect the perception and processing not only of familiar music, but also of new, unfamiliar music that violates these long-term schematic expectations (Bigand & Poulin-Charronnat, 2006; Curtis & Bharucha, 2009; Hannon & Trehub, 2005a; Kalender, Trehub, & Schellenberg, 2012; Krumhansl, 2000b; Krumhansl, Louhivuori, Toiviainen, Järvinen, & Errola, 1999; Krumhansl, et al., 2000). For instance, listeners enculturated to Western tonal music are better at judging whether a tone was presented within a preceding sequence of tones when those tones conformed to a Western modal (i.e. major mode) context, compared to an unfamiliar modal context (i.e. Indian thata Bhairav) (Curtis & Bharucha, 2009).

Expectations based on long-term knowledge affect not only tonal expectations but also temporal expectations. These temporal expectations have been shown to influence processing of rhythms (Hannon & Trainor, 2007; Kalender, et al., 2012; Trehub & Hannon, 2009). Performing an explicit similarity judgement task, listeners enculturated to primarily Western tonal music are more accurate at judging the similarity of two melodies containing temporal violations when those melodies have culturally familiar meters, compared to culturally less familiar meters (Hannon & Trehub, 2005a). Therefore, the experiments in this thesis examine the development of temporal expectations, via IL. Rhythms will have both culturally familiar and culturally less familiar temporal structures to listeners of primarily Western tonal
music. In particular, meters (i.e. repeated cycling of strong and weak beats) will be manipulated in order to determine the effect of temporal expectations, acquired over a lifetime’s exposure to rhythms with culturally specific metrical structures, on learning novel rhythms. In short, the influence of long-term knowledge-based temporal expectations on learning temporal structures by means of short-term exposure in a laboratory setting is examined.

1.3. Temporal Structure and Rhythm

Temporal structures, or rhythms, are defined by a serial ordering of IOIs (i.e. time spans marked by event onsets). A listener achieves the coherent perception and processing of a rhythm by organising these event onsets over time (Drake & Bertrand, 2003). If all events are separated by IOIs of equal duration, the resulting sequence is isochronous. If IOIs of multiple durations separate events in time, a grouping structure can be perceived. Events forming groups are separated by relatively short IOIs, with longer IOIs forming boundaries around the groups (referred to here as inter-group intervals, IGIs). A single event bounded by longer IOIs (i.e. IGIs) is also considered a group (Handel, 1998; Lerdahl & Jackendoff, 1983). In Western tonal music, IOIs of different durations within a single rhythm tend to have simple ratio relationships of 1:2 and 1:3 (London, 2002) (see Figure 1.1).
Figure 1.1. Graphical representation of a rhythm and its relationship to an even duple metric hierarchy. "●" in the metric hierarchy represents a perceived beat and "x" in the rhythmic sequence represents an auditory event and. A bold “x” indicates a strongly perceived accent. Arrows at Level 2 of the metric hierarchy show the equal spacing between beats at an intermediate level of the metric hierarchy.

Temporal structures, or rhythms, typical of Western tonal music can be organised according to their relationship to an underlying beat or pulse (See Level 1 of Figure 1.1). It is this beat structure that listeners often entrain to when clapping along to music. Beats are perceived as isochronous, equally spaced points in time (Lerdahl & Jackendoff, 1983). They are perceptual or endogenous (i.e. internally generated) events and arise in response to a heard exogenous, or external rhythm (Large, 2008). Beats often align with the events within a rhythm (e.g. musical notes). Although, a beat can still be experienced in the absence of a note onset (Large, 2008; Large & Snyder, 2009). Furthermore, beat structures tend to be robust, even in the face of tempo change, or the normal timing fluctuations expected in a musical performance. The perception of a beat structure appears to be present at birth with event-related brain potentials (ERP) demonstrating beat detection and the processing
of temporal regularity in 1 to 2 day-old infants (Winkler, Háden, Ladinig, Sziller, & Honing, 2009).

A temporal regularity, such as a beat or pulse, provides a framework within which upcoming events are assimilated. According to the Dynamic Attending Theory, attentional energy, driven by neural oscillations, is directed to points in time that are marked by perceived beats (Large & Jones, 1999; Large & Palmer, 2002). Research has shown that events occurring at points in time that align with a beat grid induced with the presentation of a simple isochronous rhythm, are judged (i.e. detected or discriminated) more accurately (Barnes & Jones, 2000; Jones, et al., 2002; Jones & Yee, 1997; Large & Jones, 1999; McAuley & Jones, 2003) and/or quickly than events occurring at misaligned points in time (Penel & Jones, 2005; Tillmann & Lebrun-Guillaud, 2006). For example, Tillmann and Lebrun-Guillaud (2006) found that listeners were faster at identifying the timbre (guitar or harp sound) of the last musical chord of a sequence of chords when it was presented on time, compared to early or late. In other words, participants were faster at processing the target chord when its temporal presentation respected the preceding temporal context (i.e. isochronous sequence of chords). Theoretically, a regular temporal context drives temporal expectations by means of attentional oscillations that track, or entrain to the incoming temporal structure (Jones & Boltz, 1989; Large & Jones, 1999; Large & Kolen, 1994).

The set of experiments reported in this thesis draws on Dynamic Attending Theory hypothesising that RT to auditory events presented in sequences with repeating temporal structures will become faster with exposure but will slow at the introduction of a sequence with a new repeating temporal structure. In other words, learning of the temporal regularities inherent in the event sequences, leading to the development of temporal expectations, is examined. It is expected that RT will be
faster when temporal expectations are upheld, but slower when these expectations are
violated. Unlike previous work (e.g. Jones, et al., 2002; Penel & Jones, 2005), the
repeating temporal structures will be complex sequences of two or three different IOIs
arranged in 10-event to 15-event sequences, rather than simple isochronous
sequences, and therefore will be more typical of musical rhythms. Furthermore,
temporal expectations acquired during the exposure phase of the experiment will be
violated in particular ways to aim at examining the features of the temporal structures
that are learned. Finally, an important aim of the experiments reported here is to
investigate whether learning of the temporal regularities emerge implicitly, that is,
without attending to the temporal structure, and without having an intention to learn
the structure.

1.4. Even Meters: Metrical Structures Typical of Western Tonal Music

A framework additional to beat structure, or pulse, within which temporal
structures or rhythms are organised, is meter. Like beat or pulse, meter is an
endogenous construct, perceived in response to an external rhythm. Meter gives rise
to the perception of cyclic and regular patterns of strong and weak beats (Lerdahl &
Jackendoff, 1983). It is a hierarchical structure with regular cycles of strong and weak
beats embedded within increasingly longer-scale cycles of strong and weak beats at
each hierarchical level (Lerdahl & Jackendoff, 1983). When beats coincide at multiple
levels in the hierarchy, they are perceived as strong, and the more beats that align, the
more readily the meter is abstracted (Jones, 1987; Large & Kolen, 1994; London,

There are a number of different metrical structures that emerge as a
consequence of the spacing between strong beats at particular hierarchical levels. In
Western tonal music, the most common meter has alternating strong and weak beats (S-W-S-W-S-W-S-W) at the second hierarchical level (see Level 2 of Figure 1.1). The next level in the hierarchy has strong beats at every fifth beat location (S-W-W-S-W-W-W) (see Level 3 of Figure 1.1). If the hierarchical level eliciting the perception of alternating strong and weak beats (S-W-S-W) is the most salient, then the rhythm is referred to as having *duple* meter and is characteristic of “march” music. If the most salient level has a strong beat at every fifth beat location (S-W-W-S-W-W-W), then the rhythm has a *quadruple* meter. *Triple* meters have strong beats at every fourth beat location (S-W-W-S-W-W) at the most salient hierarchical level and these meters characterise “waltz” music (London, 2002).

Musical events (e.g. tones or notes, percussive events) are more likely to occur at strong beat, compared to weak beat locations (Jones, 1987; Palmer & Krumhansl, 1990) and strong beats also tend to align with events of tonal and harmonic importance (Ellis & Jones, 2009; Krumhansl, 2000a; Lerdahl & Jackendoff, 1983). In addition, strong beats tend to be associated with notes of relatively long duration, and are often marked with amplitude accents (i.e. brief increases in intensity) during musical performance (Pfordresher, 2003). In equitonal sequences, when tonal and harmonic cues to meter are absent, and in the absence of amplitude accents, a rhythm’s grouping structure can also give rise to the perception of meter (Povel & Essens, 1985). Specifically, (a) isolated tones, (b) the second tone in a group of two, (c) and the first and last tones in a group of three or more, tend to be perceived as accented. Moreover, perhaps as a consequence of a lifetime’s exposure to musical rhythms with metrical structures, listeners perceive strong beats in equitonal, isochronous sequences. That is, listeners impose a metrical structure on a series of
identical and equally spaced tones (Brochard, Abecasis, Ragot, Potter, & Drake, 2003).

The type (e.g. duple, triple) and strength of the emergent meter is a function of the frequency with which perceptually accented events (due to the event’s location in the grouping structure) align with various possible beat grids. At least for listeners of Western tonal music, rhythms with strong duple meters are perceived and produced more accurately than non-metrical (Essens & Povel, 1985) or weakly metrical rhythms (Grube & Griffiths, 2009; Patel, et al., 2005; Povel & Essens, 1985). For instance, discriminating the pitch of a target tone is faster when preceded by strongly metrical rhythmic context, compared to a non-metrical context (Ellis & Jones, 2010). Povel and Essens (1985), using grouping principles to elicit meter, found that strongly metrical rhythms were reproduced more accurately and after fewer exposures than weakly metrical rhythms. Synchronising taps with a rhythm with a strong meter is also more accurate than when synchronising with a rhythm with a weak meter (Patel, et al., 2005; Povel & Essens, 1985). Research with infants further suggests a processing advantage for strong meters that is acquired early in life (Bergeson & Trehub, 2006). Nine-month old infants were able to detect a change in the duration of a note presented in a rhythm with a strong meter, but not weak meter.

Particularly relevant to the first three experiments reported here is the finding that participants are more accurate at detecting temporal violations to IGIs (i.e. longer IOIs between event groups) when they are in rhythms that have a strong, compared to weak meter (Handel, 1998; Hébert & Cuddy, 2002; Ross & Houtsma, 1994). While Handel (1998) suggested that grouping structure is the predominant cue to perceptually organising rhythms, Hébert and Cuddy (2002) proposed the presence of
a timing mechanism, or an internal clock, elicited by a strong meter that facilitates processing of the temporal intervals between events.

In this thesis, the aim of Experiments 1 – 3 (reported in Chapters 2 and 3) is to further examine temporal processing of grouping structures and IGIs. Specifically, these experiments will examine whether learning of complex rhythms is limited to grouping structure, or whether IGIs can also be learned. As a robust test of this, the complex rhythms presented in the first experiment will be weakly metrical. Using an IL paradigm, learning of IGIs, or the precise timing between groups of auditory events, will be examined. In the Experiments 4 to 6 (reported in Chapters 4 and 5), the cultural familiarity of the metrical structures of rhythms will be manipulated. The aim will be to examine the effect of temporal expectation acquired over a lifetime’s exposure to culturally specific meters on IL of novel rhythms with familiar and less familiar meters. Throughout all experiments, meter will primarily be generated using the grouping principles outlined by Povel and Essens (1985). However, to ensure that meter is unambiguous, additional cues, including the addition of an accented pulse, and increases in the amplitude of events aligning with strong beats will be implemented in Experiments 2 - 6.

Although the rhythms of Western tonal music typically have duple and triple meters, duple meters are more common (Fraisse, 1982). Research with adults and infants indicates that the relative familiarity of duple, over triple meters improves processing of rhythms with duple meters (Abecasis, Brochard, Granot, & Drake, 2005; Bergeson & Trehub, 2006; Brandon, et al., 2012; Drake, 1993; K. C. Smith & Cuddy, 1989). It is likely that this processing advantage for duple meters arises from enculturation. Phillips-Silver and Trainor (2005) reported that 7-month old infants preferred rhythms with meters that corresponded to the way they were bounced
during exposure to a metrically ambiguous rhythm. Infants that were bounced on every second beat preferred rhythms with duple meters and those bounced on every third beat preferred rhythms with triple meters. Therefore, it appears that processing advantages for particular meters arises from exposure.

Overall, it appears that prior exposure and the resulting relative familiarity with metrical structures influences the processing of a rhythm (Creel, 2011). In this thesis, the effect of enculturation, via a lifetime’s exposure to certain metrical structures, in learning novel rhythms is investigated in Experiments 4 - 6. However, rather than examining the role of enculturation using relatively familiar duple and relatively less familiar triple meters (i.e. both even meters typical of Western tonal music), duple even meters and culturally less familiar uneven meters are used.

1.5. Uneven Meters: Metrical Structure Less Familiar to Listeners of Western Tonal Music

Uneven meters are often present in musical rhythms of the Balkan region (e.g. Macedonia, Bulgaria, Hungary and Greece), the Middle East, South-Asia, West Africa and Latin America. Although more rarely, uneven meters are also utilised in some jazz (e.g. Dave Brubeck), and in some Western classical music (e.g. Béla Bartók). As with even meters, uneven meters have isochronously spaced beats at the lowest level of the hierarchy but they have unevenly spaced strong beats at the intermediate level of the hierarchy (Clayton, et al., 2004; Fracile, 2003; Moelants, 2006; Singer, 1974). This uneven spacing of strong beats gives rise to a perception of S-W-S-W-W or S-W-W-S-W beat structures (Fracile, 2003) (see Level 2 of Figure 1.2).
Figure 1.2. Graphical representation of an uneven meter rhythm and its relationship to an uneven metric hierarchy with a S-W-W-S-W beat structure. “●” in the metric hierarchy represents a perceived beat and “x” in the rhythmic sequence represents an auditory event and. A bold “x” indicates a strongly perceived accent. Arrows at Level 2 of the metric hierarchy show the unequal spacing between beats.

Relative to listeners who have been enculturated with uneven meters (via a lifetime’s exposure to musical rhythms with these meters), listeners exposed primarily to Western tonal music tend to perceive and process rhythms with uneven meters with difficulty. Rhythms with uneven meters are difficult to tap along to and to reproduce for participants enculturated with even meters, irrespective of participants’ level of formal musical training (Repp, London, & Keller, 2005; Snyder, Hannon, Large, & Christiansen, 2006). For instance, Snyder et al. (2006) had North American adults synchronise with non-isochronous melodies with accompanying drum patterns with uneven meters (S-W-W-S-W-S-W and S-W-S-W-S-W-W). During synchronisation, the longer intervals tended to be lengthened so that tapping was more characteristic of an even meter pattern (i.e. 2:1 ratio between long and short intervals). Participants then tapped in the absence of the melody and/or drum pattern and the lengthening of the long interval continued. This lengthening was most pronounced in the absence of both the drum pattern and melody.
Further research with infants and adults has indicated that the relative ease or difficulty with which culturally specific meters are processed is a function of early exposure (Hannon, Soley, & Levine, 2011; Hannon, Soley, & Ullal, 2012; Hannon & Trainor, 2007; Hannon & Trehub, 2005b; Kalender, et al., 2012; Soley & Hannon, 2010; Trehub & Hannon, 2006). Hannon and Trehub (2005a) reported that North American adults (with a lifetime’s exposure to even meter rhythms) were better at detecting rhythmic alterations in music with even compared to uneven meters. However, adults from Macedonia and Bulgaria (with a lifetime’s exposure to both even and uneven meters) detected violations equally accurately in music with both even and uneven meters. Kalender et al. (2012) found that participants with a lifetime’s exposure to only Western tonal music (i.e. even meters) could detect rhythmic changes in Turkish music, but only when the musical rhythms had even, but not uneven meters. This finding indicates that a lack of familiarity with an uneven meter, rather than a lack of familiarity with the culturally specific musical style, impaired performance on the task.

Using a familiarization-preference procedure, six-month old North American infants were also able to detect rhythmic alterations in melodies with both even and uneven meters. Infants’ performance was more like that of the Macedonian and Bulgarian adults. The findings suggest that infants have a capacity to adapt to various metrical structures, but over time via the process of enculturation, perception and production calibrates to rhythms with culturally specific meters. Hence, adults posses performance advantages for meters to which they have been primarily exposed to over their lifetime (Hannon & Trehub, 2005a).

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1 Hannon, Soley, and Ullal (2012) reported similar findings with North American and Turkish adults and in addition were able to show that the effect was not due to rhythmic complexity but to the familiarity with culturally specific meters.
More evidence for the role of enculturation in processing rhythms comes from research with older infants. For example, North American infants of 12-months age show adult-like processing of rhythms with uneven meters (Hannon & Trehub, 2005a, 2005b). These older infants were better at detecting a rhythmic violation in melodies with even, compared to uneven, meters. However, after two weeks (twice daily) exposure to music with an uneven meter, 12-month old infants (Hannon & Trehub, 2005b) and children of 5–7 years of age are able detect rhythmic violations in rhythms with uneven meters. Older children (11 year olds) and adults do not benefit from this passive exposure to music with an uneven meter (Hannon, Vanden Bosch der Nederlanden, & Tichko, 2012).

These findings demonstrate that the capacity to perceive and produce rhythms with particular meters develops through the process of early enculturation to culturally specific musical styles. In other words, long-term temporal expectations are acquired via mere exposure and these expectations influence processing of rhythms with meters that either conform to, or violate, expectations (Bigand & Poulin-Charronnat, 2006; Hannon & Trehub, 2005b; Huron, 2006; Jones, 2009; Trehub & Hannon, 2006). In the current thesis, the role of a lifetime’s exposure to culturally specific meters on the processing of rhythms is examined in the context of IL. In a controlled laboratory setting, learning of rhythms with even and uneven meters, by listeners enculturated with Western tonal music, will be investigated. In five of the six experiments, listeners’ will not be informed that the auditory sequences that they will hear contain a temporal, or rhythmic structure. Instead, listeners will attend to the identity of the events presented within the sequences and the rhythm will be incidental to the task. It is expected that rhythms with even and uneven meters will be implicitly learned. It is also expected that IL of even meter rhythms will be stronger than of
uneven meter rhythms.

1.6. IL of Visual and Auditory Sequences

With exposure to complex visual and auditory sequences, listeners can develop expectations of the identity of an upcoming event (e.g. visual spatial location, visually presented letter, musical tone) (e.g. Buchner, Steffens, Erdelder, & Rothkegel, 1997; Reed & Johnson, 1994; Riedel & Burton, 2006), or of the timing with which the upcoming event will occur (Brandon, et al., 2012; Tillmann, Stevens, & Keller, 2011). Abstracting a regularity or repeating pattern in a complex sequence with a systematic structure allows perceivers to make predictions, based on acquired expectations, about upcoming events as they unfold in time. When expectations are upheld and predictions are reliable, the events are processed faster and more accurately than when expectations are violated and predictions prove to be erroneous (Cleeremans, Destrebecqz, & Boyer, 1998).

Expectations develop as a consequence of learning the regularities, or the statistical relationships between events within a sequence and this learning can happen implicitly (Perruchet, 2008). IL occurs outside of awareness, that is, when attention is not directed to the to-be-learned structure or regularity. Learning of the structure emerges without an intention to do so and when the structure itself is incidental to the experimental task (Boyer, Destrebecqz, & Cleeremans, 2005; Perruchet, 2008; Perruchet & Pacton, 2006; A. S. Reber, 1993; Shanks, 2005). Nonetheless, the regularities, or underlying structure of the sequence is extracted and learners demonstrate evidence of acquiring a behavioural advantage from exposure to the structure (e.g. decreasing RT to events within the sequence). Despite this
behavioural advantage, learners are often unable to describe the structure, or regularities in the sequences to which they have been exposed (Perruchet, 2008).

Learning can be of the *ordinal structure*, or the regular sequencing of event identities (e.g. visual spatial locations, tone pitches), or it can be of the *temporal structure*, or rhythmic presentation of events. The temporal structure of a sequence defines the timing with which each event is presented (i.e. the duration between event presentations). In some cases, an event might be presented a fixed amount of time after a response to the previous event and consequently, the temporal structure is defined by a repeating sequence in these response-stimulus intervals (RSIs). In other cases, an event might be presented a fixed amount of time after the onset of the previous event and hence the temporal structure is determined by a repeating sequence of inter-onset intervals (IOIs). Learning can also be of the relationship, or correlation between the ordinal and temporal structures. In this case, listeners learn the association between event identities and the particular timing with which each event type is presented (Buchner & Steffens, 2001; Lee, 2000; Shin & Ivry, 2002).

A large body of research has examined IL of ordinal structures, particularly in the visual modality and there has been some investigation of IL of temporal structures in both visual and auditory modalities (see Table 1.1 for a summary). However, there remains some debate as to whether temporal structures can be learned when the ordinal structure is unpredictable (i.e. non-learnable) (Brandon, et al., 2012; Buchner & Steffens, 2001; Lee, 2000; Salidis, 2001; Shin & Ivry, 2002; Tillmann, et al., 2011). Therefore, the research project reported here builds on this previous research by further examining whether temporal structure, independent of ordinal structure (i.e. event identities are presented pseudo-randomly), can be learned. Temporal structures defined by repeating sequences of IOIs, and adhering to principles of music theory
will be employed. Hence, two fields of research - implicit learning and music perception - will be brought together to further study the independent learning of temporal structure. Specifically, the benefit of meter, with varying degrees of cultural familiarity, on IL of temporal structure is examined.
Table 1.1

Overview of Selected Research into IL of Ordinal and Temporal Structures in the Visual and Auditory modalities (DV = dependent variable, RT = reaction time, Acc = accuracy, Task = event requiring discrimination or identification)

<table>
<thead>
<tr>
<th>Modality</th>
<th>Study</th>
<th>Dimension</th>
<th>Task</th>
<th>DV</th>
<th>Test block manipulation</th>
<th>Key test block analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auditory</td>
<td>Buchner et al. (1997)</td>
<td>Ordinal</td>
<td>Pitch</td>
<td>RT</td>
<td>Random</td>
<td>Test vs. previous exposure block</td>
</tr>
<tr>
<td></td>
<td>Brandon et al. (2012)</td>
<td>Temporal (IGI)</td>
<td>Syllable</td>
<td>RT</td>
<td>New structured with violation of auditory groups, same or different meter to exposure</td>
<td>Test vs. mean adjacent exposure blocks</td>
</tr>
<tr>
<td></td>
<td>Schultz et al. (2013)</td>
<td>Temporal (IGI)</td>
<td>1. Spatial location of tone 2. Detection</td>
<td>RT</td>
<td>New structured with violation of auditory groups, weakly- and nonmetrical</td>
<td>Test vs. mean adjacent exposure blocks</td>
</tr>
<tr>
<td></td>
<td>Tillmann et al. (2011)</td>
<td>Temporal (IGI)</td>
<td>Syllable</td>
<td>RT</td>
<td>No test block</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>Salidis (2001)</td>
<td>Temporal (RSI)</td>
<td>Target detection</td>
<td>RT</td>
<td>Random</td>
<td>Test vs. mean adjacent exposure blocks</td>
</tr>
<tr>
<td></td>
<td>Buchner &amp; Steffens (2001)</td>
<td>Temporal (RSI)/Ordinal</td>
<td>Pitch</td>
<td>RT</td>
<td>Random temporal/same structured ordinal as exposure</td>
<td>Test vs. mean adjacent exposure blocks</td>
</tr>
<tr>
<td>Visual</td>
<td>Mayr (1996)</td>
<td>Ordinal</td>
<td>Object (shape and colour of object)</td>
<td>RT</td>
<td>Random</td>
<td>Test vs. mean adjacent exposure blocks and test vs. subsequent exposure block</td>
</tr>
<tr>
<td></td>
<td>Meier &amp; Cock (2010)</td>
<td>Ordinal</td>
<td>Object classification</td>
<td>RT</td>
<td>Random</td>
<td>Test vs. mean adjacent exposure blocks</td>
</tr>
<tr>
<td></td>
<td>Pohl &amp; McDowd (2006)</td>
<td>Ordinal</td>
<td>Sequence of motor responses</td>
<td>RT</td>
<td>Random</td>
<td>Test vs. mean adjacent exposure blocks</td>
</tr>
<tr>
<td>Modality</td>
<td>Study</td>
<td>Dimension</td>
<td>Task</td>
<td>DV</td>
<td>Test block manipulation</td>
<td>Key test block analyses</td>
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<tr>
<td>Visual</td>
<td>Cohen et al. (1990)</td>
<td>Ordinal</td>
<td>Location</td>
<td>RT</td>
<td>Random</td>
<td>Test block manipulation</td>
</tr>
<tr>
<td></td>
<td>Curran &amp; Keele (1993)</td>
<td>Ordinal</td>
<td>Location</td>
<td>RT</td>
<td>Random</td>
<td>Expt1: No test block</td>
</tr>
<tr>
<td></td>
<td>Destrebecqz &amp; Cleeremans (2001)</td>
<td>Ordinal</td>
<td>Location</td>
<td>RT</td>
<td>New second-order conditionals (SOC) structure</td>
<td>Test vs. previous exposure block</td>
</tr>
<tr>
<td></td>
<td>Lewicki, Hill, &amp; Bizot (1988)</td>
<td>Ordinal</td>
<td>Location</td>
<td>RT</td>
<td>New second-order conditionals (SOC) structure</td>
<td>Test vs. previous exposure block</td>
</tr>
<tr>
<td></td>
<td>Nissen &amp; Bullemer (1987)</td>
<td>Ordinal</td>
<td>Location</td>
<td>RT</td>
<td>New structured with a change in the SOC probabilities</td>
<td>Test vs. previous exposure block</td>
</tr>
<tr>
<td></td>
<td>Norman, Price, Duff, &amp; Mentzoni (2007)</td>
<td>Ordinal</td>
<td>Location</td>
<td>RT</td>
<td>New second-order conditionals (SOC) structure</td>
<td>Test vs. previous exposure block</td>
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<td></td>
<td>Reber &amp; Squire (1998)</td>
<td>Ordinal</td>
<td>Location</td>
<td>RT</td>
<td>Random (Expt1 and new second-order conditionals (SOC) structure (Expt1 and 2)</td>
<td>Test vs. previous exposure block</td>
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<td></td>
<td>Reed &amp; Johnson (1994)</td>
<td>Ordinal</td>
<td>Location</td>
<td>RT</td>
<td>New second-order conditionals (SOC) structure</td>
<td>Test vs. mean adjacent exposure blocks</td>
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<td>Ordinal</td>
<td>Location</td>
<td>RT</td>
<td>New second-order conditionals (SOC) structure</td>
<td>Test vs. mean adjacent exposure blocks</td>
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<td>Study</td>
<td>Dimension</td>
<td>Task</td>
<td>DV</td>
<td>Test block manipulation</td>
<td>Key test block analyses</td>
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<td>Visual</td>
<td>Willingham, Nissen, &amp; Bullemer (1989)</td>
<td>Ordinal</td>
<td>Location</td>
<td>RT Acc</td>
<td>No test block</td>
<td>N/A</td>
</tr>
<tr>
<td>Visual</td>
<td>Willingham, Greenberg, &amp; Thomas (1997)</td>
<td>Ordinal</td>
<td>Location</td>
<td>RT</td>
<td>Random</td>
<td>Test vs. previous exposure block and test vs. mean adjacent exposure blocks</td>
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<td>Visual</td>
<td>Lee (2000)</td>
<td>Temporal (RSI)/Ordinal</td>
<td>Location</td>
<td>RT</td>
<td>Phase shift between temporal and ordinal structures</td>
<td>Trend analysis</td>
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<tr>
<td>Visual</td>
<td>Miyawaki (2006)</td>
<td>Temporal (RSI)/Ordinal</td>
<td>Location</td>
<td>RT</td>
<td>Interchange of short and long RSIs</td>
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<tr>
<td>Visual</td>
<td>O'Reilly, McCarthy, Capizzi &amp; Nobre (2008)</td>
<td>Temporal (RSI)/Ordinal</td>
<td>Location</td>
<td>RT</td>
<td>Random temporal and/or ordinal</td>
<td>Test vs. three previous exposure blocks</td>
</tr>
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<td>Visual</td>
<td>Shin &amp; Ivry (2002): Experiment 1</td>
<td>Ordinal</td>
<td>Location</td>
<td>RT Acc</td>
<td>As above</td>
<td>Test vs. mean adjacent exposure blocks</td>
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<tr>
<td>Visual</td>
<td>Shin &amp; Ivry (2002): Experiment 2</td>
<td>Temporal (IOI)/Ordinal</td>
<td>Location</td>
<td>RT</td>
<td>As above</td>
<td>Test vs. mean adjacent exposure blocks</td>
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1.6.1. Methods of Investigating IL

Initial research into IL employed finite-state artificial grammars based on hidden Markov models to demonstrate that statistical regularities could be extracted from the surface features of the presented stimulus (i.e. visually presented letters) (see A. S. Reber, 1993). In an artificial grammar learning (AGL) experiment, participants memorise visual presentations of letter strings generated according to rules that dictate permissible relationships between adjacent letters. Participants are not made aware of the grammatical rules but typically they are better than chance at discriminating new letter strings that conformed to the grammatical rules from those that violated them. AGL tasks have also been used to demonstrated learning sequences of musical tones (e.g. Kuhn & Dienes, 2005; Loui & Wessel, 2008; Rohrmeier, et al., 2011; Saffran, Johnson, Aslin, & Newport, 1999; Tillmann & Poulin-Charronnat, 2010; Zhuang, et al., 1998), musical chords (Jonaitis & Saffran, 2009), and timbre (Tillmann & McAdams, 2004).

IL has also been demonstrated using a Serial Reaction Time Task (SRTT) (Cleeremans, et al., 1998; A. Cohen, et al., 1990; Nissen & Bullemer, 1987). Much of this research has investigated learning of the ordinal structure (i.e. serial ordering of events) of visual-spatial sequences. In these tasks, participants respond to every event in a sequence, for example, indicating the spatial location of a visual stimulus (e.g. illumination) presented in one of four quadrants on a screen. Participants are not informed that the locations of events within the sequence follow a repeating structure. Nonetheless, RT to identify the spatial-location of events decreases with exposure to the structured sequences. When the spatial-locations of events are presented in a random order, there is a small RT decrease due to task learning. However, the decrease is much less so that when the sequences are structured (e.g. Nissen &
Bullemer, 1987). Therefore, the larger RT decrease to structured, compared to random, sequences indicates that learning was of the structural regularities, not just of the task itself (i.e. task learning).

The addition of a test sequence is another way to determine the presence of learning a structure, or regularity (i.e. beyond task learning). In an SRTT using a test sequence, participants are exposed to sequences containing a regularity over a number of exposure blocks. In a test block, a sequence with either a random series of events (i.e. spatial-locations) or a new regular series of events is presented. Typically, RT to events increases at the test block. Furthermore, RT decreases when there is a return to the original exposure sequence (i.e. a sequence upholding the established expectations) (e.g. Curran & Keele, 1993; Destrebecqz & Cleeremans, 2001).

An important goal of IL research is to determine what structural features are, or can be, learned. It may be that learning arises from the abstraction of event frequency, event probability, and/or transitional probability (Perruchet, 2008). Hence, the addition of a test sequence in the SRTT is an important way to examine learning of particular features. While a test block with a random ordinal presentation can be used to determine that learning over exposure is not due solely to task learning, it is not possible to isolate the precise structural regularities (e.g. event frequency, transitional probability) that participants are extracting from the exposure sequences. This is because a random ordinal presentation can violate multiple regularities. Therefore, manipulating a specific statistical regularity at the test block can determine if that particular regularity was learned (A. Cohen, et al., 1990; Destrebecqz & Cleeremans, 2001). For instance, using a visual spatial SRTT, Reed and Johnson (1994) controlled event frequency (i.e. the number of times an illumination appeared in each of the spatial locations) across exposure and test sequences but varied second-
order conditionals (SOCs). In a regular SOCs sequence, the location at which each visual event is presented is determined by the location of the previous two events. RT decreased over exposure blocks (i.e. with sequences following the same SOC structure) but increased when a new SOC structure was presented in a test block. Through manipulating the SOC sequence across exposure and test sequences, Reed and Johnson were able to conclude that these higher-order relationships (i.e. SOCs), rather than just first-order relationships, between event locations could be learned.

Therefore, manipulating specific features of a sequence and controlling others at a test block can reveal what precisely is learned. In the experiments reported in this thesis, rhythms in test blocks will be carefully constructed in order to determine the precise feature of the temporal structure that is learned. For instance, in Experiments 1 to 3, the grouping structure will be maintained across exposure and test blocks, but the IGIs will be altered (i.e. lengthened or shortened). The purpose of this manipulation will be to determine if learning of temporal structures, or rhythms, goes beyond grouping structure but in fact extends to the precise durations between groups (i.e. IGIs). It is hypothesised that in the context of an SRTT, IGIs will be implicitly learned. In Experiment 4, again grouping structure will be maintained across exposure and test blocks but meter will be manipulated in order to determine the effect of violating long-term temporal expectations (via enculturation) on temporal expectancy acquired during the experimental session. It is expected that rhythms with both even and uneven meters will be implicitly learned. However, it is also expected that IL of the even meter rhythms will be stronger than of the uneven meter rhythms. Table 1.2 outlines the test block manipulation across exposure and test blocks for each of the six experiments.
1.6.2. IL of Temporal Structures

1.6.2.1. Visual Modality

While most IL research has examined learning of ordinal structures (e.g. order of event locations or event identities), the learning of temporal structures or rhythms has received less attention. Nonetheless, there is some research in the visual modality to suggest that temporal structures can be implicitly learned. However, these findings have indicated that temporal structures can only be learned when there is a relationship between the temporal structure and a concurrent ordinal structure. For example, in an SRTT, Shin and Ivry (2002) had participants identify the spatial location of a visually presented ‘X’. A series of locations followed either a repeating sequence or was random (ordinal dimension). Likewise, the temporal presentation of the events (X) followed either a repeating series of RSIs (200 ms, 500 ms, and 800 ms) or was random (temporal dimension). Learning of the ordinal structure occurred regardless of whether the temporal structure was defined by the repeating series of intervals, or was random. However, the temporal structure was learned only when the ordinal dimension was also structured (but not random). In other words, the temporal structure was only learned when both the ordinal and temporal structures were predictive of one another. The same results have been found when the temporal structures were defined by repeating sequences of IOIs of 550 ms, 1100 ms, and 1650. Similarly, O’Reilly, McCarthy, Capizzi, and Nobre (2008) used four IOIs of 500, 750, 1125 and 1687 ms and reported learning only when the temporal structure was integrated with an ordinal sequence of finger movements. These studies suggest that, at least in the visual modality, temporal structures cannot be learned independently of ordinal structures.
However, some contradictory evidence has emerged using a different method; a serial recall task (Ullén & Bengtsson, 2003). In this task (Experiment 2), the temporal structures were generated from three intervals (375 ms, 750 ms, and 1125 ms) and the ordinal structures were generated from schematic visual key displays corresponding to keys on a computer keyboard. Participants were exposed to sequences that had, (a) a fixed temporal structure but random ordinal structure, (b) a fixed ordinal structure but random temporal structure, and (c) random ordinal and temporal structures. Each visual event (i.e. key display) was presented concurrently with its own corresponding brief tone of a particular frequency. After each audiovisual presentation, participants reproduced the sequence using the corresponding keys on a computer keyboard. There was no evidence of learning of the random ordinal and temporal sequence. However, there was learning of both the fixed ordinal and fixed temporal sequences. The temporal structures were learned whether or not the ordinal structures were fixed or random. Hence, using a serial recall task, Ullén and Bengtsson demonstrated independent learning of temporal structures. The independent learning of temporal structures was also demonstrated by Karabanov and Ullén (2008). Ullén and Bengtsson (2003) argued that the SRTT used by Shin and Ivry (2002) was not optimal for eliciting independent learning of temporal structure, primarily because even when the temporal structure was predictable (i.e. structured), the identities of events in the random ordinal dimension were unpredictable. Therefore, although a temporal structure might have been learned, this learning would not have been evident in RT data as responses were to the unpredictable ordinal events.
1.6.2.2. Auditory Modality

While it appears from IL research in the visual modality that the SRTT may not be the optimal method for investigating independent temporal structure learning, auditory adaptations of the SRTT have been used (Brandon, et al., 2012; Buchner & Steffens, 2001; Salidis, 2001; Tillmann, et al., 2011). These studies have yielded inconsistent results. Buchner and Steffens (2001) used an SRTT requiring participants to identify the pitch of tones presented in a sequence. The order of the tones followed a repeating pattern (i.e. a 10-element sequential ordering of 4 tones with different pitches). Learning of an RSI structure (i.e. repeating pattern of RSIs of 200 ms, 400 ms, 600ms, and 800ms) occurred only when the RSI structure was correlated with the repeating pitch structure (i.e. when the RSI and pitch structures were predictive of one another). RT increased at two test blocks that presented the same repeating pattern of tone identities as in the exposure blocks, but now according to a random ordering of RSIs. However, this increase was only evident when the pitch and RSI structures were correlated over exposure. When these structures were unrelated over exposure, no RT increase was evident at the test blocks. These results suggested that the temporal structures, independent of an ordinal structure, were not learned.

However, learning of temporal structure has been demonstrated when the ordinal structure was held constant (Salidis, 2001). Performing an SRTT, participants responded to a series of beeps. The task was simply to press a key every time a beep (83 ms, 392 Hz tone) was heard. For the first four blocks of the experiment, these beeps were presented according to one of two symmetrical orderings of RSIs (Short (S): 180 ms, Medium (M); 450 ms, Long (L); 1125). The two symmetrical orderings were: SMSLML, and LSLMSM. In the fifth block, RSIs were then presented in a random order with the final block returning to the original fixed RSI order. RT
decreased over the first four blocks and then increased at the introduction of the random RSI sequence, decreasing again in the final block. In a control condition, random RSIs were presented across all blocks and RT was overall slower in this condition, compared to the structured condition.

Salidis (2001) also analysed RT to the beeps separately according to whether they followed the short, medium and long RSIs and found that, in the structured condition, the RT decrease across the first four exposure blocks, and the subsequent RT increase at the test block (Block 5), was more evident to beeps following the short, compared to medium and long, RSIs. To ascertain that the learning in the structured condition was implicit, participants performed a post-test reproduction task in which they attempted to generate the temporal structure of the SRTT sequences. Reproduction accuracy was no better in the structured, compared to the control (i.e. random RSI) condition.

Although Salidis did not consider the metrical structure of the stimuli in this experiment, the temporal structures employed were generated from a serial ordering of RSIs that had complex ratio relationships, thus were non-metrical. Furthermore, the use of RSIs meant that the temporal presentation of a beep was somewhat dependent on RT to the previous beep. This inevitably introduced variability into the temporal structure. Due to the non-metricality and variability within the structures, it is possible that the absence of a perceived temporal grid, or pulse, may have impeded learning of the longer, and more difficult to predict intervals (i.e. medium and long RSIs). In other words, perhaps the relative temporal irregularity inherent in the structures prevented the activation of neural oscillations that in regular temporal contexts, direct attention to future points in time and guide the development of temporal expectations.
While Salidis (2001) was able to provide preliminary evidence for the IL of independent temporal structures, it is important to note that the events themselves (i.e. beeps) required simple detection. In Buchner and Steffens (2001), the task was rather to identify the pitch of tones with the order of the tones either structured, or random. As discussed above, Ullén and Bengtsson (2003) argued that the expression of independent temporal structure learning (i.e. structured temporal dimension presented with a random ordinal dimension) in the visual modality was weakened by the fact that the identity of each upcoming event was unpredictable. Likewise, it could be argued that the random presentation of the tones employed by Buchner and Steffens to examine independent temporal structure learning in the auditory modality may have reduced the learning effect. Conversely, the type of SRTT used by Salidis (i.e. event detection) was not prone to this potential weakening as event identification was not required (see also Schultz, Stevens, Keller, & Tillmann, 2013).

However, two particular features of the temporal structures may also have impeded learning as reported by Buchner and Steffens (2001) and of the longer intervals as reported by Salidis (2001); (a) The relative temporal unpredictability elicited by the use of RSIs, and (b) the absence of a metrical structure. It is possible that independent temporal structure learning may not have emerged in the experiment conducted by Buchner and Steffens as the structures employed were very weakly metrical. Likewise, Salidis may not have found learning of the longer IOIs due to the non-metricality of the structures. The absence of a temporal grid, normally elicited by the presence of a metrical structure, may have reduced participants’ capacity to develop temporal expectations of the more difficult-to-process longer IOIs. Therefore, learning of temporal structures, in the presence of a random ordinal structure, may be best explored using temporal structures or rhythms more typical of music, that is, with
metrical structures. Furthermore, the implementation of metrical structures that are culturally familiar and less familiar to listeners allows for an investigation of the effects of temporal expectations, acquired via long-term exposure to culturally specific music, on learning of new temporal structures (with short-term exposure in an experimental setting).

Consistent with the proposition that the use of IOIs and the presence of a metrical structure may facilitate learning, it has been reported that IL of temporal structures, or rhythms, can be learned independently of ordinal structure when the rhythms have music-like features: (a) Structure are based on a serial ordering of IOIs (not RSIs), and (b) structures are strongly metrical (Brandon, et al., 2012; Tillmann, et al., 2011). Tillmann et al. (2011) used an auditory SRTT to demonstrate IL of simple rhythms with meters culturally familiar (even meters) and less familiar (uneven meter) to listeners of Western tonal music. The temporal structures were repetitions of serial orderings of fixed short and long IOIs: short-short-long. The short and long intervals in the even meter sequences had simple integer ratio relationships (1:2) and the short and long intervals in the uneven meter sequences had complex ratio relationships (1:1.5), typical of the uneven temporal spacing between strong beats.

The events instantiating the rhythms were a random order presentation of two spoken syllables (Pa and Ta). Syllables were chosen as they provided a cover story to minimise the likelihood that participants would attend explicitly to the temporal structure. Therefore, participants with long-term exposure to Western tonal music were instructed that the task was to identify the syllables as quickly and accurately as possible. No reference was made to the presence of a temporal structure, or rhythm. In both the even meter (simple ratio) and uneven meter (complex ratio) conditions, RT to identify the syllables decreased with exposure to the sequences, particularly for
syllables following the long IOI in the uneven meter exposure condition. This suggests that although the relatively simple uneven meter rhythm was learned, participants decreased their RT to the long interval in order to create a 1:1 timing ratio between all events, thus assimilating their timing to fit a familiar even metrical structure.

Tillmann et al. (2011) did not include a test block in the design, hence, did not examine the effects of violating temporal expectations acquired during the SRTT by presenting a new rhythm. However, in a follow-up production task, participants who performed the SRTT, compared to those that did not, showed significant reduced variability in their performance of the rhythms. Despite the fact that no test of acquired awareness was made, the overall findings reveal that temporal expectations of rhythms with culturally familiar and less familiar meters can be acquired when the temporal structures are incidental to the task, and the ordinal dimension (i.e. syllables) is random. It appears therefore, that relative temporal predictability promoted by the use of IOIs, and the presence of a metrical structure, facilitates independent learning of temporal structures or rhythms.

The role of meter on IL has been further investigated by Brandon et al (2012) employing longer and more complex rhythms than those used by Tillmann et al. (2011). Rhythms were repeating structures of eight IOIs (serial orderings of 700 ms, 1400 ms and 2100 ms IOIs) and had even duple and triple meters. As noted, duple and triple meters are both common in Western tonal music. However, duple meters are more common (Fraisse, 1982) and have been shown to elicit better perception and production than triple meters (Abecasis, et al., 2005; Bergeson & Trehub, 2006; Drake, 1993; K. C. Smith & Cuddy, 1989). The ordinal dimension was a pseudo-random presentation of spoken syllables, Pa, Ta, and Ka. Over exposure blocks, a
rhythm with a duple or triple meter was presented (instantiated with these syllables). A test block then presented a different rhythm, again with either a duple or triple meter, and this was followed by a final block, returning to the original exposure rhythm. The test rhythms differed from the exposure rhythms according to their grouping structures (i.e. the number and size of groups). Participants identified the syllables as quickly and accurately as possible and were not informed of the presence of a rhythm. For syllables following the longer IOIs (1400 ms and 2100 ms)\(^2\), RT decreased over exposure in the duple meter conditions but not in the triple meter condition. When exposure was to a duple meter rhythm, RT to the longer IOIs increased at the test block when a new duple meter rhythm was introduced. It was argued that over exposure, the relatively familiar duple meter initiated a temporal grid that facilitated the establishment of expectations of the longer IOIs. When these expectations were violated at the test block, RT increased. In the triple meter condition however, RT to syllables following the longer IOIs did not increased when a new duple meter rhythm was introduced at the test block. The authors suggested that the triple meter was less effective than the duple meter at eliciting a temporal grid during exposure. Thus, temporal expectations of the longer IOIs were less well established and therefore less susceptible to the violations at the test block. The more familiar duple meter at the test block allowed participants to better anticipate the longer and more difficult-to-process IOIs and counteracted the RT increase that was expected in response to the temporal violation. Hence, it appears that the more familiar duple meter provided a temporal framework that enabled more efficient processing of the longer IOIs.

\(^2\) The longer IOIs bounded groups of syllables and therefore are referred to here as inter-group interval (IGIs).
To ensure that the learning elicited with exposure to the rhythms was implicit, Brandon et al. (2012) employed post-test questionnaires and recognition tasks. The questionnaires asked participants to firstly report any regularities they noticed in the sequences, and secondly to report any regularities they noticed in the timing of the sequences. A post-test recognition task presented sequences of piano tones with the rhythmic structures of exposure and test sequences, or with a novel rhythmic structure. Participants rated the degree to which they believed the rhythm of the sequence was in the SRTT (1 = Certain the sequence was Not in the study to 6 = Certain the sequence Was in the study). The results of the post-test phase revealed that explicit knowledge of the rhythms presented in the SRTT was not evident. Participants were not more familiar with the exposure rhythm, than the test or novel rhythm. Therefore, the rhythms were implicitly learned.

The experiments in the current thesis use a similar method to that used by Brandon et al. (2012) with the aim of addressing two key issues. Firstly, a set of experiments (Experiments 1 to 3) will determine that learning goes beyond grouping structure. Unlike Brandon et al. who had a change in grouping structure at the test block, exposure and test rhythms will have the same grouping structure but the IGIs between groups will be altered. With this manipulation, learning of the duration of the intervals between event groups can be determined. Secondly, a set of experiments (Experiments 4 to 6) will further investigate the effect of familiarity with meter on learning. Brandon et al. investigated this issue but by using a relatively more familiar duple meter, and a relatively less familiar triple meter, both even meters typical of Western tonal music. However, in the current thesis, rhythms with culturally familiar even, and culturally less familiar uneven, meters will be employed in order to examine whether familiarity with musical rhythmic structures modulates learning.
Therefore, complex temporal structures with an unpredictable ordinal dimension (i.e. pseudo-random order of syllables) will be presented. These temporal structures, or rhythms, will be based on serial orderings of IOIs with simple integer ratios and will have metrical structures that are familiar (even) or less familiar (uneven) to listeners of Western tonal music. The use of these meters will allow for an investigation of the effect of long-term temporal expectations, acquired over a lifetime’s exposure to Western tonal music, on learning rhythms with familiar and less familiar meters in a single experimental session. It is hypothesised that rhythms with even and uneven meters will be implicit learned. It is also hypothesised that IL of the even meter rhythms will be stronger than of the uneven meter rhythms. Test blocks will also form an important part of the design as particular violations will be used to examine the precise temporal features that are learned. Finally, post-test phases will be employed to measure the presence of explicit knowledge of the rhythm and to determine that learning was implicit. Firstly, open-ended questionnaires will elicit reports of awareness of the presence of temporal structure in the SRTT sequences. Secondly, as familiarity has been shown to be an effective measure of explicit knowledge (Scott & Dienes, 2008), participants will rate their familiarity with the temporal structures of exposure, test and novel sequences and then indicate the certainty with which they made their familiarity rating. The testing conditions in the post-test rating task will be as closely matched to the SRTT as possible to maximise the opportunity for explicit knowledge to be expressed. Therefore, participants will identify syllables presented in the post-test sequences, with exposure, test, and novel temporal structures, just as they did in the SRTT. Familiarity ratings, and correlations between familiarity and confidence ratings will measure the presence of explicit knowledge (Scott & Dienes, 2008) (see Section 1.7.2.2 for further details). Together, these multiple post-test
measures will be a rigorous test of awareness of the temporal structures, or rhythms, presented in the SRTT.

1.6.3. Strengths of IL and the Advantage of the SRTT

Some studies in the visual domain have shown that implicit processes are an effective means of learning regularities (i.e. the serial order of visual events) in sequences, particularly when the regularities are complex (Fletcher, et al., 2005) or when cognitive capacity is reduced (Howard & Howard Jr, 2001). In fact, IL has been shown to be more effective than explicit learning in these instances as a conscious search for regularity can impede the learning process (Fletcher, et al., 2005; Howard & Howard Jr, 2001; A. S. Reber, 1976).

There appears to be no published literature reporting explicit, compared to implicit learning of auditory temporal structures. However, there is some neurological evidence that attention must be directed toward the auditory stimulus for temporal processing to occur. For instance, research using event-related brain potentials (ERPs) has shown that the processing of a deviant tone (i.e. a change in the pitch) amongst a sequence of standard tones benefited from a regular temporal context over an irregular temporal context, but only when attention was directed to the tone sequence. Attention was directed to the sequence by requiring participants to silently count the deviant tones but there was no requirement for them to attend to the temporal structure itself (Schwartze, Rothermich, Schmidt-Kassow, & Kotz, 2011). Furthermore, brain regions associated with meter processing (i.e. basal ganglia and supplementary motor areas) was shown to be activated only when attention was directed towards, but not away from a rhythm (Chapin, et al., 2010). The benefit of the SRTT adapted from Brandon et al. (2012) for use in the current thesis, is that
attention must be directed to the sequences for syllables to be identified. However, it is only this ordinal dimension (i.e. order of the identity of syllables) that participants will consider relevant to the task. The temporal structure, or rhythm will be incidental. An additional benefit of the SRTT is that a motor response to every syllable is required and motor responses have been argued to be central to IL in SRT learning (Willingham & Goedert-Eschmann, 1999).

Therefore, it is argued certain features of the SRTT make it a potentially effective method of investigating IL of temporal structures, or rhythms, with even and uneven meters: (a) The cover story to participants that the experiment is a syllable identification task will support IL, (b) the syllables will be presented in a pseudo-random order, promoting independent learning of the temporal structures, (c) attention will be directed to the sequences without it being specifically directed to the temporal dimension, (d) a motor response to every event will be required, (e) RT to every correct response will be collected and, (f) RT to particular categories of events (e.g. Within-group syllables or those following short IOIs, Post-IGI syllables or those following the longer inter-group intervals) will be analyzed separately, permitting a detailed investigation into the specific features of the temporal structures that are learned.

1.7. Research Overview

1.7.1. Research Aims

The purpose of the research program as a whole was to investigate IL of precise features of temporal structures, or rhythms. Using an auditory SRTT, and through the careful design of exposure and test rhythms, learning of the time intervals
between groups of auditory events (i.e. learning beyond grouping structure) was examined. The broad aim of the first set of experiments (Experiments 1 – 3) was to investigate the learning of temporal structures, or rhythms, with weak even meters. The specific aim was to determine if the intervals between groups of auditory events (i.e. IGIs) could be learned without attention being directed to the temporal structure and when the temporal structure was incidental to the task (identifying pseudo-randomly presented syllables). This builds on the work of Handel (1998), Hébert and Cuddy (2002), Ross and Houtsma (1994) by examining, within the context of IL, whether IGIs in temporal structures with metrical frameworks are processed. It also builds on the work of Brandon et al. (2012) by applying the same method of examining temporal structure learning but by controlling grouping structure and manipulating the temporal feature of interest, IGIs. The impact on IGI learning of cueing meter with the addition of an accented pulse (Experiment 2) and of giving an explicit instruction to learn the rhythm of the auditory sequence (Experiment 3) was also examined.

The broad aim of the second set of experiments (Experiments 4 – 6) was to investigate IL, by listeners of primarily Western tonal music, of rhythms with culturally familiar even meters and culturally less familiar uneven meters. In other words, three experiments examined the effects of long-term temporal expectations (established over a lifetime’s exposure to rhythms with even meters) on the development of short-term temporal expectations (acquired during exposure in a single experimental session). Previous research has shown that a relatively familiar duple meter aids in the learning of the longer and more difficult-to-predict IGIs, compared to a relatively less familiar triple meter (Brandon, et al., 2012). Therefore, a particular aim of the current program of research was to examine the effect of a
familiar even meter and a less familiar uneven meter on IL of IGIs. An uneven meter was the medium used to probe the capacity of listeners to adapt to complex and less familiar temporal frameworks. Employing a post-test phase, evidence of explicit knowledge of the rhythms acquired during the SRTT phase was determined. Hence, a subsequent aim of the research program was to establish that learning occurred implicitly.

1.7.2. General Experimental Method and Design

1.7.2.1. SRTT

Non-musicians and minimally musically trained participants were recruited, as they are likely to have had less exposure to uneven meters compared to those with formal musical training. Participants will also have had long-term exposure to Western tonal music but not to music with uneven meters. All experiments employed an auditory SRTT to examine learning of temporal structures, or rhythms. In this task, participants identified, as quickly and accurately as possible, syllables presented in sequences with repeating temporal structures (i.e. series of IOIs). The syllable order was pseudo-random³ so that participants were not able to abstract any regularities in the ordinal presentation. Consequently, the only learnable feature was the temporal structure, or rhythm. Syllables were chosen as the events to instantiate the rhythms as a syllable identification task provided a “cover story” for participants. In all experiments (with the exception of Experiment 3, see Section 1.5.4 below), participants were advised that they were performing a syllable identification task and

³ Each block contained an equal number of each syllable, syllable identities were equally distributed across all serial positions, and there were constraints on the number of repetitions and alternations of syllables.
no reference was made to the presence of a rhythmic structure within the sequences. Therefore, the opportunity for participants to ascertain the purpose of the task was minimised and IL was be promoted. Furthermore, syllables are a relatively easy stimulus for participants to respond to. In a pilot study/perceptual test (reported in Footnote 2 in Tillmann, et al, 2011), the syllables used in the current experiments were easily discernable. In this pilot study reported by Tillmann et al. (2011), each syllable (Pa, Ta, Ka) was presented five times over 10 trials and participants (N = 14) identified the syllables with 100% accuracy. Discriminating tones, for instance, at the speed of presentation required to represent rhythms with even and uneven meters would be untenable and would require a significant amount of training (see Buchner & Steffens, 2001 for such a training). For these reasons, syllable sequences acted as the stimulus conveying the rhythmic structures (A CD-ROM containing audio examples is attached inside the back cover of Volume 2).

Sequences were presented over a number of exposure blocks and, at test blocks, sequences with new rhythmic structures were presented. The purpose of the test block(s) was two-fold. Firstly, it was possible that the learning evident over exposure blocks (i.e. decreases in RT) was the partial result of task learning. Therefore, a test block, presenting a new rhythm, was required to determine the presence of temporal structure learning. Consequently, an RT increase at the test block(s) would be attributed to the violation of temporal expectations acquired during exposure blocks. These test blocks acted as a measure of temporal structure learning. Secondly, the test blocks allowed for a careful manipulation of the rhythms in order to determine the temporal features that were learned. For example, maintaining the grouping structure across exposure and test blocks, but manipulating only the IGIs, permitted an examination of learning the duration of IGIs over exposure blocks.
After the presentation of the test block(s), a final block of the exposure sequence was be presented. This final block was a further test of whether learning of the rhythms over exposure occurred. The return to the expected temporal structure should facilitate RT, relative to the preceding test block(s).

Across all experiments, the same basic design applied. Firstly, the dependent variable (RT to correct responses) was compared across exposure blocks in a within-subject design. Secondly, RT at the test block(s) was compared to the mean of the adjacent exposure blocks (see each experiment for a detailed description of the relevant design). In SRTT research, comparing RT at a test block to the mean of the adjacent exposure blocks is the most common practice. A survey of a selection of the literature conducted for this thesis shows that approximately 58% of surveyed experiments adopt this analysis. Thirty-two percent report the difference between the test block and just the preceding exposure block, and 10% report both analyses (See Table 1.1). In the current program of research, comparing the test block to the mean of the adjacent exposure blocks was the primary analysis. In this analysis, the effect of returning to the exposure rhythm after the test block was measured and provided further evidence that the exposure rhythm was learned. It was hypothesised that RT at the final exposure block, as it upheld the acquired temporal expectations, would be facilitated compared to RT at the test block. That is, if the exposure rhythms were learned, then RT at the final exposure block should return to the speed of the exposure block presented just prior to test. To examine learning of particular structural features, separate analyses were conducted for IGI and within-group intervals. Between-subjects factors (e.g. even and uneven exposure conditions) also formed a part of the design of certain experiments and these factors are shown in Table 1.2.
Table 1.2

Outline of Experiments \((IL = implicit learning, \ EL = explicit learning)\)

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Chapter</th>
<th>Title</th>
<th>Between-subjects factor</th>
<th>Manipulation across exposure and test</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>IL of IGIs in Weakly Metrical Temporal Structures</td>
<td>Pattern 1 and Pattern 2</td>
<td>IGIs</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>IL of IGIs in Weakly Metrical Temporal Structures: The Effect of Strengthening Meter with an Accented Pulse</td>
<td>Pattern 1 and Pattern 2</td>
<td>IGIs</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>EL of IGIs in Weakly Metrical Temporal Structures Presented with an Accented Pulse</td>
<td>Pattern 1 and Pattern 2</td>
<td>IGIs</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>IL of Auditory Rhythms with Even and Uneven Meters</td>
<td>Even and Uneven Meter</td>
<td>Meter</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>IL of an Auditory Rhythm with an Uneven Meter</td>
<td>None</td>
<td>IGIs</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>IL of Rhythms with Identical Temporal Structures but Culturally Familiar Even and Less Familiar Uneven Meters</td>
<td>Even and Uneven Meter</td>
<td>Meter and grouping structure</td>
</tr>
</tbody>
</table>
1.7.2.2. Post-tests

In a post-test phase, the presence of any explicit knowledge of the rhythms acquired during the SRTT was established. Initially, participants responded to open-ended questions: the first question asking for a description of any regularities noticed in the sequences presented in the SRTT, the second question asking for a description of any regularity noticed in the *timing* of the presentation of the syllables (adapted from Brandon, et al., 2012).

After responding to these questions, participants were advised that the presentation of syllables followed a repeating timing pattern or rhythm (N.B. In Experiment 3, this information was provided prior to the SRTT). In a subsequent post-test rating task, short sequences with the temporal structures of the SRTT exposure and test sequences, and with novel temporal structures, were presented. The testing conditions were as equivalent as possible across the SRTT and post-test phase to maximise recognition of the rhythms. Therefore, syllables were the events to which participants responded, just as they did in the SRTT. This differs from Brandon et al (2012) who used piano tones to present the rhythm. In addition, participants rated their familiarity with the rhythm of each sequence using a scale from 1 (very unfamiliar) to 6 (very familiar). A familiarity scale was chosen as familiarity has been shown to be an effective measure of explicit knowledge (Scott & Dienes, 2008). In a second rating, participants indicated the certainty with which they made their familiarity rating from 1 (complete guess) to 6 (completely certain). The scales themselves were adapted from Destrebecqz and Cleeremans (2001).

Within each experiment, mean familiarity ratings to exposure, test, and novel sequences were compared. Where relevant, between-subjects factors (e.g. even and uneven exposure conditions) were considered. In a second analysis, familiarity and
confidence ratings were regarded together. For each participant, the mean familiarity rating to exposure sequences was subtracted from the mean familiarity rating to all sequences. This difference score was transformed to a z-score and correlated with the participant’s mean certainty rating to exposure sequences. A positive correlation indicates that high levels of familiarity with the temporal structures exposure sequences were held with confidence (i.e. high certainty ratings) and low levels of familiarity with the temporal structure of exposure sequences were held with a lack of confidence (i.e. low certainty ratings). This relationship between familiarity and confidence suggests that participants had explicit knowledge of the temporal structures of exposure sequences. The absence of a correlation, or a negative correlation between familiarity and confidence implies that participants were guessing when making their familiarity ratings (Scott & Dienes, 2008). Together, these post-test analyses were employed to determine the presence of explicit knowledge and to show the degree to which learning was implicit.

1.7.3. General Hypotheses

1.7.3.1. SRTT

Across all experiments, it is hypothesised that RT to identify syllables will decrease over exposure blocks as temporal expectations develop via IL. In experiments comparing learning of rhythms with even and uneven meters, it is hypothesised that RT will be faster to even, compared to uneven meter rhythms. Furthermore, it is predicted that the decrease will be greater for even, compared to uneven meter rhythms, as rhythms with relatively familiar even meters may be easier to learn. At the introduction of a new rhythm at the test block(s), it is expected that
RT to identify syllables will increase as temporal expectations are violated. If temporal expectations acquired over exposure are more strongly established in the even, compared to uneven meter condition, then it is hypothesised that this RT increase at the test block(s) will be greater in the even, compared to uneven, meter exposure conditions. Specific hypotheses are detailed in each experiment chapter.

1.7.3.2. Post-tests

With the exception of Experiment 3, where an explicit instruction will be given to learn the rhythm, it is hypothesised that familiarity ratings to exposure, test, and novel sequences will not differ. It is also hypothesised that there will be no relationship between familiarity and confidence ratings, i.e. that learning will be implicit.

1.8. Outline of Following Chapters

Chapter 2 presents two of the six experiments conducted in this program of research. IL of the precise timing between groups of auditory events (i.e. IGIs) presented in weakly metrical temporal structures will be reported. Chapter 3 will examine IL of IGIs further but with an explicit instruction to learn the rhythms. Chapters 4 and 5 report three experiment investigating learning of rhythms with even and uneven meters (see Table 1.2 for an outline of experiments). These experiment chapters (Chapters 2 to 5) are written in the form of journal manuscripts. Therefore, there is some repetition in the Introduction and Method sections of each chapter. A manuscript based on Chapter 2 (Experiments 1 and 2) has been submitted to *Attention, Perception and Psychophysics* and a manuscript based on Chapter 4 (Experiments 4 and 5) has been submitted to *Psychological Research*. These
submitted manuscripts were prepared by the author of this thesis. The principal and associate supervisors of this research projects were second and third authors and, in the case of the manuscript based on Experiments 1 and 2, a fourth author (Dr Gabrielle Weidemann) was credited for providing advice on the post-test stimulus design. The final chapter (Chapter 6) will provide a general discussion, including, (a) a summary of the findings, (b) a discussion of the implications of these findings for current theories of temporal processing and IL, and (c) suggestions for future directions.
Chapter 2 Preface

Previous research has demonstrated IL of musical rhythms with strongly metrical duple and triple meters (Brandon, et al., 2012). Chapter 2 reports two experiments (Experiments 1 and 2) that extend this research by specifically investigating IL of the intervals between groups of auditory events (i.e. IGIs). Based on results from explicit discrimination tasks, Handel (1998) has argued that IGIs are not abstracted and are consequently not integrated into the perceptual organisation of a temporal structure. However, Hébert and Cuddy (2002) and Ross and Houtsma (1994) have shown that the presence of a strong meter facilitate the abstraction of IGIs. The aim of Experiments 1 and 2 is to establish that IL is of more than the grouping structure but of the IGIs as well. Therefore, the two experiments reported in Chapter 2 examine IL of IGIs in weakly metrical temporal structures. Experiment 2 employs the same temporal structures as in Experiment 1 but an accented pulse is added to cue meter.
Chapter 2

Implicit Learning of Inter-group Intervals (IGIs) in Auditory Temporal Structures

A manuscript based on Chapter 2 has been submitted to *Attention, Perception and Psychophysics*:

Implicit Learning of Inter-group Intervals (IGIs) in Auditory Temporal Structures

Terry, J., Stevens, C. J., Weidemann, G., & Tillmann, B.

*Note*: C. J. Stevens and B. Tillmann are the author’s principal and associate supervisors, respectively. G. Weidemann provided advice on the post-test stimulus design.
2. Implicit Learning of Inter-group Intervals (IGIs) in Auditory Temporal Structures

2.1. Introduction

Sequences of auditory events such as speech and music unfold in time and, via mere exposure, humans are able to perceive and learn the temporal structure of these sequences (Bigand & Poulin-Charronnat, 2006; Jones & Boltz, 1989). Learning leads to the development of expectations about when events are going to occur and, theoretically, having temporal expectations is crucial to making sense of an otherwise complex array. We are able to take advantage of this expectation by directing attentional energy to the points in time when an event is expected to occur, facilitating responses to the event (Jones & Boltz, 1989; Large & Jones, 1999; Penel & Jones, 2005). The rationale underpinning the present study is that even if the identity of an upcoming auditory event is unknown, having an expectation of when it will occur will lead to faster responses to that event than when there are no temporal expectations or when expectations are violated.

Using a serial reaction time task (SRTT), we investigated the proposition that learning of temporal structure can occur implicitly. That is, we examined whether learning could occur without awareness being drawn to the temporal structure and without requiring participants to have an intention to learn (Cleeremans, Destrebecqz, & Boyer, 1998). More specifically, implicit learning of the temporal intervals between groups of auditory events, defined here as inter-group-intervals (IGIs), was investigated. We tested the hypothesis that identification of syllables presented according to a repeating temporal structure (but syllables being presented in a pseudo-random order) would become faster over exposure blocks, as the temporal
structure of the sequence was learned. Following previous SRTT research (Brandon, Terry, Stevens, & Tillmann, 2012), we also examined whether violating the temporal structure by shortening or lengthening the IGIs would lead to slower syllable identification at a test block.

2.1.1. Perceptual Advantages of Temporal Expectations

A temporal context (e.g. a short isochronous sequence of tones) can establish, in listeners, expectations of when a subsequent event might occur. Judgements of an auditory event occurring at an expected compared to unexpected time point are faster and more accurate (Jones, Moynihan, MacKenzie, & Puente, 2002; Jones & Yee, 1997; Penel & Jones, 2005; Tillmann & Lebrun-Guillaud, 2006). For instance, Jones, Moynihan, MacKenzie, and Puente (2002) presented participants with a standard and comparison tone separated by an isochronous sequence of eight distracter tones with inter-onset intervals (IOIs) of 600 ms. Participants judged the comparison tone, which either respected or violated the established temporal regularity, as being “higher”, “same”, or “lower” in pitch than the standard tone. Responses were most accurate when the comparison tone was presented 600 ms after the onset of the last distracter tone, respecting the temporal regularity and occurring at the expected point in time. However, accuracy deteriorated when the presentation of the comparison tone violated the established temporal regularity and was presented earlier or later than expected. Other research into temporal orienting of attention and the development and violation of temporal expectations has demonstrated that RT is slower to events (e.g. visual targets and chords) presented earlier than expected compared to events presented later than expected (e.g. Correa, Lupiáñez, Milliken, Tudela, 2004; Correa, Lupiáñez, Tudela, 2006; Tillmann & Lebrun-Guillaud, 2006).
According to the *Dynamic Attending Theory*, attentional energy is directed to expected points in time so that perceptual processing of events is optimised (Bausenhart, Rolke, & Ulrich, 2007; Jones & Boltz, 1989; Large & Jones, 1999). In both the auditory and visual domains, research has demonstrated that temporal orienting of attention results in faster responses to events occurring at expected time points, driven by facilitation at the perceptual stage (Bausenhart, et al., 2007; Correa, Lupiáñez, Madrid, & Tudela, 2006; Correa, Lupiáñez, & Tudela, 2005; Rolke & Hofmann, 2007; Sanabria, Capizzi, & Correa, 2011). Our reported experiments draw on this research, but are extended into the domain of implicit learning. The first research question was whether perceptual facilitation of events (reflected in identification times decreasing over exposure) presented at expected time points would occur when the temporal structure was incidental to the task. Importantly, the event types themselves were presented in a random order so learning could only relate to the temporal structure rather than to any statistical regularity in the order of event types. A second question was to determine if learning extended to complex temporal structures beyond the simple isochronous sequences that have been used to induce temporal expectation in previous research (e.g. Jones et al., 2002; Jones & Yee, 1997; Penel & Jones, 2005). Consequently, rather than using a simple isochronous sequence to induce expectation, the sequences in the experiments presented here were 15-interval structures created from particular orderings of three IOIs with simple integer ratio relationships (600 ms, 1200 ms, and 1800 ms).

2.1.2. Grouping Structure and Inter-group Intervals (IGIs)

One way in which listeners perceptually organise temporal structure is to group events together that have similar time spans between them (Deutsch, 1999;
Lerdahl & Jackendoff, 1983). Longer time spans or inter-group intervals (IGIs) mark the boundaries between these groups, or figures. An isolated event bounded by an equivalent time span is also considered a group, or figure (Handel, 1998; Jackendoff & Lerdahl, 2006). Auditory grouping based on temporal structure is somewhat analogous to the Gestalt concept of figure-ground in visual perception. However, auditory groups, or figures, are perceived against a background of unfolding time (Handel, 1998). Hence, a sequence of these groups and isolated events gives a temporal pattern its grouping structure (See Figure 2.1). It has been demonstrated that listeners are significantly better than chance at explicitly discriminating between two sequences of tones with temporal structures that differ according to their grouping organisation but are less able to so when the grouping structure is maintained while the IGIs are violated (Handel, 1998). Handel reported that this difficulty distinguishing between two patterns with the same grouping but differing IGIs was, for the most part, independent of the metrical strength of the sequence pairs.
Figure 2.1. Temporal structures used in Experiment 1 (Pattern 1 and Pattern 2): “X” represents a syllable, digits indicate the serial positions of the syllables, bold font represents Post-IGI positions, lower-case font represents controlled within-group positions (see text). Syllable groups are enclosed in boxes. Horizontal arrows represent short (→) and long (→→) IGIs (inter-group intervals), and vertical lines represent the hypothesised metrical structure (the longer the line the stronger the perceived beat).

2.1.3. Benefits of Metrical Structure in Processing Temporal Structures

Meter is a hierarchical structure that gives rise to a perception of regular patterns of strong and weak beats embedded within larger-scale patterns of strong and weak beats (Lerdahl & Jackendoff, 1983) (see Figure 2.1). When events align with beats at multiple levels in the hierarchy, the more readily the meter is abstracted and perceived as strong (Jones, 1987; Lerdahl & Jackendoff, 1983; Palmer & Krumhansl, 1987). Temporal structures or rhythms with strong meters are easier to synchronise
with, to memorise and to reproduce than structures with weak meters (Grahn & Brett, 2007; Patel, et al., 2005; Povel & Essens, 1985). According to Handel (1998), the presence of a metrical structure should allow listeners to use a perceived temporal grid to abstract IGIs. However, he found that above-chance discrimination of two sequences with identical groupings but with an alteration to an IGI occurred only when an external pulse was presented, and when the first of the pair was strongly metrical and the second weakly metrical. Hence, Handel argued for a limited role of meter in the discrimination of sequences with identical grouping structures. This suggests that at the level of explicit processing, IGIs are uninformative when perceiving temporal structure, except when a strong metrical grid is initially established with the use of a cue (e.g. external pulse).

Without the use of an external pulse, Hébert and Cuddy (2002) and Ross and Houtsma (1994) demonstrated that pairs of tone sequences with identical grouping structures but alterations to IGIs were discriminated above chance when the first of the pair was either strongly or weakly metrical. However, consistent with Handel (1998) but without the addition of a pulse, they found better performance when the first of the pair had a strong, compared to weak meter. This result provides evidence for the utilisation of a metrically based timing mechanism when processing temporal structures and when perceiving IGIs.

In our study, the abstraction of IGIs within a complex temporal structure will be investigated in the context of implicit learning rather than explicit discrimination. It has been proposed previously that implicit learning may be a powerful means through which listeners develop temporal expectations (Salidis, 2001; Tillmann, Stevens, & Keller, 2011). Much of the previous research investigating temporal structure has employed explicit judgement and discrimination tasks or
synchronisation and reproduction tasks. However, research investigating implicit learning of temporal structure has the potential to further contribute to the understanding of temporal processing. The present research investigates whether both the grouping structure and the IGIs can be learned when the temporal structure is weakly metrical. Weakly metrical patterns were chosen as they allowed us to examine the learning of IGIs without the benefit of a strong meter. As explicit discrimination tasks have shown that listeners are less sensitive to IGIs in weakly metrical patterns (compared to strongly metrical patterns), the use of weak meters allowed us to examine the power of implicit learning. In other words, we asked whether listeners could in fact develop temporal expectations of IGIs in weakly metrical patterns via implicit processes.

2.1.4. Implicit Learning of Temporal Structures

Implicit learning occurs outside of awareness and without an intention to learn (Boyer, Destrebecqz, & Cleeremans, 2005; Perruchet, 2008; Reber, 1993). Learners are often unable to describe the regularities in the materials to which they have been exposed despite showing evidence of a benefit from these regularities when performing a behavioural task.

Implicit learning of ordinal structure (i.e. order of events in a sequence) in both auditory and visual sequences has been demonstrated using SRTTs (e.g. A. Cohen, Ivry, & Keele, 1990). In an SRTT, participants respond to every item in a sequence, for instance, indicating the spatial location of a visual stimulus presented in one of four quadrants on a screen. Unbeknown to participants, the sequence is a repeating structure from which statistical regularities emerge (e.g. event frequency, event probability, and/or transitional probability) (Perruchet, 2008).
While implicit learning of visual-spatial sequences has been demonstrated (e.g. Destrebecqz & Cleeremans, 2001; Mayr, 1996; Nissen & Bullemer, 1987; Reed & Johnson, 1994), there is little empirical research investigating in either the visual or auditory modality implicit learning of a temporal structure that is independent of, or uncorrelated with, an ordinal structure (e.g. Buchner & Steffens, 2001; Shin & Ivry, 2002). In one study, Buchner and Steffens (2001) used temporal structures based on repeating sequences of response-stimulus intervals (RSIs) between tones of varying pitch (i.e. frequency), and knowledge of the temporal structure was acquired only when it was correlated with a systematic pitch sequence. The use of RSIs however, meant that the temporal presentation of events was somewhat dependent on the participants’ reaction time (RT) to the previous event. This inevitably introduced variability into the temporal structure.

In another study, the learning of an auditory temporal structure based on RSIs but independent of an ordinal structure was demonstrated (Salidis, 2001). Performing an SRTT, participants responded with a key press to a sequence of beeps (i.e. detection task). Over four exposure blocks, the temporal presentation of beeps was determined by a repeating sequence of short (S), medium (M), and long (L) RSIs: SMSGML or LSLMSM. RT decreased over the first four blocks of the repeating RSI sequence and then increased at the introduction of a random RSI sequence. The use of a random RSI sequence at the test block inevitably meant that the perceptual grouping of tones during exposure was violated at the test block. Therefore, the RT increase was most likely induced by the change in the perceived grouping structure.

In an adaptation of the auditory SRTT, Tillmann et al. (2011) demonstrated learning of temporal structures determined not by RSIs but fixed alternating short and long IOIs with simple and complex ratio relationships. Participants identified
randomly ordered syllables ("Pa", "Ta") presented in sequences with a simple repeating chaining of IOIs such as: XXX.XXX.XXX. (where “X” represents a syllable and “.” represents a silent interval). To promote implicit learning, participants were informed that they were performing a syllable identification task and no reference was made to the temporal structure of the sequences. RT decreased with exposure. While there was no test block to assess learning (as per the SRT-paradigm), exposure had some influence on a subsequent production task, indicating that the temporal structure had been learned.

Using a similar protocol to Tillmann et al. (2011), a recent study demonstrated IL of more complex temporal structures (Brandon, Terry, Stevens, & Tillmann, 2012). Participants responded to seven blocks of sequences with three randomly presented syllables ("Pa", "Ta", "Ka"). The temporal structure presented over exposure blocks (Block 1 – 5, and Block 7) was a repeating rhythm with either a duple or triple meter (hierarchical structure with perceived beats grouped into two and three, respectively). RT decreased with exposure and increased at a test block (Block 6). The test block is an important addition to the SRTT method as it measures temporal structure learning beyond the task learning that occurs over exposure. Furthermore, specific temporal features (e.g. IGIs, grouping structure, meter) can be manipulated at the test block in order to determine what features of the temporal structure are learned.

The present study builds on previous research by: (a) examining IL of weakly metrical structures based on repeating sequences of IOIs with simple integer ratios, (b) employing, unlike Tillmann et al. (2011), complex temporal structures with repetitions of 15 rather than two IOIs and by presenting a more difficult 3AFC, rather than a 2AFC task, and (c) introducing a test block to ensure that learning is of the
temporal structure (i.e. IGIs), rather than of the task (i.e. task learning). Specifically, here the test block is designed to measure learning beyond grouping structure, or simple repetitions of intervals, and rather examines learning of the timing between auditory groups (IGIs). This was achieved by maintaining the grouping structure across exposure and test and by violating the order of the IGIs (the same durations were used in exposure and test blocks).

2.1.5. Aims of Experiments 1 and 2

The aim of the two experiments was to examine implicit learning of the complex and weakly metrical temporal structures in sequences of pseudo-randomly presented auditory events (syllables). Specifically, we investigated learning of the durations between groups of syllables (IGIs). Using an adaptation of the SRTT, participants identified syllables presented in exposure sequences with temporal structures defined by a sequential ordering of IOIs (see Figure 2.1). A test block sequence was presented that had an identical grouping structure to the exposure blocks (i.e. the same number of groups, number of events within groups, and the order of groups), but differed in terms of the duration of the IGIs. More specifically, short (1200 ms) and long (1800 ms) IGIs within an exposure sequence were interchanged in the test sequence, so that a short IGI became a long IGI and a long IGI became a short IGI. The test block was introduced to be certain that learning was of the temporal structure rather than simply learning of the task. The IGI manipulation at the test block also allowed us to measure learning of this precise feature of the temporal structure.
2.1.6. Design

Two weakly metrical patterns were used in a counterbalanced design. One group of participants (*Pattern 1 condition*) was exposed to *Pattern 1* and tested on *Pattern 2*, while this was reversed for the other group of participants (*Pattern 2 condition*). In Experiment 2, meter was strengthened with the addition of a monaural amplitude-accented woodblock pulse presented concurrently with the syllable sequences.

In both experiments, the main dependent variable was correct RT to identify syllables. The experimental design consisted of seven blocks: Blocks 1 to 5 presented an exposure sequence (*Pattern 1* or *Pattern 2*), and Block 6 – the test block – presented the alternate sequence. Block 7 presented again the exposure sequence. To measure learning across exposure blocks, we examined correct RT to syllables in serial positions that directly followed the IGIs (*post-IGI positions*) (see Figure 2.1). To determine whether learning extended beyond task learning and was specifically of IGIs, RT to syllables following IGI changes at the test block (Block 6) was also examined. This was done by comparing RT to post-IGI positions at Block 6 to these same positions in the two adjacent exposure blocks (mean of Blocks 5 and 7). An RT increase to post-IGI syllables would provide evidence that IGIs were learned. That is, learning would be of the precise temporal intervals between syllable groups, even when presented within a weakly metrical structure. Conversely, a lack of RT increase would indicate, consistent with Handel (1998), that IGIs are not encoded. Rather, the processing of temporal structure relies on grouping structure.

In order to measure learning beyond the IGIs (measured by RT to directly following syllables), we also examined RT to particular serial positions within groups of syllables (*within-group positions*), i.e. positions 2, 10, and 11 (see Figure 2.1).
These positions were selected as they maintained their global position and their status within the metrical structure across exposure and test. For instance, position 11 aligned with a hypothetical strong beat in both Patterns 1 and 2, whereas position 10 aligned with a weak beat in both patterns. Given that the three positions are matched across exposure and test they allow for a precise comparison without any other influencing factors. They are a measure of learning of the temporal structure in its entirety, rather than a measure of local temporal violation (i.e. due to a change in the preceding IOI), or of location change within the metrical hierarchy (i.e. aligning with weak or strong beats). An RT increase at the test block to these positions indicates that temporal violations (i.e. IGI changes) affect temporal processing not just at the local level (e.g. post-IGI positions) but also at a more global level. Hence, they are the most sensitive positions to show learning of the global temporal structure.

In a post-test phase, an open-ended questionnaire was administered to determine the presence of explicit knowledge of the temporal structure. Finally, participants rated their familiarity with the exposure, test, and novel sequences, and indicated the certainty with which they made their familiarity rating.

2.1.7. Hypotheses

In Experiments 1 and 2, it was broadly hypothesised that learning would not only be of the grouping structure but of the IGIs between groups. Specifically, it was hypothesised that: (a) correct RT to post-IGI positions and to controlled within-group positions would decrease over exposure blocks as participants became familiar with the task and learned the temporal structure, (b) RT to post-IGI syllables and controlled within-group positions would be slower at the test block compared to the adjacent exposure blocks, and (c) if learning remained implicit, participants would
report equivalent levels of familiarity across exposure, test, and novel sequences and be unable to describe the temporal structure in an open-ended questionnaire.

2.2. Experiment 1: Implicit Learning of IGIs in Weakly Metrical Temporal Structures

2.2.1. Method

2.2.1.1. Participants

Forty-three participants from the University of Western Sydney took part in the experiment in exchange for course credit. The 38 female and 5 male participants had a mean age of 21.8 years ($SD = 6.6$ years, range = 18 – 46 years). All participants had self-reported normal hearing. Participants were randomly assigned to either the Pattern 1 ($N = 21$) or Pattern 2 ($N = 22$) exposure condition. The two participant groups were equivalent in terms of years of musical training. Participants in the Pattern 1 condition had a mean of 1.78 years of training ($SD = 2.63$ years, median = .50) and participants in the Pattern 2 condition had a mean of 1.32 years of training ($SD = 2.15$ years, median = 0). These levels of musical training were not statistically different between the two conditions ($p = .53$).

2.2.1.2. Materials

2.2.1.2.1. SRTT. The temporal structure of each sequence was a chaining of 15 IOIs, which was repeated nine times in a block. The shortest IOI was 600 ms and the longer IOIs were multiples of this base temporal unit (i.e. 1200 ms and 1800 ms). The base temporal unit (600 ms) has been shown to be a “preferred tempo” with spontaneous finger tapping and clapping often being performed around this rate
(Fraisse, 1982; van Noorden & Moelants, 1999). The IOI chaining of Pattern 1 was 600-1800-600-600-600-1200-1200-600-600-600-600-600-1800, and the IOI chaining of Pattern 2 was 600-1200-600-600-600-1200-1800-1800-600-600-600-1200 (see Figure 2.1). The longer IOIs, that is IGIs (1200 ms and 1800 ms), formed boundaries between groups of syllables and isolated syllables. The two patterns were identical in terms of grouping structure: the number of groups, number of events within groups, and the order of groups were identical in the two patterns. For instance, in both patterns, a group of two events was followed by a group of four events, followed by an isolated syllable, and so on (2-4-1-1-3-4). This is illustrated in Figure 2.1. The difference between Pattern 1 and Pattern 2 was the duration of the IOIs between the groups and the isolated events (i.e. IGIs): IOIs of 1200 ms in Pattern 1 were substituted for IOIs of 1800 ms in Pattern 2. Likewise, IOIs of 1800 ms in Pattern 1 were substituted for IOIs of 1200 ms in Pattern 2.

Events in the sequences were three syllables, “Pa”, “Ta”, and “Ka”, spoken with a male voice generated using a text-to-speech synthesizer, Mbrola. The syllables had a fundamental frequency of 120 Hz, a duration of 218 ms and were normalized for intensity.

Each block consisted of a sequence of 136 syllables presented in a pseudo-random order. As the first syllable in each block did not follow an IGI, it was not included in the analyses. Instead an additional syllable was added at the end of each block to create the final IGI. The following constraints were applied from the second to the final syllable in each sequence. There were 45 presentations of each syllable, with no adjacent repetitions and with second- and third-order repetitions roughly equated across blocks. Second-order repetitions are instances when, for example, two “Pa”s are interposed with one of the other syllables (“Pa Ta Pa”), and third-order
repetitions are instances when, for example, two Pas are interposed with two of the other syllables (“Pa Ta Ka Pa”). Finally, as the temporal structure of the presentation of syllables was defined by a repeating basic sequence of 15 IOIs, syllables were distributed equally across all serial positions in each sequence. To ensure that any effects could not be attributed to syllable order, half the participants were presented with a second syllable order that was a reversal of the order presented to the other half of participants.

For each block, AIFF files of each syllable sequence, with the defined repeating IOI chaining were created in Matlab. Each sequence had a duration of 2 mins and 10 s. Two practice sequences with two repetitions of the temporal structure of Pattern 1 and Pattern 2 were also created. The experiment was run in Psyscope (J. Cohen, MacWhinney, Flatt, & Provost, 1993) and the sequences were presented over Sennheiser HD 25 closed headphones.

Although Experiment 1 investigated learning of IGIs, and was not aimed at manipulating meter, a measure of metrical strength (C-score) was applied (Povel & Essens, 1985)\(^4\) to ensure that both patterns were weakly metrical. The C-scores for Pattern 1 and Pattern 2 were 15 and 19, respectively, indicating that while both patterns were weakly metrical, Pattern 2 had a slightly weaker meter (a score of zero indicates maximal metrical strength). This difference was due to Pattern 2 having one less event on a beat, compared to Pattern 1. While it would have been optimal to have identical C-scores for both patterns, the choice of patterns was limited by the following constraints: (a) both patterns needed to have identical grouping structures; and (b) there needed to be an even number of IGIs (3 long and 3 short) directly transposed across the two patterns (i.e. a long IGI in Pattern 1 became a short IGI in

\(^4\) See Appendix A for a description of the C-score calculation.
Pattern 2, and vice versa). Nonetheless, both patterns were weakly metrical and as closely matched in their degree of metrical strength as possible.

2.2.1.2.2. Post-tests. The purpose of the post-test phase was to measure participants’ explicit knowledge of the temporal structures to which they were exposed in the SRTT. Post-test stimuli were short syllable sequences presented with the temporal structure of Pattern 1 and Pattern 2. Each post-test sequence was one cycle of the chaining of 15 IOIs. As the temporal structure was repeated in the SRTT, it was possible that participants may have segmented the sequence using any of the groups or isolated syllables as a starting point. Hence, six versions of each pattern were created, each starting at a different group or isolated syllable.

In addition to the post-test sequences based on the temporal structure of Pattern 1 and Pattern 2, two sets of six sequences were created that had novel grouping structures while still using the same number of groups and group sizes. Novel 1 and Novel 2 had grouping structures of 1-2-1-4-4-3 and 1-4-4-3-1-2, respectively. The first novel set of sequences (Novel 1) differed from Pattern 1, and the second novel set (Novel 2) differed from Pattern 2 in terms of the group-to-IGI chaining. The six versions of the two novel post-test patterns began on different groups or isolated syllables. Both novel patterns were weakly metrical. The Novel 1 and Novel 2 patterns respectively were “X..XX.X..XXXX.XXXX.XXX..” and “X.XXXX..XXXX..XXX.X.X..” (X” represents a syllable and a full stop(s) represents an IGI).

The syllables used in the post-test sequences (“Pa”, “Ta”, “Ka”), and the method for creating the AIFF files was as per the SRTT. The post-test task was run in Psyscope (J. Cohen, MacWhinney, Flatt, & Provost, 1993).
2.2.1.3. Procedure

2.2.1.3.1. SRTT. As a cover story, participants were advised that the experiment was investigating the speed and accuracy of syllable identification. They were not informed of the temporal structure of the sequences. Participants listened to the sequences of syllables and identified each syllable as quickly and accurately as possible. They made their responses using keys 1, 2, and 3 on the numeric keypad of a computer keyboard. Labels identifying the appropriate response key were placed on the keys above. Using the right hand, participants kept their index, middle, and ring fingers on the keys at all times. Participants were instructed to not correct themselves if they made a mistake or if they missed any syllables. To minimise motor-based effects, three key-to-syllable mappings were counterbalanced across participants.

A practice block with the temporal structure of the exposure sequence was completed and participants were reminded of the instructions before beginning the experimental blocks. The participants in the Pattern 1 condition were presented with five exposure blocks of Pattern 1. This was followed by a test block presentation of Pattern 2 (Block 6) and a final block of Pattern 1 (Block 7). Conversely, the participants in the Pattern 2 condition were presented five exposure blocks of Pattern 2, followed by a test block presentation of Pattern 1 and a final block of Pattern 2. A short break with a minimum duration of 30 s was provided between each block.

2.2.1.3.2. Post-tests. After completing the SRTT, participants filled in a questionnaire asking them to describe any temporal regularity they noticed in the sequences. They were then informed that the sequences followed a repeating timing or rhythmic pattern.

In the post-test task, participants responded to the syllables as they had in the SRTT. This was done in order to ensure that the testing conditions were as equivalent
as possible across the SRTT and post-test task, thus giving participants the best opportunity to extract any explicit knowledge. Again, participants were instructed to identify each syllable as quickly and accurately as possible and to not correct themselves if they made a mistake or missed syllables. Participants exposed to Pattern 1 in the SRTT responded to the six post-test sequences from the Pattern 1, Pattern 2, and Novel 1 sets. Participants exposed to Pattern 2 in the SRTT responded to the six post-test sequences from the Pattern 1, Pattern 2, and Novel 2 sets. The sequences were presented in random order.

After responding to each sequence, participants were given two rating tasks. They were asked to think back to the blocks in the SRTT of the exposure phase of the experiment and rated their familiarity with the timing pattern of the post-test sequence just heard using a scale: 1 = very unfamiliar, 2 = unfamiliar, 3 = somewhat unfamiliar, 4 = somewhat familiar, 5 = familiar, 6 = very familiar. They were then asked to indicate the certainty with which they made their familiarity rating: 1 = complete guess, 2 = very uncertain, 3 = somewhat uncertain, 4 = somewhat certain, 5 = very certain, 6 = completely certain (adapted from Destrebecqz & Cleeremans, 2001). Ratings were made using the numeric keys across the top of the computer keyboard. After making their ratings, participants pressed a key to continue with the next post-test sequence. Participants then completed a demographic questionnaire and were debriefed. The experiment took 50 minutes.
2.2.2. Results

2.2.2.1. SRTT

Correct responses were included in the analysis if they occurred 250 – 900 ms after the onset of the syllable. RTs less than 250 ms were assigned to the previous syllable if it was missed and, if multiple responses were made within the 250 – 900 ms window, only the first response was kept. The upper limit (900 ms) allowed us to retain any longer RTs made to the syllables immediately preceding an IGI. Mean accuracy to syllables across all serial positions was significantly above chance (33.33%) for the Pattern 1 condition (58%; SD = 14%), \( t(20) = 7.75, p = .00 \), and Pattern 2 condition (60%; SD = 14%), \( t(21) = 9.28, p = .00 \). For Post-IGI syllables, accuracy was 69% and 70% in the Pattern 1 and Pattern 2 conditions, respectively.

2.2.2.1.1. Mean RT to Post-IGI positions over exposure blocks. RT to post-IGI syllables was averaged for each block. Testing the hypothesis that RT would decrease over the first five exposure blocks, a 5 x 2 ANOVA with Block (Blocks 1 – 5) as a within-subjects factor and Pattern condition (Pattern 1, Pattern 2) as a between-subjects factor was conducted (Figure 2.2a). The main effect of block was significant, \( F(4, 164) = 2.95, p = .02 \), partial \( \eta^2 = .07 \). There was no main effect of pattern condition, \( F(1, 41) = 0.00, p = .97 \), partial \( \eta^2 = .00 \), and no interaction, \( F(4, 164) = .41, p = .80 \), partial \( \eta^2 = .01 \). The difference between Block 1 and Block 5 fell just short of significance, \( F(1, 41) = 3.54, p = .06 \), partial \( \eta^2 = .08 \). However, Block 5 was significantly faster than Block 2, \( F(1, 41) = 8.56, p = .01 \), partial \( \eta^2 = .17 \).

2.2.2.1.2. Mean RT to post-IGI positions at the test block. To investigate the effect of introducing changes to the IGIs at the test block, a 2 x 2 ANOVA with Block

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Footnote 5: Analyses of accuracy over blocks, and correlations between post-IGI accuracy and correct RT showing no speed/accuracy trade-off are presented in Appendix B.
as a within-subjects factor (mean of Blocks 5 and 7, Block 6) and Pattern condition (Pattern 1, Pattern 2) as a between-subjects factor was conducted. This revealed a significant effect of Block, $F(1, 41) = 3.98, p = .05$, partial $\eta^2 = .08$, and a significant Block by Pattern condition interaction, $F(1, 41) = 4.74, p = .04$, partial $\eta^2 = .10$. A contrast analysis revealed an effect of Block in the Pattern 1 condition, with RT slowing significantly at the test block compared to the mean of the two adjacent exposure blocks, $F(1, 20) = 8.34, p = .01$, partial $\eta^2 = .29$. There was no significant increase in RT at the test block in the Pattern 2 condition, $F(1, 21) = .02, p = .90$, partial $\eta^2 = .00$.

Figure 2.2. Experiment 1: Correct RT to a) post-IGI syllables and, b) controlled within-group syllable positions 2, 10, and 11, presented as a function of Block and Pattern condition. Error bars show standard error of the mean.

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6 RT was slower to controlled within-group positions, compared to post-IGI positions. This is likely because within-group positions were contained within a string of rapidly presented syllables (with 600 ms IOIs) making response more difficult. In addition, two within-group positions (positions 2 and 11) are the last in a group, and participants may take advantage of the immediately following long IGI to make their response (slowing down to do so). On the other hand, post-IGI positions indicate the start of a group and participants have additional preparation time to make their response. This is particularly relevant once the IGIs are learned. Participants must
Additional analyses were conducted to ensure that the RT increase at the test block in the Pattern 1 condition was not driven only by the IGIIs that were lengthened (1200 ms to 1800 ms), but by both types of IGI changes. Hence, we examined separately, RT to post-IGI positions that followed a 1200 ms to 1800 ms change and an 1800 ms to 1200 ms change at the test block (Figure 2.3). The results showed a significant increase at the test block (compared to the mean of the adjacent exposure blocks) for post-IGI syllables that followed either an IGI increase (1200 ms to 1800 ms), $F(1, 20) = 4.54, p = .04, \text{partial } \eta^2 = .19$, or an IGI decrease (1800 ms to 1200 ms), $F(1, 20) = 5.97, p = .02, \text{partial } \eta^2 = .23$.

also be prepared to respond to the subsequent and relatively fast run of syllables and hence RT to post-IGI positions may be sped up in general (relative to within-group positions).

7 Slower RT to syllables following the 1800ms IGIIs, compared to 1200ms IGIIs, in the exposure blocks cannot be explained by a variable foreperiod effect (e.g. Ellis & Jones, 2010). The variable foreperiod effect would predict that RT to syllables should be slower following 1200ms IGIIs than 1800ms IGIIs in the current experiments. However, the reverse was found in the exposure blocks: RT was faster following 1200ms IGIIs compared to 1800ms IGIIs.
Figure 2.3. Experiment 1/Pattern 1 condition: Black bars show mean correct RT (ms) to positions following 1200 ms and 1800 ms IGIs during exposure Blocks 5 and 7. White bars show correct RT (ms) to the same positions but following the IGI change at the test block, to 1800 ms and 1200 ms, respectively. Error bars show standard error of the mean.

2.2.2.1.3. Mean RT to controlled within-group positions over exposure blocks.

Serial positions within groups that maintain their global position and metric location across exposure and test were analysed. RT to positions 2, 10, and 11 were collapsed to give a mean for each block (Figure 2.2b). First, to examine learning over exposure blocks, a 5 x 2 ANOVA with Block (Blocks 1 – 5) as a within-subjects factor and Pattern condition (Pattern 1, Pattern 2) as a between-subjects factor was conducted. There was a main effect of block, \( F(4, 164) = 6.75, p = .00, \text{ partial } \eta^2 = .14 \), but no effect of Pattern condition, \( F(1, 41) = .16, p = .70, \text{ partial } \eta^2 = .00 \), and no
interaction, $F(4, 164) = 1.42, p = .23$, partial $\eta^2 = .03$. RT at Block 5 was significantly faster than RT at Block 1, $F(1, 41) = 18.22, p = .00$, partial $\eta^2 = .31$.

2.2.2.1.4. Mean RT to controlled within-group positions at the test block. To examine the effect of the introduction of the test block on the three within-group positions, RT at the test block (Block 6) was compared to the mean of the two adjacent blocks (Blocks 5 and 7). A 2 x 2 ANOVA with Block (mean of Blocks 5 and 7, Block 6) as a within-subjects factor and Pattern condition (Pattern 1, Pattern 2) as a between-subjects factor was conducted. RT at the test block (Block 6) was slower than at the adjacent exposure blocks (Blocks 5 and 7), $F(1, 41) = 4.10, p = .05$, partial $\eta^2 = .09$. There was no effect of Pattern condition, $F(1, 41) = 0.00, p = .95$, partial $\eta^2 = .00$, and no interaction $F(1, 41) = 1.80, p = .19$, partial $\eta^2 = .04$, even though the Pattern 1 condition showed a larger increase at the test block than Pattern 2 (Figure 2.2b).

2.2.2.1.5. Individual post-IGI and controlled within-group positions at exposure and test blocks. Results of individual post-IGI and controlled within-group positions are plotted in Figure 2.4. Descending black bars indicate faster RT over exposure (i.e. Block 5 compared to Block 1), and ascending grey bars indicate slower RT at the test block (Block 6) compared to the adjacent exposure blocks (mean of Blocks 5 and 7). As the figure shows, there was learning in both the Pattern 1 (Figure 2.4a) and Pattern 2 (Figure 2.4b) conditions over exposure blocks for both post-IGI and controlled within-groups positions. While the RT decrease over exposure indicates the presence of task learning, the increase at the test block demonstrates learning of the temporal structure in the Pattern 1 condition.
Figure 2.4. Experiment 1: a) For the Pattern 1 condition and b) Pattern 2 condition, the RT differences between Block 1 and Block 5 (black bars) and between Block 6 and the mean of adjacent exposure Blocks 5 and 7 (grey bars) are shown. Descending black bars indicate faster RT at Block 5 compared to Block 1. Ascending grey bars indicate slower RT at the test block (Block 6) compared to the adjacent exposure blocks (Blocks 5 and 7).

2.2.2.1.6. Effects of the violation of global temporal expectations. For post-IGI syllables, it is possible that violations at the test block to the global temporal location (i.e. within each cycle of the temporal structure) modulated RT and partially explain the difference between the Pattern 1 and Pattern 2 conditions. At the test block in the Pattern 1 condition (see Figure 2.5, Pattern 2), positions 3, 7, and 8 are presented earlier than expected and position 12 is presented later than expected. Conversely, at the test block in the Pattern 2 condition (see Figure 2.5, Pattern 1), position 12 is presented earlier than expected and positions 3, 7, and 8 are presented later than expected.
Figure 2.5. Temporal structures: Pattern 1 presented during exposure in the Pattern 1 condition and during test in the Pattern 2 condition. Pattern 2 presented during exposure in the Pattern 2 Condition and during test in the Pattern 1 condition. Bold font indicates positions presented later than expected at the test blocks and overlined font indicates positions presented earlier than expected at the test blocks.

Previous research on temporal expectations (e.g. Capizzi, Sababria, Correa, 2012; Correa et al., 2004; Correa et al., 2006; Tillmann & Lebrun-Guillaud, 2006) has demonstrated that RT is slower to events presented earlier than expected compared to events presented later than expected. In the present experiment, expectations about the temporal location of events within the global structure were developed during the exposure blocks and were violated at the test block. In the Pattern 1 condition, more post-IGI positions were presented earlier, compared to later than expected at the test block thus potentially leading to slower overall RT. On the other hand, more post-IGI positions were presented later than expected at the test block in the Pattern 2
condition, thus diminishing the expected RT increase.

To investigate this hypothesis, additional analyses of post-IGI positions presented earlier and later than expected were conducted. For each Pattern condition, the mean of positions 3, 7, and 8 (earlier than expected at the test block in the Pattern 1 condition, and later than expected at the test block in the Pattern 2 condition) was calculated at the test block (Block 6) and at the two adjacent exposure blocks (Blocks 5 and 7). These means were compared to RT at position 12 (later than expected at the test block in the Pattern 1 condition, and earlier than expected at the test block in the Pattern 2 condition). An ANOVA was conducted with Block (Block 6 vs. mean of Blocks 5 and 7) and Violation (Early, Late) as within-subjects factors, and Pattern condition (Pattern 1, Pattern 2) as a between-subjects factor.

There was a significant three-way interaction between Pattern condition, Violation, and Block, $F(1, 41) = 6.32, p = .02, \eta^2 = .13$. An investigation of this interaction revealed that in the Pattern 1 condition, a significant increase in RT at the test block was evident for the earlier than expected positions 3, 7, and 8, $F(1, 20) = 8.05, p = .01, \eta^2 = .29$ (mean of Blocks 5 and 7: $M = 566.38\text{ms}, SD = 79.64$; Block 6: $M = 598.50\text{ms}, SD = 97.89$), but not for the later than expected position (position 12) ($p = .40$; mean of Blocks 5 and 7: $M = 528.27\text{ms}, SD = 71.28$; Block 6: $M = 514.25\text{ms}, SD = 58.84$; see Figure 2.4a). In the Pattern 2 condition, there was no RT difference at the test block for either the earlier than expected, or later than expected positions (see Figure 2.4b). Hence, the effect of a global violation at the test block was evident in the Pattern 1 condition, with an RT increase to earlier, but not later than expected positions. This was not the case in the Pattern 2 condition.
2.2.2.2. Post-tests

In the open-ended questionnaire asking for a description of any regularity in the timing of the presentation of the syllables, 30% of participants reported that the speed of the presentation of the syllables changed within a block, and 25% reported that there were pauses between some syllables. However, no participants were able to report the temporal structure in detail. To further test for the presence of awareness of the temporal structure, familiarity ratings to the exposure sequence, test sequence, and novel sequence were compared. Ratings (1 = very unfamiliar through to 6 = very familiar) were collapsed across the 6 presentations of each sequence to obtain a mean rating (Table 2.1), and analysed with a 3 x 2 ANOVA with Sequence as a within-subjects factor (Exposure, Test, Novel) and Pattern condition (Pattern 1, Pattern 2) as a between-subjects factor. There was no effect of Sequence, $F(2, 82) = 1.42, p = .25$, partial $\eta^2 = .03$, or Pattern condition, $F(1, 41) = .07, p = .97$, partial $\eta^2 = .00$, and no interaction, $F(2, 82) = 2.45, p = .10$, partial $\eta^2 = .06$, indicating that participants had not acquired explicit knowledge of the temporal structure, even in the condition (Pattern 1) that showed evidence of learning at the test block (see RT analyses).

Appendix B presents an additional assessment of explicit knowledge, i.e. correlations between familiarity and certainty ratings (Scott and Dienes, 2008).
Table 2.1

*Experiment 1: Post-test Familiarity (1 = very unfamiliar, through to 6 = very familiar) and Certainty (1 = complete guess, through to 6 = completely certain)*

*Mean Ratings and Standard Deviations presented as a function of Sequence Type and Exposure Condition*

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<th>Novel</th>
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</table>

### 2.2.3. Discussion

The aim of Experiment 1 was to investigate implicit learning of IGIs in weakly metrical temporal structures. As hypothesised, RT to syllables, presented according to a repeating temporal structure, decreased over exposure blocks as participants became familiar with the task and developed expectations of when the syllables would occur.

In the Pattern 1 condition, the shortening (1800 ms to 1200 ms) and lengthening (1200 ms to 1800 ms) of the IGIs at the test block resulted in RT to the subsequent (post-IGI) syllables becoming significantly slower compared to the mean of the adjacent exposure blocks. The effect of changing the IGIs at the test block also carried over to the within-group syllable positions that maintained their location within the global temporal structure and the metrical structure. We also found evidence of global temporal structure violation with RT slowing at the test block to
post-IGI positions presented earlier, compared to later, than expected. Together, these results suggest that learning of temporal expectations was not only related to the IGIs, but also to the global temporal structure of the sequence.

Furthermore, post-test familiarity and certainty ratings indicated that the learning evident in the SRTT was implicit. Participants were no more familiar with the exposure sequence than with the Test or Novel sequence. It appears that awareness was not a necessary requirement for learning the temporal structure of Pattern 1 (see Appendix B for further details). Hence, this experiment demonstrated implicit learning of IGIs in a weakly metrical temporal structure. The study builds on the research conducted by Hébert and Cuddy (2002) and Ross and Houtsma (1994) who found a greater sensitivity to IGIs in strongly, compared to weakly, metrical structures in an explicit discrimination task. These authors argue that a strong meter initiates an internal timing mechanism that allows listeners to abstract the IGIs and incorporate them into the grouping structure. In the present experiment, IGIs were learned even though the structure was weakly metrical. This may have been because our task required a response to every event, and participants had more exposure to the temporal structure than is typical in pattern discrimination tasks. In addition, the IGI changes in our test block were proportionally larger than those made to the comparison patterns used by Hébert and Cuddy. Our changes at the test block either doubled (600 ms to 1200 ms) or halved (1200 ms to 600 ms) the IGIs of the exposure sequence, whereas Hébert and Cuddy had increases of 33% (600 ms to 800 ms). Nonetheless, our results support the hypothesis that implicit processes are an effective means by which temporal structure can be learned.

Contrary to our hypothesis, the Pattern 2 condition did not lead to the same results as the Pattern 1 condition. Despite the RT decrease over exposure blocks to
post-IGI and controlled within-group positions in the Pattern 2 condition, shortening or lengthening the IGIs at the test block did not lead to increased RT. The lack of RT increase might be partially due to the greater number of post-IGI positions being presented later (compared to earlier) than expected in the global temporal structure.

While metrical strength was not experimentally manipulated across the two Pattern conditions, Pattern 2 did have a slightly weaker metrical structure than Pattern 1 (C = 19 and C = 15, respectively), and this may have made learning the IGIs in Pattern 2 more difficult. Hence, a rhythm notation task was conducted to further investigate differences in metrical interpretation, or rhythmic complexity between Pattern 1 and Pattern 2. Greater variability in the metrical interpretation of Pattern 2 would likely indicate its metrical ambiguity and help to explain the lack of RT increase at the test block. In the notation task, six musically trained adults (4 females, \( M = 10.5 \) years musical training, \( SD = 5.9 \) years) were instructed to notate both Pattern 1 and Pattern 2 and to indicate the metrical structure. The patterns were presented with a piano timbre and the order of pattern presentation was counterbalanced across participants. All participants notated Pattern 1 with the intended metrical structure. However, only 3 participants notated Pattern 2 as intended, that is, with metrical divisions of two (duple meter). The other three notations segmented the metrical structure at different points and indicated metrical divisions of three (triple meter).

In the SRTT, it is possible that the weaker meter (relative to Pattern 1) and the metrical ambiguity of Pattern 2 made it more difficult to learn the longer IGIs. However, RT over exposure blocks was equivalent in both conditions, indicating that responding to Pattern 2 was not more difficult overall than responding to Pattern 1. Equivalence over exposure blocks and diverging results at the test block may indicate
that participants in the two conditions were learning different features of the exposure sequence: they may have learned the grouping structure and IGIs in the Pattern 1 condition, but only the grouping structure in the Pattern 2 condition. This proposition is supported by previous work suggesting that grouping is the dominant strategy used in perceptually organising temporal structure in the absence of a perceived metrical grid (Hébert & Cuddy, 2002; Ross & Houtsma, 1994).

Although the role of metrical strength across the Pattern 1 and Pattern 2 conditions was not initially investigated in Experiment 1, the second experiment addressed the contribution of meter to implicit learning. Therefore, Experiment 2 examined learning of the same temporal structures, but with an additional cue to meter. Handel (1998) found in an explicit discrimination task that the presence of an external pulse facilitated the abstraction of IGIs in tone sequences. As pulses have been used previously to support metrical structure (Handel, 1998; Hannon & Trehub, 2005a), in Experiment 2 we presented an isochronous and amplitude-accented woodblock pulse concurrently with the syllable sequences. It was hypothesised that the presence of the pulse, facilitating the abstraction of a metrical structure, would enable participants to learn the IGIs in Pattern 2. As in Experiment 1, for Pattern 1 and Pattern 2 conditions, we hypothesised that RT to post-IGI syllables would decrease over exposure blocks but increase (compared to the adjacent exposure blocks) at the test block (Block 6) with the change in IGIs. Also, at the test block, it was expected that there would be an increase in RT to controlled within-group syllable positions that maintain their position in the global and metrical structure in both Pattern 1 and Pattern 2 conditions.
As it was possible that the addition of the isochronous accented pulse would lead to explicit knowledge of the temporal structure, post-tests were administered as per Experiment 1.

2.3. Experiment 2: Implicit Learning of IGIs in Weakly Metrical Temporal Structures:

The Effect of Strengthening Meter with an Accented Pulse

2.3.1. Method

2.3.1.1. Participants

Forty-five participants from the University of Western Sydney took part in the experiment in exchange for course credit. The 35 female and 10 male participants had a mean age of 21.57 years ($SD = 6.55$ years range = 18 - 52 years). All participants had self-reported normal hearing. Participants were randomly assigned to either the Pattern 1 ($N = 22$) or Pattern 2 ($N = 23$) condition. The two participant groups were equivalent in terms of years of musical training: participants in the Pattern 1 condition had a mean of .93 years of training ($SD = 2.3$ years, median = 0) and participants in the Pattern 2 condition had a mean of 1.82 years of training ($SD = 3.63$ years, median = 0). These levels of musical training were not statistically different between the two conditions ($p = .33$).

2.3.1.2. Materials

2.3.1.2.1. SRTT. Experiment 2 was identical to Experiment 1 in all respects except that an isochronous woodblock pulse with IOIs of 600 ms (i.e. a woodblock sound presented every 600 ms) was played concurrently with the syllable sequences.
The 218 ms woodblock sound was sourced from Logic Pro 8. An amplitude-accent structure was added to the pulse so that woodblock sounds aligning with strong beats were 3dB louder than sounds aligning with moderate beats, and 6dB louder than sounds aligning with weak beats. This resulted in an alternation of a strong accent, no accent, moderate accent, no accent, followed again by a strong accent, and so on. Hence, a woodblock sound could be heard with each syllable and during each IGI.

The onset of the woodblock sound was synchronised with the voicing onset of each syllable. The syllable sequences were presented binaurally, and the woodblock pulse was presented to the left channel only. Measured at the headphones using a sound pressure level meter, the syllables were approximately 5dBA louder than the strong accents of the woodblock pulse.

2.3.1.2.2. Post-tests. The post-test phase in Experiment 2 was identical to Experiment 1 except for the addition of the accented isochronous woodblock pulse to each of the post-test sequences. There were six versions of each temporal structure (Exposure, Test, Novel), each starting from the six different groups or isolated syllables. The accents of the woodblock pulse were aligned with the temporal structure of the syllable sequences as per the SRTT in the main phase of the experiment.

2.3.1.3. Procedure

2.3.1.3.1. SRTT and post-tests. The SRTT and post-test procedures were identical to Experiment 1 except that participants were informed that this experiment was investigating the speed and accuracy of syllable identification in the presence of a stream of non-speech sounds. Participants were instructed to focus on the syllables and to respond as quickly and accurately as possible.
2.3.2. Results

2.3.2.1. SRTT

The criteria for identifying correct responses were as in Experiment 1. Mean accuracy was significantly better than chance (33.3%) in the Pattern 1 condition, 67% (SD = 12%), \( t(21) = 12.56, p = .00 \), and in the Pattern 2 condition, 66% (SD = 15%), \( t(22) = 10.57, p = .00 \). For Post-IGI syllables, accuracy was 75% and 74% in the Pattern 1 and Pattern 2 conditions, respectively.

2.3.2.1.1. Mean RT to post-IGI positions over exposure blocks. The first set of analyses tested for learning of IGIs by examining RT to post-IGI syllables. A 5 x 2 ANOVA with Block (Blocks 1 – 5) as a within-subjects factor and Pattern condition (Pattern 1, Pattern 2) as a between-subjects factor was conducted (Figure 2.6a).

![Figure 2.6](image)

Figure 2.6. Experiment 2: Correct RT to a) post-IGI syllables and b) controlled within-group syllable positions 2, 10, and 11, presented as a function of Block and Pattern condition. Error bars show standard error of the mean.

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8 Analyses of accuracy over blocks, and correlations between post-IGI accuracy and correct RT showing no speed/accuracy trade-off are presented in Appendix B.
For the exposure phase analysis, there was no main effect of Block, $F(4, 172) = .86, p = .49$, partial $\eta^2 = .02$, or Pattern condition, $F(1, 43) = .25, p = .62$, partial $\eta^2 = .01$, and no interaction, $F(4, 172) = 1.94, p = .11$, partial $\eta^2 = .04$. In an additional analysis comparing Block 1 with Block 5, an ANOVA with Block as a within-subject factor (Block 1, Block 5) and Pattern condition as a between-subjects factor (Pattern 1, Pattern 2) was conducted. This analysis revealed no effect of Block, $F(1, 43) = .08, p = .78$, partial $\eta^2 = .00$, no effect of Pattern condition, $F(1, 43) = .18, p = .68$, partial $\eta^2 = .00$, but there was a significant interaction, $F(1, 43) = 3.94, p = .05$, partial $\eta^2 = .08$. A contrast analysis revealed that RT at Block 5 was faster than Block 1 in the Pattern 2 condition only, $F(1, 22) = 4.29, p = .05$, partial $\eta^2 = .16$. However, with a Bonferroni correction ($p < .025$), this did not reach significance.

2.3.2.1.2. Mean RT to post-IGI positions at the test block. To investigate the effect of introducing changes to the IGIs at the test block, a 2 x 2 ANOVA with Block as a within-subjects factor (mean of Blocks 5 and 7, Block 6) and Pattern condition (Pattern 1, Pattern 2) as a between-subjects factor was conducted. This revealed a significant effect of Block, $F(1, 43) = 11.21, p = .00$, partial $\eta^2 = .21$, and a significant Block by Pattern condition interaction, $F(1, 43) = 6.11, p = .01$, partial $\eta^2 = .12$. A contrast analysis revealed a significant effect of Block for Pattern 1 with RT becoming significantly slower at the test block compared to the mean of the two adjacent exposure blocks, $F(1, 21) = 16.17, p = .00$, partial $\eta^2 = .44$. As in Experiment 1, there was no significant increase at the test block in the Pattern 2 condition, $F(1, 22) = .40, p = .53$, partial $\eta^2 = .02$.

In the Pattern 1 condition, an analysis was conducted separately on RT to post-IGI positions that followed a 1200 ms to 1800 ms change and 1800 ms to 1200 ms change at the test block (Figure 2.7). This was done to ensure that the increase at
the test block in the Pattern 1 condition was not due to either the lengthening or shortening of the preceding IGI, but in fact to both. As in Experiment 1, significant RT increases at the test block were found for post-IGI positions regardless of whether the preceding IGI change was 1200 ms to 1800 ms, $F(1, 21) = 13.98, p = .00$, partial $\eta^2 = .40$, or 1800 ms to 1200 ms, $F(1, 21) = 9.23, p = .00$, partial $\eta^2 = .31$.

**Figure 2.7.** Experiment 2/Pattern 1 condition: Black bars show mean correct RT (ms) to positions following 1200 ms and 1800 ms IGIs during exposure blocks 5 and 7. White bars show correct RT (ms) to the same positions but following the IGI change at the test block to 1800 ms and 1200 ms, respectively. Error bars show standard error of the mean.

2.3.2.1.3. *Mean RT to controlled within-group positions over exposure blocks.*

As in Experiment 1, RT to syllables in the within-group positions (2, 10, and 11) that maintained their location in the global temporal and metrical structure was examined
for evidence of global structure learning. First, to examine learning over exposure blocks, a 5 x 2 ANOVA with Block (Blocks 1 – 5) as a within-subjects factor and Pattern condition (Pattern 1, Pattern 2) as a between-subjects factor was conducted. The results show a main effect of Block $F(4, 172) = 3.83, p = .01$, partial $\eta^2 = .08$, with Block 5 significantly faster than Block 1, $F(1, 43) = 8.05, p = .01$, partial $\eta^2 = .16$. There was no main effect of Pattern condition, $F(1, 43) = 1.01, p = .32$, partial $\eta^2 = .02$, and no interaction, $F(1, 43) = .42, p = .52$, partial $\eta^2 = .01$ (Figure 2.6b).

2.3.2.1.4. Mean RT to controlled within-group positions at the test block.

Turning now to the effect of the IGI changes on the within-group positions at the test block, a 2 x 2 ANOVA with Block (mean of Blocks 5 and 7, Block 6) as a within-subjects factor and Pattern condition (Pattern 1, Pattern 2) as a between-subjects factor was conducted. There was a main effect of block with a significant RT increase at the test block, compared to the mean of the adjacent exposure blocks, $F(1, 43) = 10.64, p = .00$, partial $\eta^2 = .20$. There was no main effect of Pattern condition, $F(1, 43) = 1.19, p = .28$, partial $\eta^2 = .03$, and no interaction, $F(1, 43) = .94, p = .34$, partial $\eta^2 = .02$ (Figure 2.6b).

2.3.2.1.5. Individual post-IGI and controlled within-group positions at exposure and test blocks. Individual post-IGI and controlled within-group positions are plotted in Figure 2.8. Descending black bars indicate faster RT at Block 5 compared to Block 1 and ascending grey bars indicate slower RT at the test block (Block 6) compared to the adjacent exposure blocks (mean of Blocks 5 and 7). As the figure shows, there was learning in both the Pattern 1 and Pattern 2 conditions over exposure blocks for both post-IGI and controlled within-groups positions. While the RT decrease over exposure could reflect task learning, the increase to post-IGI and controlled within-group positions at the test block demonstrate learning of the
temporal structure in the Pattern 1 condition. The RT increase to controlled-within group positions in the Pattern 2 condition indicates that the presence of the woodblock pulse facilitated learning of the temporal structure of Pattern 2.

Figure 2.8. Experiment 2: a) Pattern 1 condition and b) Pattern 2 condition RT difference between Block 1 and Block 5 (black bars) and between Block 6 and the mean of adjacent exposure Blocks 5 and 7 (grey bars). Descending black bars indicate faster RT at Block 5 compared to Block 1. Ascending grey bars indicate slower RT at the test block (Block 6) compared to the adjacent exposure blocks (Blocks 5 and 7).

2.3.2.1.6. Effects of the violation of global temporal expectations. As in Experiment 1, additional analyses of post-IGI positions presented earlier and later than expected were conducted. For each Pattern condition, the mean of positions 3, 7, and 8 was calculated at the test block (Block 6) and at the two adjacent exposure blocks (Blocks 5 and 7). For each Pattern condition, the mean of positions 3, 7, and 8 (earlier than expected at the test block in the Pattern 1 condition, and later than expected at the test block in the Pattern 2 condition) was calculated at the test block (Block 6) and at the two adjacent exposure blocks (Blocks 5 and 7). These means
were compared to RT at position 12 (later than expected at the test block in the Pattern 1 Condition, and earlier than expected at the test block in the Pattern 2 Condition). An ANOVA was conducted with Block (Block 6 vs. mean of Blocks 5 and 7) and Violation (Early, Late) as within-subjects factors, and Condition (Pattern 1, Pattern 2) as a between-subjects factor.

A significant two-way interaction was found between Violation (Early, Late), and Block (mean of Blocks 5 and 7, Block 6), $F(1, 43) = 5.73, p = .02, \eta^2 = .12$. There was no interaction with Pattern condition. Follow-up contrasts revealed that, for earlier than expected positions, there was a significant increase in RT at Block 6, $F(1, 44) = 7.34, p = .01, \eta^2 = .14$ (mean of Blocks 5 and 7: $M = 526.85$ms, $SD = 62.20$; Block 6: $M = 554.08$ms, $SD = 75.20$). However, there was no effect for later than expected position (see Figure 2.8 for a plot of individual positions).

2.3.2.2. Post-tests

Responses to the open-ended questionnaire asking for a description of any regularity in the timing of the presentation of the syllables indicated that, for some participants, the addition of the woodblock pulse elicited awareness of the presence of a temporal structure. Thirty-eight percent of participants reported that there were variations in the speed of presentation of the syllables, and 42% reported that there were pauses between some syllables. However, no participants described the temporal structure accurately. To examine ratings of familiarity, a 3 x 2 ANOVA with Sequence as a within-subjects factor (Exposure, Test, Novel) and Pattern condition (Pattern 1, Pattern 2) as a between-subjects factor was conducted. The results show a main effect of Sequence, $F(2,86) = 6.38, p = .00, partial \eta^2 = .13$. However, there was no effect of Pattern condition, $F(1,43) = .91, p = .35, partial \eta^2 = .02$, and no interaction, $F(2, 86) = 1.72, p = .19, partial \eta^2 = .04$. Descriptive statistics are shown
in Table 2.2. Additional comparisons revealed that participants in both conditions rated the Exposure sequences as significantly more familiar than the Test, $F(1, 43) = 10.49, p = .00$, partial $\eta^2 = .20$, and Novel sequences, $F(1, 43) = 8.20, p = .01$, partial $\eta^2 = .16$. Appendix B presents correlations between familiarity and certainty ratings. Additional analyses revealed that awareness was not required for learning to occur (Scott and Dienes, 2008).

Table 2.2

Experiment 2: Post-test Familiarity ($1 =$ very unfamiliar, through to $6 =$ very familiar) and Certainty ($1 =$ complete guess, through to $6 =$ completely certain) Mean Ratings and Standard Deviations presented as a function of Sequence Type and Exposure Condition

<table>
<thead>
<tr>
<th>Pattern</th>
<th>Familiarity</th>
<th>Certainty</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exposure</td>
<td>Test</td>
</tr>
<tr>
<td>1</td>
<td>4.19 0.79</td>
<td>3.58 0.65</td>
</tr>
<tr>
<td>2</td>
<td>4.04 0.65</td>
<td>3.85 0.69</td>
</tr>
</tbody>
</table>

2.3.3. Discussion

The aim of Experiment 2 was to investigate whether the presence of an accented isochronous woodblock pulse facilitated implicit learning of weakly metrical structures, in particular a metrically ambiguous structure (Pattern 2). In Experiment 1, evidence of implicit learning of IGIs was found in the Pattern 1 condition only. Previous research has shown that listeners are better able to perceive the IGIs in relatively strong compared to weak metrical structures (Hébert & Cuddy, 2002; Ross
& Houtsma, 1994), and that a concurrently presented pulse aids this perception (Handel, 1998). Therefore, we hypothesised in Experiment 2 that the additional cue to meter (isochronous pulse), would lead to a decrease in RT over exposure blocks in both Pattern 1 and Pattern 2 conditions. Slower RT at the test block to syllables that followed the change in IGI was also expected for both patterns. A decrease in RT over exposure blocks was evident only in the Pattern 2 condition. In the Pattern 1 condition, RT was fast starting with Block 1. The addition of the pulse seemingly allowed participants to develop temporal expectations early in the exposure phase. Given that each block consisted of nine repetitions of the basic temporal pattern (i.e. 135 syllables per block), learning most likely occurred during Block 1.

As in Experiment 1, changing the IGIs at the test block resulted in significantly slower RT to the post-IGI syllables in the Pattern 1 condition only. This increase in RT occurred when the IGIs either shortened (1800 ms to 1200 ms) or lengthened (1200 ms to 1800 ms). The pulse did elicit some learning in the Pattern 2 condition however, as revealed by the analyses of RT to the within-group positions that maintained their location in the global and metrical structure. For both conditions, RT was significantly slower at the test block, compared to the adjacent exposure blocks, thus providing evidence of learning of these within-group intervals in both patterns.

Evidence of global structure learning arose from the analyses of post-IGI positions presented earlier and later than expected. RT was slower at the test block, compared to the mean of the adjacent exposure blocks, to syllables that were presented earlier than expected. Unlike Experiment 1, there was no interaction with Pattern condition, indicating that violation of global temporal expectation occurred in both conditions.
The post-tests revealed that some participants acquired explicit knowledge of the temporal structure of the exposure sequence. Familiarity ratings were significantly higher for the exposure compared to test and novel sequences. However, additional analyses (reported in Appendix B) revealed that explicit knowledge was not a requirement for learning of temporal structure to occur.

2.4. General Discussion

Implicit learning of temporal structures, in both auditory and visual modalities, has primarily been demonstrated when the temporal structure is correlated with a systematic ordering of events (e.g. Buchner & Steffens, 2001; Shin & Ivry, 2002). These findings suggest that temporal structure cannot be learned independently of ordinal structure. In Experiment 1 and 2, some evidence of implicit learning of weakly metrical temporal structures in the presence of an uncorrelated and pseudo-random ordinal structure was demonstrated. However, metrical strength moderated learning. As was evidenced by increases in RT at the test block, learning was of IGIs and globally maintained within-group intervals in the pattern with the slightly stronger meter. When the metrically weaker of the two patterns was presented with a concurrent woodblock pulse, evidence of learning of the maintained within-group intervals emerged. A key difference between the present study and earlier studies (e.g. Salidis, 2001) was that the temporal structures in Experiments 1 and 2 were based on a repeating sequence of IOIs, rather than RSIs. Presentation of events based on IOIs eliminates the variability inherent in RSI structures where the temporal presentation of events is somewhat determined by the RT to the previous event. Furthermore, our temporal structures were metrical, albeit weakly metrical. Consequently, participants
were able to exploit these additional regularities (i.e. IOI and metrical structure) in learning the independent temporal structure.

The use of a highly controlled test block, designed to specifically examine the learning of a particular temporal feature (i.e. IGIs), allowed us to make further contributions to the literature. An important aim of the present experiments was to determine if a precise feature of the temporal structure could be implicitly learned: the duration of intervals, or IGIs, between groups of auditory events. Previous research has shown that IGIs are more readily abstracted in relatively strong, compared to weak metrical sequences (Hébert & Cuddy, 2002; Ross & Houtsma, 1994). In two experiments, we demonstrated IL in weakly metrical structures. While metrical strength was not experimentally manipulated across the two counterbalanced conditions of the experiments, evidence of learning was clearer in the condition that presented the exposure pattern with a slightly stronger meter. However, when meter was strengthened by the addition of the woodblock pulse in Experiment 2, evidence of IL across the exposure blocks, and at the test block, emerged for controlled within-group positions. Based on this finding, it is speculated that metrical strength may moderate IL. However, a comprehensive set of experiments would be required to determine under what metrical contexts IL occurs. Nonetheless, previous research has demonstrated learning under duple and triple meter contexts (Brandon et al., 2012; Tillmann et al., 2011) and in non-metrical contexts (Salidis, 2001; but with a random test block sequence).

Other specific features of the temporal structures also appeared to modulate RT at the test blocks. RT has been shown in previous research to slow to events that occur earlier, compared to later than expected (e.g. Capizzi et al., 2012; Correa et al., 2004; Correa et al., 2006; Tillmann & Lebrun-Guillaud, 2006). Consistent with this
previous research, when considering the global temporal structure, we found that RT increased at the test block when post-IGI positions were presented earlier, but not later than expected. In Experiment 1, evidence of this violation of global temporal expectation at the test block was found only in the Pattern 1 condition. However, the effect was elicited in the Pattern 1 and Pattern 2 conditions in Experiment 2, indicating that the presence of the woodblock pulse strengthened the metrical structure of Pattern 2 and facilitated the development of temporal expectation. We claim that in these cases, participants learned not only the IGIs but also the global temporal structure.

The results suggest that developing expectations of when syllables should occur over the course of exposure blocks led to progressively faster RT in the syllable identification task (with the exception of post-IGI syllables in Experiment 2 where RT was fast from Block 1). While task learning may have contributed to the decrease in RT with exposure, learning of the temporal structure was clearly evident with the introduction of the test block. Changing the temporal structure in the test block violated temporal expectations and led to slower RT in the syllable identification task. This is consistent with the work of Jones et al. (2002) and others who have shown that responses to auditory events are faster when they occur at expected compared to unexpected points in time (e.g. Jones & Yee, 1997; Penel & Jones, 2005; Tillmann & Lebrun-Guillaud, 2006). Attentional energy is drawn to these expected time points, facilitating processing and responding (Jones & Boltz, 1989).

The present findings demonstrate that temporal expectations can be acquired implicitly, with participants’ attention drawn to the syllables rather than the temporal structure. The post-test results revealed that awareness of the temporal structure was not necessary for learning to occur (see Appendix B).
In summary, two experiments employing an SRTT demonstrated implicit learning of a weakly metrical temporal structure. It was shown that IGIs, or in other words, the duration between groups of auditory events, could be learned. Manipulation of IGIs was of particular interest as a means to examine learning beyond grouping structure, particularly in weakly metrical sequences. Although it has been proposed that weak meters do not readily activate an internal clock (Povel & Essens, 1985), consequently making the abstraction of IGIs more difficult (Hébert & Cuddy, 2002), we demonstrated IL of IGIs in weakly metrical sequences. It is likely that the multiple exposures in the current task and the required responses to all events enabled participants to exploit an internal clock or timing mechanism. Within this context, participants were able to develop temporal expectations of when post-IGI events would occur.

Most prior understanding of the perception and cognition of temporal structure has been gained via the use of either judgement tasks, requiring a response to a final tone in an isochronous sequence (e.g. Jones et al., 2002; Tillmann & Lebrun-Guillaud, 2006), or sequence discrimination tasks, presenting more complex temporal structures (Handel, 1998; Hébert & Cuddy, 2002; Ross & Houtsma, 1994). However, the results of Experiments 1 and 2 indicate that further understanding of temporal structure learning and temporal cognition more broadly would benefit from the use of temporally complex stimuli that requires a response to every event. Manipulating specific features of temporal structure and examining responses to corresponding events would determine precisely what is learned. Grouping structure, IGIs, meter, and the relationship between these local and higher-order features can be further examined using the auditory SRTT presented here. The results provide evidence that
temporal structure, and specifically the durations between groups of auditory events, can be implicitly learned.
Chapter 3 Preface

Experiments 1 and 2 (reported in Chapter 2) demonstrated IL of IGIs and controlled within-group intervals in a weakly temporal structure, with RT to syllables increasing when the temporal structure was violated at a test block. Although two weakly metrical patterns were tested, learning of both these interval types (i.e. post-IGI and within-group) emerged for only the metrically stronger of the two patterns, suggesting that meter modulates learning. Indeed, learning of within-group intervals was demonstrated when the metrically weaker of the two patterns was presented concurrently with an accented woodblock pulse. Overall, the result confirms that IL was not just of grouping structure but also of the intervals between groups of auditory events (i.e. IGIs) and of the global temporal structure. In the visual modality, some research suggests that an explicit instruction facilitates learning of ordinal structures (Curran, 1997; Jiménez, Méndez, & Cleeremans, 1996). Conversely, other research suggests that an explicit instruction impedes learning (Fletcher, et al., 2005; Howard & Howard Jr, 2001). Experiment 3 (reported in Chapter 3) investigates whether an explicit search for a temporal regularity facilitates or impedes learning. Thus, participants are given an explicit instruction to learn the rhythm in the SRTT.
Chapter 3

Explicit Learning of Inter-group Intervals (IGIs) in Auditory Temporal Structures
3. Explicit Learning of Inter-group Intervals (IGIs) in Auditory Temporal Structures

3.1. Introduction

Learning a temporal structure via exposure to complex sequences of auditory and visual events allows the perceiver to predict the timing of the onset of upcoming events. These acquired temporal expectations improve perception of the event and allow for enhanced preparation (Bolger, Trost, & Schön, 2013; Brandon, et al., 2012; Escoffier, Sheng, & Schirmer, 2010; Jones, Boltz, & Kidd, 1982; Tillmann, et al., 2011). Learning of temporal structure can occur incidentally, outside of awareness, and without an intention to learn; that is, it can occur implicitly (Cleeremans, et al., 1998; Perruchet, 2008; Shanks, 2005). The current experiment is an adaptation of a previous study that demonstrated implicit learning (IL) of temporal structures (Experiment 2 reported in Chapter 2 of this thesis). We investigate the effects of giving participants an explicit instruction to learn the temporal structures and also examine the influence of meter (i.e. perception of cycling strong and weak beats) and temporal complexity on learning.

3.1.1. Implicit Learning of Temporal Structure

Using an auditory serial reaction time task (SRTT), implicit learning (IL) of complex auditory temporal structures has received some recent support (Brandon, et al., 2012; Salidis, 2001; Schultz, et al., 2013; Tillmann, et al., 2011). In these studies, the temporal structures, or rhythms, are delineated by a repeating series of inter-onset intervals (IOIs) or response-stimulus intervals (RSIs) between auditory events (e.g.
musical tones, spoken syllables). The identity of the events themselves either remains constant (Salidis, 2001) or the order with which the events are presented is pseudo-random (Brandon, et al., 2012; Tillmann, et al., 2011). Consequently, the ordinal presentation (i.e. order of events presented in the sequence) is non-learnable. In these tasks, participants detect or identify the auditory events and the rationale is that as the temporal structures are learned via exposure to the sequences, RT to the auditory events becomes faster (i.e. acquired temporal expectation). If temporal expectations are violated with the introduction of a new temporal structure, RT slows. In other words, expectations of when an event will occur facilitate responses to that event (Barnes & Jones, 2000; Large & Jones, 1999; Large & Kolen, 1994; Penel & Jones, 2005; Tillmann & Lebrun-Guillaud, 2006).

In two previous experiments (see Chapter 2), IL of a particular feature of temporal structure was examined: the duration of the IOIs between groups of syllables, or inter-group intervals (IGIs). The aim of these experiments was to determine if IGIs could be implicitly learned in weakly metrical structures. Meter is a hierarchical structure that gives rise to a perception of regular patterns of strong and weak beats embedded within larger-scale patterns of strong and weak beats (Lerdahl & Jackendoff, 1983). When events align with beats at multiple levels in the hierarchy, the more readily the meter is abstracted and perceived as strong (Jones, 1987; Lerdahl & Jackendoff, 1983; Palmer & Krumhansl, 1990). A strong meter is more likely to activate a temporal grid that aids in the prediction of IGIs (Hébert & Cuddy, 2002). Weak meters have been shown, using explicit discrimination tasks, to impede encoding of IGIs. For instance, when two temporal structures with identical grouping organisations (see Figure 3.1 for a description of event grouping) are weakly, compared to strongly metrical, listeners are worse at discriminating the structures
when there are temporal violations to the IGIs (Handel, 1998). Therefore, the two experiments reported in Chapter 2 sought to examine listeners’ sensitivity to IGIs in weakly metrical structures but in the context of an implicit learning paradigm (i.e. an auditory SRTT), rather than in the context of an explicit discrimination task.

Participants identified pseudo-randomly presented syllables (Pa, Ta, Ka) in sequences with the repeating temporal structures. Participants were not informed of the presence of a temporal structure, but rather were advised that they were performing a syllable identification task, and they were to respond to the syllables as quickly and accurately as possible. After exposure to five blocks of a repeating temporal structure, a new temporal structure was introduced at a test block. Exposure and test sequences had identical grouping structures, but short and long IGIs were directly transposed across the two sequences: a short IGI and a long IGI in the exposure sequence became a long IGI and a short IGI, respectively, in the test sequence (see Figure 3.1 and Method section for more details). In a counterbalanced design, half the participants were exposed to one temporal structure (Pattern 1) and tested with the other (Pattern 2), while the presentation was reversed for the remaining participants (i.e. exposed to Pattern 2 and tested with Pattern 1). Although the two temporal structures (Pattern 1 and Pattern 2) were both weakly metrical, Pattern 2 was slightly less metrical and more complex than Pattern 1⁹.

⁹ See Method section and Appendix A for details on the applied measures of metrical strength.
Figure 3.1. Temporal structures used in Experiment 3 (Pattern 1 and Pattern 2): “X” represents a syllable, digits indicate the serial positions of the syllables, bold font represents Post-IGI positions, lower-case font represents controlled within-group positions (see text). Syllable groups are enclosed in boxes. Horizontal arrows represent short (→) and long (→→) IGIs (inter-group intervals), and vertical lines represent the hypothesised metrical structure (the longer the line the stronger the perceived beat).

In the first of the reported experiments (Experiment 1 in Chapter 2), RT to syllables that followed the IGIs (post-IGI positions) decreased over exposure and increased at the introduction of the test sequence but only in the condition that presented Pattern 1 during exposure and Pattern 2 at test. In an additional analysis it was also found that serial positions that maintained their location within the temporal structure across exposure and test rhythms (i.e. controlled within-group positions) also showed the expected effect of learning (see positions 2, 10 and 11 in Figure 3.1).
The temporal violation to the IGIs at the test block not only disrupted responses to the immediately following syllable but also other syllables within the sequence, indicating the presence of global temporal structure learning. Furthermore, post-tests revealed that learning was implicit, with participants not showing explicit knowledge of the temporal structures to which they were exposed.

The RT results in the Pattern 1 exposure condition were not elicited in the condition that presented Pattern 2 over exposure and Pattern 1 at test. A possible reason for this lack of effect was the slightly weaker meter and greater complexity of Pattern 2. Hence, in a second experiment, an isochronous woodblock pulse was added to the syllable sequences to strengthen the meter of the temporal structures. Learning in the condition presenting Pattern 1 over exposure and Pattern 2 at test was replicated and in the condition presenting Pattern 2 over exposure, some evidence of learning emerged with RT increasing to the controlled within-group positions at the test block. Finally, post-tests revealed that participants had acquired some explicit knowledge of the temporal structures. While there was no statistical difference across the two pattern conditions in familiarity ratings to exposure and test sequences, participants were more confident of their ratings in the Pattern 1 exposure condition. However, further analyses revealed that explicit knowledge was not necessary to elicit learning.

From the results of these experiments, two hypotheses can be drawn. Firstly, it may be that metrical strength and temporal complexity modulate IL, with learning reduced in weaker and more complex structures (i.e. Pattern 2). It may also be that awareness interacts with temporal complexity, with knowledge of the temporal structure facilitating learning. Issues of stimulus complexity and its influence on both implicit and explicit modes of learning have not yet been addressed in the auditory
and temporal domains. However, it has been addressed in the visual domain and ordinal domains.

3.1.2. Implicit Learning of Ordinal Structures in the Visual Modality

In the visual modality, when investigating IL of ordinal structures (i.e. a repeating order of events), participants indicate the spatial location of a visual stimulus presented in one of four locations on a screen. Participants are not informed that the events in the sequence are presented according a repeating pattern (e.g. defined by a statistical regularity) but are instead informed that the task measures perceptual-motor learning (e.g. A. Cohen, et al., 1990; Destrebecqz & Cleeremans, 2001; Nissen & Bullemer, 1987). Typically, reaction time (RT) to events decreases with exposure to the sequences and increases when a random sequence or a sequence with a new regularity is presented.

These tasks can also be performed with an explicit instruction to learn the regularities in the sequences (e.g. Destrebecqz, et al., 2005; Howard & Howard Jr, 2001; Jiménez, Vaquero, & Lupiáñez, 2006; Song, Howard Jr, & Howard, 2007; Stefaniak, Willems, Adam, & Meulemans, 2008; Willingham & Goedert-Eschmann, 1999). A conscious search for the regularities is undertaken and consequently, the hypotheses that emerge during exposure are tested and updated as the task progresses. The effects of giving implicit and explicit instructions can be compared and used as a measure of the relative power of both modes of learning (i.e. degree of learning), and to determine if implicit learning persists independently of an explicit search for regularities.
3.1.3. Explicit Instructions Facilitate or Impede Learning: The Role of Stimulus Complexity in Ordinal Structures

From the research comparing explicit and implicit learning strategies, two diverging bodies of literature emerge. The first indicates a performance advantage for explicit over the implicit learning. For instance, participants are faster at identifying the location of visual stimuli presented in repeating sequences when given an explicit, compared to an implicit instruction. There is a steeper RT slope over exposure blocks (Curran, 1997) and responses can also be more accurate under explicit, compared to implicit learning conditions (Jiménez, et al., 1996). Similar results have been yielded in an auditory adaptation of the SRTT that required participants to identify the pitch of tones presented in a repeating sequence (N.B. with a constant response-to-signal interval of 1000 ms). When instructed to detect the repeating pitch order (vs. no instruction regarding regularities in pitch order), RT was faster to identify the pitch of the tones (Buchner, et al., 1997). These studies suggest that explicit instructions facilitate performance.

However, there are circumstances under which explicit instructions impede performance. For instance, Rüsseler & Rösler (2000) found that during the first part of the exposure phase explicit learners were slower than implicit learners at identifying letters presented in a repeating sequence. After a certain amount of exposure, explicit learners then demonstrated a performance advantage over implicit learners. The authors suggested that perhaps early in the exposure phase, explicit learners were attempting to identify the regularities in the sequence, creating an analogue of a dual task. In this conceptualization of a dual task, the primary task was the letter identification and the second task was the search for regularity. The
explanation of the results was that the cognitive load induced by the dual task analogue impeded learning early in the exposure phase.

The search for regularities is a process of hypothesis-testing and this process may or may not be successful. Using an artificial grammar task, an alternative to the SRTT as a measure of IL, Reber (1976) reported that explicit learners were less successful than implicit learners at extracting the underlying regularities present in the stimulus (i.e. visually presented letter strings). In fact, explicit learners had engaged in ineffective search processes and often reported erroneous regularities. Hence, Reber argued that implicit learning is more effective than explicit learning in complex stimulus situations where the search for regularities is demanding and often unsuccessful.

Support for the argument has also been observed using the SRTT method. Research investigating the role of cognitive capacity on learning has indicated that the complexity of the sequences presented in an SRTT modulates the relative effectiveness of an explicit strategy. Regardless of an implicit or explicit instruction, learning of a simple visual-spatial sequence was elicited. However, when the sequence was more complex, contained regularly occurring and predictable locations alternating with random locations, learning was inhibited with an explicit instruction (Fletcher, et al., 2005; Song, et al., 2007). The active search for regularities in the complex sequence interfered with the learning processes normally elicited in the SRTT when an implicit instruction is given.

It is possible that the hypothesis-testing strategy elicited with an explicit instruction drains cognitive resources, impeding learning. Research with older adults has suggested that this is the case. Howard and Howard Jr (2001) examined learning of the regularities in a complex (i.e. alternating predictable and random locations)
visual-spatial sequence with young and older adult populations. As older adults tend to have reduced working-memory capacity and slower cognitive speed compared to younger adults, it was hypothesised that learning would be less evident for the older group, particularly when an explicit instruction was given. This was found to be the case. Older, but not younger adults, demonstrated reduced learning effects when an explicit instruction to learn the regularities was given, compared to no such instruction. The authors concluded that reduced cognitive capacity interferes with learning of complex sequential structures when an explicit instruction is given. Specifically, the cognitive resources required for the execution of the hypothesis-testing strategy impedes an associative system that detects statistical regularities in a sequence. Thus, implicit learning may be an optimal strategy in circumstances where extracting complex relationships between sequential events is required (Berry & Broadbent, 1988).

However, it should be noted that implicit and explicit learning can occur in parallel, with implicit learning unperturbed by the attentional load induced by a dual task (Curran & Keele, 1993; Jiménez & Méndez, 1999; Stefaniak, et al., 2008; Willingham & Goedert-Eschmann, 1999; Willingham, Salidis, & Gabrieli, 2002). Willingham & Goedert-Eschmann (1999) argue that concurrent implicit learning is reliant on the presence of a motor-response. That is, IL is essentially a form of motor-skills learning and arises from the pattern of motor responses. This has relevance in the current experiment, as participants are required to identify each auditory event with a key press. Consequently, participants may implicitly learn the temporal structure via the timing of their motor responses to syllables, irrespective of whether they learn the temporal structure via explicit processes. Therefore, it is possible that
learning will be evident even when participants are unable to extract the temporal structures explicitly.

3.1.4. Aims of Experiment 3

In Experiment 3, we address the issue of stimulus complexity and explicit learning but in the auditory and temporal domains. “Complexity” in a temporal context is not analogous to complexity in the visual-spatial sequences previously used to investigate interactions between implicit/explicit learning and cognitive overload. Further, it may be that transience of auditory sequences induces an additional load above that of visual sequences. However, it is argued that this experiment is a first step in addressing the issue of temporal complexity and its effects on explicit learning and may help clarify the results reported in Chapter 2 of this thesis. Finally, by employing a post-test phase during which participants rate their familiarity with the temporal structures to which they are exposed during the SRTT, we are able to determine the presence of implicit learning in the absence of explicit knowledge. In this case, participants would exhibit the typical RT learning profile in the SRTT but not rating the exposure sequence as more familiar than a novel sequence.

The two weakly metrical temporal structures used in the experiments reported in Chapter 2, will be employed (Pattern 1 and Pattern 2 presented with the isochronous pulse) but participants will be given an explicit instruction to identify and learn the repeating structure or rhythm. We propose to use Pattern 1 and the slightly less metrical and more complex Pattern 2 as a manipulation of complexity in the current experiment. The purpose is not to directly manipulate the learning strategy (i.e. implicit vs. explicit) but to manipulate rhythmic complexity in the context of an explicit learning task. In addition, a comparison can be made between the results of
this current experiment giving an explicit instruction to learn the temporal regularities and the previous experiment (Experiment 2 reported in Chapter 2) investigating IL of the same temporal structures.

3.1.5. Design

The between-subjects variable is temporal complexity (Pattern 1, Pattern 2) and the within-subjects variable is Block (exposure, test). The dependent variable is correct RT to identify the syllables and the post-IGI and controlled within-group syllable categories will be analysed separately.

3.1.6. Hypotheses

There are two competing hypotheses that arise from the literature. Firstly, if an explicit instruction enhances learning, then in both the Pattern 1 (less complex) and Pattern 2 (more complex) exposure conditions, it is expected that RT will decrease over exposure and increase at the introduction of the test sequence to post-IGI and controlled within-group positions. Secondly, if the explicit search for the a temporal structure overloads the cognitive system and inhibits learning of more complex sequences, then learning will be evident in the Pattern 1 (less complex) exposure condition but not in the Pattern 2 (more complex) exposure condition. Post-tests assessing the degree of explicit knowledge of the temporal structures will be administered and it is hypothesised that participants will rate the temporal structures to which they were exposed as more familiar than novel temporal structures.
3.2. Experiment 3: Explicit Learning of IGIs in Weakly Metrical Temporal Structures

Presented with an Accented Pulse

3.2.1. Method

3.2.1.1. Participants

Fifty participants from the University of Western Sydney took part in the experiment in exchange for course credit. All participants were naive to the purpose of the task. The 38 female and 12 male participants had a mean age of 22.6 years (SD = 7.1 years, range = 17 – 46 years). All participants had self-reported normal hearing. Participants were randomly assigned to either the Pattern 1 (N = 24) or Pattern 2 (N = 26) exposure condition. The two participant groups were equivalent in terms of years of musical training. Participants in the Pattern 1 condition had a mean of 1.42 years of training (SD = 2.04 years, median = 0) and participants in the Pattern 2 condition had a mean of 0.94 years of training (SD = 1.65 years, median = 0). These levels of musical training were not statistically different between the two conditions (p = .73).

3.2.1.2. Materials

3.2.1.2.1. SRTT. The temporal structures used in the current experiment were identical to those used in the previous experiment reported in Chapter 2. Consequently, each sequence was a chaining of 15 IOIs, which was repeated nine times in a block. The shortest IOI was 600 ms and the longer IOIs were multiples of this base temporal unit (i.e. 1200 ms and 1800 ms). The base temporal unit (600 ms) has been shown to be a “preferred tempo” with spontaneous finger tapping and clapping often being performed around this rate (Fraisse, 1982; van Noorden &
Moelants, 1999). The IOI chaining of Pattern 1 was 600-1800-600-600-600-1800-1200-600-600-600-600-1800, and the IOI chaining of Pattern 2 was 600-1200-600-600-1200-1800-600-1800-600-1800-600-600-600-1200 (see Figure 3.1). The longer IOIs, that is IGIs (1200 ms and 1800 ms), formed boundaries between groups of syllables and isolated syllables. The two patterns were identical in terms of grouping structure: the number of groups, number of events within groups, and the order of groups were identical in the two patterns. For instance, in both patterns, a group of two events was followed by a group of four events, followed by an isolated syllable, and so on (2-4-1-1-3-4). The difference between Pattern 1 and Pattern 2 was the duration of the IOIs between the groups and the isolated events (i.e. IGIs). IOIs of 1200 ms in Pattern 1 were substituted for IOIs of 1800 ms in Pattern 2. Likewise, IOIs of 1800 ms in Pattern 1 were substituted for IOIs of 1200 ms in Pattern 2.

Events in the sequences were three syllables, “Pa”, “Ta”, and “Ka”, spoken with a male voice generated using a text-to-speech synthesizer, Mbrola. The syllables had a fundamental frequency of 120 Hz, a duration of 218 ms and were normalized for intensity.

Each block consisted of a sequence of 136 syllables presented in a pseudo-random order. As the first syllable in each block did not follow an IGI, it was not included in the analyses. Instead an additional syllable was added at the end of each block to create the final IGI. The following constraints were applied from the second to the final syllable in each sequence. There were 45 presentations of each syllable, with no adjacent repetitions and with second- and third-order repetitions roughly equated across blocks. Second-order repetitions are instances when, for example, two “Pa”s are interposed with one of the other syllables (“Pa Ta Pa”), and third-order
repetitions are instances when, for example, two “Pa”s are interposed with two of the other syllables (“Pa Ta Ka Pa”). Finally, as the temporal structure of the presentation of syllables was defined by a repeating basic sequence of 15 IOIs, syllables were distributed equally across all serial positions in each sequence. To ensure that any effects could not be attributed to syllable order, half the participants were presented with a second syllable order that was a reversal of the order presented to the other half of participants.

For each block, AIFF files of each syllable sequence, with the defined repeating IOI chaining were created in Matlab.

An isochronous woodblock pulse with IOIs of 600 ms (i.e. a woodblock sound presented every 600 ms) was played concurrently with the syllable sequences. The 218 ms woodblock sound was sourced from Logic Pro 8. An amplitude-accent structure was added to the pulse so that woodblock sounds aligning with strong beats were 3dB louder than sounds aligning with moderate beats, and 6dB louder than sounds aligning with weak beats. This resulted in an alternation of a strong accent, no accent, moderate accent, no accent, followed again by a strong accent, and so on. Hence, a woodblock sound could be heard with each syllable and during each IGI.

The onset of the woodblock sound was synchronised with the voicing onset of each syllable. The syllable sequences were presented binaurally, and the woodblock pulse was presented to the left channel only. Measured at the headphones using a sound pressure level meter, the syllables were approximately 5dBA louder than the strong accents of the woodblock pulse.

Each sequence had a duration of 2 mins and 10 s. Two practice sequences with two repetitions of the temporal structure of Pattern 1 and Pattern 2 were also created.
The experiment was run in Psyscope (J. Cohen, et al., 1993) and the sequences were presented over Sennheiser HD 25 closed headphones.

A measure of metrical strength (C-score) was applied (Povel & Essens, 1985)\(^\text{10}\) to ensure that both patterns were weakly metrical. The C-scores for Pattern 1 and Pattern 2 were 15 and 19, respectively, indicating that while both patterns were weakly metrical, Pattern 2 had a slightly weaker meter (a score of zero indicates maximal metrical strength). This difference was due to Pattern 2 having one less event on a beat, compared to Pattern 1. While it would have been optimal to have identical C-scores for both patterns, the choice of patterns was limited by the following constraints: (a) Both patterns needed to have identical grouping structures, and (b) there needed to be an even number of IGIs (3 long and 3 short) directly transposed across the two patterns (i.e. a long IGI in Pattern 1 became a short IGI in Pattern 2, and vice versa). Nonetheless, both patterns were weakly metrical and as closely matched in their degree of metrical strength as possible.

3.2.1.2.2. Post-tests. The purpose of the post-test phase was to measure participants’ explicit knowledge of the temporal structures to which they were exposed in the SRTT. Post-test stimuli were short syllable sequences presented with the temporal structure of Pattern 1 and Pattern 2. Each post-test sequence was one cycle of the chaining of 15 IOIs. As the temporal structure was repeated in the SRTT, it was possible that participants may have segmented the sequence using any of the groups or isolated syllables as a starting point. Therefore, six versions of each pattern were created, each starting at a different group or isolated syllable.

In addition to the post-test sequences based on the temporal structure of Pattern 1 and Pattern 2, two sets of six sequences were created that had novel

\(^{10}\) See Appendix A for a description of the C-score calculation.
grouping structures while still using the same number of groups and group sizes. Novel 1 and Novel 2 had grouping structures of 1-2-1-4-4-3 and 1-4-4-3-1-2, respectively. The first novel set of sequences (Novel 1) differed from Pattern 1, and the second novel set (Novel 2) differed from Pattern 2 in terms of the group-to-IGI chaining. The six versions of the two novel post-test patterns began on different groups or isolated syllables. Both novel patterns were weakly metrical. The Novel 1 and Novel 2 patterns respectively were “X..XX.X..XXXX.XXXX.XXX..” and “X.XXXX..XXXX..XXX.X.XX..” (X” represents a syllable and a full stop(s) represents an IGI).

The syllables used in the post-test sequences (“Pa”, “Ta”, “Ka”), and the method for creating the AIFF files was as per the SRTT. In addition, the post-test sequences were accompanied with an accented isochronous woodblock pulse. The accents of the woodblock pulse were aligned with the temporal structure of the syllable sequences as per the SRTT in the main phase of the experiment. The post-test task was run in Psyscope (J. Cohen, et al., 1993).

3.2.1.3. Procedure

3.2.1.3.1. SRTT. Participants were advised that the syllables were to be presented in a random order and that the syllable sequences followed a repeating timing pattern or rhythm. They were informed that their task was to learn the timing pattern so that they could anticipate when the next syllable will occur. The experimenter described the syllable sequences as having a rhythm with regular pauses between groups of syllables. A short verbal demonstration of a rhythmic presentation of syllables was given and participants were asked if they understood what was meant by a timing pattern or rhythm before they commenced the task. Participants listened to the sequences of syllables and identified each syllable as quickly and accurately as
possible. They made their responses using keys 1, 2, and 3 on the numeric keypad of a computer keyboard. Labels identifying the appropriate response key were placed on the keys above. Using the right hand, participants kept their index, middle, and ring fingers on the keys at all times. Participants were instructed to not correct themselves if they made a mistake or if they missed any syllables. To minimise any possible systematic motor-based effects, three key-to-syllable mappings were counterbalanced across participants.

A practice block with the temporal structure of the exposure sequence was completed and participants were reminded of the instructions before beginning the experimental blocks. The participants in the Pattern 1 condition were presented with five exposure blocks of Pattern 1. This was followed by a test block presentation of Pattern 2 (Block 6) and a final block of Pattern 1 (Block 7). Conversely, the participants in the Pattern 2 condition were presented five exposure blocks of Pattern 2, followed by a test block presentation of Pattern 1 and a final block of Pattern 2. A short break with a minimum duration of 30 s was provided between each block.

3.2.1.3.2. Post-tests. After completing the SRTT, participants filled in a questionnaire asking them to describe any temporal regularity they noticed in the sequences. In the post-test task, participants responded to the syllables as they had in the SRTT. This was done in order to ensure that the testing conditions were as equivalent as possible across the SRTT and post-test task, thus giving participants the best opportunity to extract any explicit knowledge. Again, participants were instructed to identify each syllable as quickly and accurately as possible and to not correct themselves if they made a mistake or missed syllables. Participants exposed to Pattern 1 in the SRTT responded to the six post-test sequences from the Pattern 1, Pattern 2, and Novel 1 sets. Participants exposed to Pattern 2 in the SRTT responded
to the six post-test sequences from the Pattern 1, Pattern 2, and Novel 2 sets. The sequences were presented in random order.

After responding to each sequence, participants were given two rating tasks. They were asked to think back to the blocks in the SRTT of the exposure phase of the experiment and rated their familiarity with the timing pattern of the post-test sequence just heard using a scale: 1 = very unfamiliar, 2 = unfamiliar, 3 = somewhat unfamiliar, 4 = somewhat familiar, 5 = familiar, 6 = very familiar. They were then asked to indicate the certainty with which they made their familiarity rating: 1 = complete guess, 2 = very uncertain, 3 = somewhat uncertain, 4 = somewhat certain, 5 = very certain, 6 = completely certain (adapted from Destrebecqz & Cleeremans, 2001). Ratings were made using the numeric keys across the top of the computer keyboard. After making their ratings, participants pressed a key to continue with the next post-test sequence. Participants then completed a demographic questionnaire and were debriefed. The experiment took 50 minutes.

3.2.2. Results

3.2.2.1. SRTT

Correct responses were included in the analysis if they occurred 250 – 900 ms after the onset of the syllable. RTs less than 250 ms were assigned to the previous syllable if it was missed and, if multiple responses were made within the 250 – 900 ms window, only the first response was kept. The upper limit (900 ms) allowed us to retain any longer RTs made to the syllables immediately preceding an IGI. Data from two participants were excluded as they failed to follow instructions (i.e. pressed the wrong response keys) and data from an additional participant was excluded due to
below chance performance. This resulted in data sets of $N = 23$ and $N = 24$ in the Pattern 1 and Pattern 2 conditions, respectively. Mean accuracy to syllables across all serial positions was significantly above chance (33.33%) for the Pattern 1 condition (64%; $SD = 12\%$), $t(22) = 12.45, p = .00$, and Pattern 2 condition (60%; $SD = 14\%$), $t(23) = 13.84, p = .00$. For Post-IGI syllables, accuracy was 73% and 74% in the Pattern 1 and Pattern 2 conditions, respectively (see Appendix C for analyses of accuracy and correlations between accuracy and RT. These correlations reveal that participants did not adopt a speed/accuracy trade-off strategy).

3.2.2.1.1. Mean RT to post-IGI positions over exposure blocks\textsuperscript{11}. RT to post-IGI syllables was averaged for each block. Testing the hypothesis that RT would decrease over the first five exposure blocks, a 5 x 2 ANOVA with Block (Blocks 1 to 5) as a within-subjects factor and Pattern condition (Pattern 1, Pattern 2) as a between-subjects factor was conducted (Figure 3.2a). There was no main effect of Block, $F(4, 180) = 2.09, p = .09$, partial $\eta^2 = .04$, although there was a tendency for RT to decrease from Blocks 2 - 5. There was also no main effect of Pattern condition, $F(1, 45) = .31, p = .58$, partial $\eta^2 = .01$, and no interaction, $F(4, 180) = .44, p = .77$, partial $\eta^2 = .01$.

3.2.2.1.2. Mean RT to post-IGI positions at the test block. To investigate the effect of introducing changes to the IGIs at the test block, a 2 x 2 ANOVA with Block as a within-subjects factor (mean of Blocks 5 and 7, Block 6) and Pattern condition (Pattern 1, Pattern 2) as a between-subjects factor was conducted. This revealed a significant effect of Block, $F(1, 45) = 18.13, p = .00$, partial $\eta^2 = .29$. There was no

\textsuperscript{11} In the experiments reported in Chapter 2 of this thesis, additional analyses of specific temporal violations to post-IGI positions (presented at the test block early or late in the global temporal structure) were conducted. These same analyses have been conducted in the current experiment and the results are reported in Appendix C.
effect of Pattern condition, $F(1, 45) = .60, p = .44$, partial $\eta^2 = .01$, but there was a significant Block by Pattern condition interaction, $F(1, 45) = 12.16, p = .00$, partial $\eta^2 = .21$. A contrast analysis revealed an effect of Block in the Pattern 1 condition, with RT slowing significantly at the test block compared to the mean of the two adjacent exposure blocks, $F(1, 22) = 20.19, p = .00$, partial $\eta^2 = .48$. There was no increase in RT at the test block in the Pattern 2 condition, $F(1, 23) = .54, p = .47$, partial $\eta^2 = .02$.

**Figure 3.2.** Correct RT to a) post-IGI syllables and, b) controlled within-group syllable positions 2, 10, and 11, presented as a function of Block and Pattern condition. Error bars show standard error of the mean.

Additional analyses were conducted to ensure that the RT increase at the test block in the Pattern 1 condition was not driven only by the IGIs that were lengthened (1200 ms to 1800 ms), but by both types of IGI changes. Hence, we examined separately, RT to post-IGI positions that followed a 1200 ms to 1800 ms change and an 1800 ms to 1200 ms change at the test block (Figure 3.3). The results showed a significant increase at the test block (compared to the mean of the adjacent exposure blocks) for post-IGI syllables that followed either an IGI increase (1200 ms to 1800 ms)
ms), $F(1, 22) = 5.43$, $p = .03$, partial $\eta^2 = .20$, or an IGI decrease (1800 ms to 1200 ms), $F(1, 22) = 20.18$, $p = .00$, partial $\eta^2 = .48$.

Figure 3.3. Pattern 1 condition: Black bars show mean correct RT (ms) to positions following 1200 ms and 1800 ms IGIs during exposure Blocks 5 and 7. White bars show correct RT (ms) to the same positions but following the IGI change at the test block, to 1800 ms and 1200 ms, respectively. Error bars show standard error of the mean.

3.2.2.1.3. Mean RT to controlled within-group positions over exposure blocks.
Serial positions within groups that maintain their global position and metric location across exposure and test were analysed. RT to positions 2, 10, and 11 were collapsed to give a mean for each block (Figure 3.2b). First, to examine learning over exposure blocks, a 5 x 2 ANOVA with Block (Blocks 1 to 5) as a within-subjects factor and Pattern condition (Pattern 1, Pattern 2) as a between-subjects factor was conducted.
There was a main effect of block, $F(4, 180) = 12.69, p = .00$, partial $\eta^2 = .22$, but no effect of Pattern condition, $F(1, 45) = .41, p = .53$, partial $\eta^2 = .01$, and no interaction, $F(4, 180) = 1.33, p = .26$, partial $\eta^2 = .03$. RT at Block 5 was significantly faster than RT at Block 1, $F(1, 46) = 22.98, p = .00$, partial $\eta^2 = .33$.

3.2.2.1.4. Mean RT to controlled within-group positions at the test block. To examine the effect of the introduction of the test block on the three within-group positions, RT at the test block (Block 6) was compared to the mean of the two adjacent blocks (Blocks 5 and 7). A 2 x 2 ANOVA with Block (mean of Blocks 5 and 7, Block 6) as a within-subjects factor and Pattern condition (Pattern 1, Pattern 2) as a between-subjects factor was conducted. RT at the test block (Block 6) was slower than at the adjacent exposure blocks (Blocks 5 and 7), $F(1, 45) = 7.10, p = .01$, partial $\eta^2 = .14$. There was no effect of Pattern condition, $F(1, 45) = 2.34, p = .13$, partial $\eta^2 = .05$, and but there was a significant interaction, $F(1, 45) = 6.70, p = .01$, partial $\eta^2 = .13$. The increase was significant in the Pattern 1 condition, $F(1, 22) = 14.23, p = .00$, partial $\eta^2 = .39$, but not in the Pattern 2 condition, $F(1, 23) = .00, p = .96$, partial $\eta^2 = .00$ (Figure 3.2b).

3.2.2.2. Post-tests

An open-ended questionnaire asked for a description of any regularity in the timing of the presentation of the syllables. Two participants incorrectly reported that the presentation of the syllables become faster over a sequence and two indicated that although they noticed a temporal structure, they were not able to recall it. Forty-three of the 47 participants reported that there were pauses between some syllables and 40 of these participants attempted to describe the temporal structure. Twenty-seven participants accurately described at least two group-to-group chainings, e.g.
XXX.XXXX, with the most common description (9 of the 27) being X.X.XXX. No participant accurately described the entire temporal structure.

To further test for the presence of awareness of the temporal structure, familiarity ratings to the exposure sequence, test sequence, and novel sequence were compared. Ratings (1 = very unfamiliar through to 6 = very familiar) were collapsed across the 6 presentations of each sequence to obtain a mean rating (Table 3.1), and analysed with a 3 x 2 ANOVA with Sequence as a within-subjects factor (Exposure, Test, Novel) and Pattern condition (Pattern 1, Pattern 2) as a between-subjects factor. There was a main effect of Sequence, $F(2, 90) = 7.49, p = .00$, partial $\eta^2 = .14$, but not of Pattern condition, $F(1, 45) = 1.00, p = .32$, partial $\eta^2 = .02$. There was no significant Sequence by Pattern condition interaction, $F(2, 90) = 0.71, p = .49$, partial $\eta^2 = .02$. Participants rated the exposure sequences as more familiar than the test sequences and novel sequences, $ps = .00$. There was no significant difference in ratings between the test and novel sequences, $p = .67$.

Table 3.1

*Post-test Familiarity (1 = very unfamiliar, through to 6 = very familiar) and Certainty (1 = complete guess, through to 6 = completely certain) Mean Ratings and Standard Deviations presented as a function of Sequence Type and Exposure Condition*

<table>
<thead>
<tr>
<th>Pattern</th>
<th>Familiarity</th>
<th></th>
<th>Certainty</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure</td>
<td>Test</td>
<td>Novel</td>
<td>Exposure</td>
<td>Test</td>
</tr>
<tr>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>1</td>
<td>4.25</td>
<td>0.66</td>
<td>3.77</td>
<td>0.63</td>
</tr>
<tr>
<td>2</td>
<td>3.93</td>
<td>0.61</td>
<td>3.65</td>
<td>0.72</td>
</tr>
</tbody>
</table>
To further examine awareness of the temporal structures presented in the SRTT, correlations between post-test familiarity and certainty ratings were calculated. The rationale is that if knowledge of the temporal structure is explicit, then a positive correlation between familiarity and certainty ratings to the exposure sequences is expected (Scott & Dienes, 2008). In other words, explicit knowledge is evident if participants rate the exposure sequences as familiar and they are certain of their decision. In addition, a negative correlation between familiarity and certainty ratings to the Novel sequences also indicates explicit knowledge. In this case, participants with explicit knowledge rate the Novel sequences as unfamiliar and are certain of their decision.

To calculate the correlations between Familiarity and Certainty, each participant’s mean familiarity rating (i.e. mean rating of all patterns) was subtracted from their ratings to each exposure and novel sequence, yielding a difference score. For each participant, a mean difference score was calculated for each sequence set (Exposure, Novel) and these were converted to z-scores (z-familiarity). Correlations between z-familiarity scores and certainty ratings to the exposure and novel sequences were calculated. These correlations were computed separately for each condition (Pattern 1, Pattern 2).

There were no significant correlation between z-familiarity and certainty for the exposure sequences. Unexpectedly, there was a significant positive correlation between z-familiarity and certainty for the novel sequences in the Pattern 1 condition (Table 3.2). This positive correlation indicated that the higher participants’ ratings of familiarity with the novel sequences, the more certain they were in their rating.
While the post-test ratings alone indicated the presence of some awareness, the correlations between z-familiarity scores and certainty ratings suggested that this knowledge was not held with confidence. To examine the role of explicit knowledge of the temporal structures on the learning effect, the data were re-analysed with “Awareness” as a between-subjects factor with two levels (Aware, Unaware), and RT as the dependent variable. Participants in the “Aware” condition met two criteria. Firstly, they had an exposure sequence z-familiarity scores greater than zero. That is, their mean rating to the exposure sequences was greater than their overall mean familiarity rating. Secondly, their certainty ratings to the exposure sequences were equal to, or greater than four (4 = Somewhat certain, 5 = Very certain, 6 = Completely certain). Eight participants in each condition met both these criteria and were considered to be “aware” of the temporal structure of their exposure sequence.

As with the full data set, ANOVAs were conducted on post-IGI and controlled within-group positions across exposure blocks (Blocks 1 to 5), and assessing the change at the test block (Mean over Block 5 and 7 vs. Block 6). Pattern condition

**Table 3.2.**

*Correlations between Z-familiarity and Certainty Ratings to Exposure and Novel Patterns in each Condition (Pattern 1, Pattern 2)*

<table>
<thead>
<tr>
<th>Condition</th>
<th>Pattern</th>
<th>r</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pattern 1 (N = 23)</td>
<td>Exposure</td>
<td>.20</td>
<td>.37</td>
</tr>
<tr>
<td></td>
<td>Novel</td>
<td>.74</td>
<td>.00</td>
</tr>
<tr>
<td>Pattern 2 (N = 24)</td>
<td>Exposure</td>
<td>.15</td>
<td>.48</td>
</tr>
<tr>
<td></td>
<td>Novel</td>
<td>.19</td>
<td>.37</td>
</tr>
</tbody>
</table>
(Pattern 1, Pattern 2) and Group (Aware, Unaware) were between-subjects factors. These ANOVAs revealed no effect of Group. The same pattern of results reported with the full sample was evident for both the Aware (Pattern 1 condition: \(N = 8\); Pattern 2 condition: \(N = 8\)) and Unaware group (Pattern 1 condition: \(N = 15\); Pattern 2 condition: \(N = 16\)) (see Appendix C for the full results). Hence, the evidence of learning in the SRTT was not driven by explicit knowledge of the temporal structures of the exposure sequences.

3.2.3. Discussion

Two previous experiments (reported in Chapter 2 of this thesis) demonstrated IL of weakly metrical temporal structures - one temporal structure being slightly less metrical and therefore more complex than the other. For the temporal structure with the slightly stronger meter, this learning was evidenced by an RT increase to post-IGI and within-group positions when the temporal structure was violated at a test block. However, some evidence of learning of maintained within-group intervals in the less metrical structure emerged when meter was strengthened by the presence of an isochronous accented pulse. In the current experiment, the question under investigation was whether temporal complexity would modulate learning when an explicit instruction was given to learn the temporal structure of the syllable sequences (also in the presence of an accented pulse). It was expected that evidence of learning of controlled within-group positions in the more complex Pattern 2 condition, reported in Chapter 2 (Experiment 2), would be attenuated. In other words, we hypothesised that an explicit instruction would result in learning of the more metrical and less complex Pattern 1 but not of the relatively less metrical and more complex Pattern 2.
As hypothesised, we found evidence of learning of the slightly more metrical and less complex temporal structure at the test block. RT to post-IGI and within-group positions increased at the test block when the temporal structure was violated. However, there was no evidence of learning of the less metrical and more complex temporal structure. Therefore, giving an explicit instruction appeared to impede learning of the more complex structure. This is consistent with earlier research showing that, at least with visual-spatial sequences, learning is modulated by the complexity of the stimulus. That is, learning of the ordinal structure of complex sequences is inhibited when participants adopt a hypothesis-testing strategy in their search for regularities (Fletcher, et al., 2005; Howard & Howard Jr, 2001). According to Howard and Howard Jr (2001), searching for regularities in a complex sequence acts as an analogue to a dual-task, leading to cognitive overload and an inhibition of learning.

While temporal complexity in the current experiment is not a direct equivalent of complexity in the visual-spatial sequences used to assess explicit vs. implicit learning (Fletcher, et al., 2005; Howard & Howard Jr, 2001; Song, et al., 2007), we know from previous studies that metrical strength - a proxy of complexity - influences task performance. For instance, rhythms with strong meters are reproduced more accurately after fewer exposures compared to weakly metrical rhythms (Grahn & Brett, 2007; Patel, et al., 2005; Povel & Essens, 1985). In the current study, it is possible that the task of explicitly searching for temporal regularities in the more complex structure may have been more cognitive demanding than searching for regularities in the slightly less complex structure. The cognitive demands induced by the search in the more complex temporal structure may have limited the capacity to learn (i.e. indicated by the lack of RT increase at the test block).
As an alternative to the cognitive overload explanation, shifts of attention may have had a detrimental effect on learning the more complex temporal structure. Participants possibly used the woodblock pulse as a cue to the temporal regularity, or to identify a relationship between the pulse and the syllables sequences. This may have acted as a dual task analogue, overloading cognitive resources, or may have led participants to fail to attend to the syllable sequences, perhaps shifting their attention between the pulse and the syllable sequences. The issue of attention has been proposed previously as an explanation for the absence of learning in explicit conditions (Fletcher, et al., 2005). It is possible that directing attention away from the syllable sequences towards the pulse may have disrupted the establishment of correlations, or contingencies between adjacent temporal intervals. The suggestion that attention is required to process temporal regularity has been supported with neurological data. For instance, research using event-related brain potentials (ERPs) has shown that attention is required to exploit the benefit of temporal regularity (i.e. isochronous presentation) when processing a deviant tone (i.e. a change in the pitch of a tone) presented in a sequence of standard tones. No benefits of temporal regularity over temporal irregularity (i.e. random IOI presentation) are seen when attention is directed away from the auditory sequence (Schwartze, et al., 2011). Furthermore, using brain imaging data (Chapin, et al., 2010), brain regions associated with processing of meter (i.e. basal ganglia and supplementary motor areas) have been shown to be active only when attention was directed to a complex syncopated rhythm (i.e. having events frequently aligning with weak beats but often not aligning with strong beats), but not when attention was directed away from the rhythm. In the current experiment, although attending to the syllable sequences was necessary to
perform the task, participants may have at times shifted their attention to the pulse in an effort to integrate it with the slightly less metrical and more complex sequence.

As attention and cognitive load were not directly manipulated in this current study, further research is required to determine the nature of the interference that gave rise to an absence of learning in the Pattern 2 exposure condition. Nonetheless, in the auditory temporal domain, the results begin to address the question of whether implicit learning is obligatory, independent of cognitive load and attentional demand. In the visual-ordinal domain, the requirement that attention is directed to the stimulus containing the to-be-learned regularities is under debate (see Perruchet, 2008 for a review). For instance, some research suggests that attention is required for learning of complex, but not of simple sequences (A. Cohen, et al., 1990). Other research suggests that attention must be directed towards the stimulus in order for learning to occur irrespective of complexity (Jiménez & Méndez, 1999). Furthermore, it has been suggested that attention is not required for learning of simple associations between successive events but is required for learning of the serial position at which an event is presented at a particular spatial-location (Curran & Keele, 1993). Issues concerning the independence of implicit and explicit processes are also under debate (Perruchet, 2008; Stefaniak, et al., 2008; Willingham & Goedert-Eschmann, 1999; Willingham, et al., 2002). For example, implicit and explicit learning may occur in parallel, without an explicit strategy to learn or cognitive load impacting on IL (Willingham & Goedert-Eschmann, 1999; Willingham, et al., 2002). However, divided attention (Shanks & Channon, 2002) and increases in cognitive load have been shown to disrupt implicit learning, indicating that IL processes are not automatic or independent of explicit hypothesis-testing strategies (Fletcher, et al., 2005; Howard & Howard Jr, 2001). In the current study, the evidence suggests that while learning of
a more metrical and less complex temporal structure was not disrupted by an explicit instruction, learning of a less metrical and more complex structure was.

Post-tests revealed that despite the explicit instruction, the learning that occurred in the condition that presented the exposure sequence with the more metrical and less complex temporal structure was implicit. There were RT increases at the test block in this condition and participants demonstrated some familiarity with the temporal structure to which they were presented over exposure blocks. However, this awareness was not held with confidence and was not required for learning to occur. According to the methods of Scott and Dienes (2008) that measure awareness, it is proposed that participants in this condition had acquired unconscious judgment knowledge. That is, while they were able to accurately report familiarity with the temporal structure of the exposure sequence, they lacked confidence in their judgments. The lack of interaction between familiarity with the post-test sequences and Pattern condition suggests that a similar level of unconscious judgment knowledge was also present in the condition that did not show learning (i.e. presented the slightly less metrical and more complex structure). This indicates that awareness was independent of both learning and temporal structure complexity. However, learning was dependent on the complexity of the temporal structure.

Implicit learning occurred in parallel with an explicit instruction but only in the condition that presented the exposure sequence with the slightly more metrical and less complex temporal structure. Although we did not manipulate explicit and implicit learning conditions, it was observed that the explicit instruction abolished the evidence of learning of the more complex structure elicited in Experiment 2 (i.e. presenting the same stimuli but under implicit learning conditions. See Chapter 2). We did not statistically compare the results of the current experiment with
Experiment 2, as the task (implicit vs. explicit) was not a between-subjects factor in the original design of these experiments. However, it can be reported that RT to post-IGI positions at Block 5 (i.e. the last exposure block before the test block) was equivalent across the implicit learning (IL) and explicit learning (EL) experiments in the less complex Pattern 1 condition (IL = 534.71 ms, EL = 533.38 ms), but RT was slower in the EL experiment, compared to the IL experiment in the Pattern 2 condition (IL = 529.15 ms, EL = 543.61 ms). This further suggests that performance was hindered by the explicit instruction in the more complex Pattern 2 condition.

Howard and Howard Jr (2001) found that in the context of a visual-spatial SRTT, both sequence complexity and explicit instruction inhibited learning and our results are consistent with the proposition that IL occurs independently of the presence of an explicit learning strategy in relatively simple stimulus environments but is inhibited when stimulus complexity increases (Berry & Broadbent, 1988; Howard & Howard Jr, 2001).

However, further research is required to address a number of issues. Firstly, a clearer definition of temporal complexity is required. A number of measures of metrical strength and complexity have been proposed previously and may be useful for investigating the conditions under which an explicit instruction impedes learning (McAuley & Semple, 1999; Povel & Essens, 1985; Pressing, 1998; Shmulevich & Povel, 2000). For instance, complexity might be defined along a continuum of metrical strength with strongly metrical rhythms being less affected by an explicit instruction than weakly, or non-metrical rhythms. Secondly, the manipulation of cognitive load and attentional shift, independent of temporal complexity, may begin to reveal the mechanism underpinning inhibition of learning of temporal structure. Thirdly, the conditions under which clear explicit conscious knowledge arises from
exposure to temporal structures needs further investigation. In the current experiment, despite having an explicit instruction to learn the temporal structure, participants were not able to correctly identify the structures, nor were they confident in rating their familiarity with the temporal structure of their exposure sequence. When the instruction is to learn the temporal structure, the emergence of explicit knowledge may be more likely to occur when the temporal structure is strongly metrical. Finally, research into the relationship between explicit knowledge and learning as measured by the SRTT is required to deepen an understanding of the relative benefits of implicit and explicit approaches to learning temporal structure.

The roles of learning mode and of temporal complexity have important implications for many motor-based sequential tasks, such as language acquisition, music performance, dance, sport, and other complex tasks that rely on the accurate prediction of event timing. There may be instances when the relevant temporal structures to be learned are too complex to benefit from an explicit, hypothesis-testing strategy. Rather implicit learning might be the most effective mode when the search for temporal regularities in complex auditory stimuli is demanding.
Chapter 4 Preface

In Experiments 1 to 3, IL of IGIs in a weakly metrical temporal structure was demonstrated. While, there was less evidence of learning of the temporal structure with a slightly weaker meter, cueing meter with an accented woodblock pulse did elicit an RT increase at the test block to maintained within-group syllables. However, giving an explicit instruction to learn the rhythm failed to enhance learning and although Experiments 2 and 3 were not statistically compared, this explicit instruction in fact appeared to eliminate learning in the less metrical temporal structure. Therefore, it appears that IL is a powerful means of developing temporal expectations but learning is moderated by metrical strength. Experiments 4 and 5 (reported in Chapter 4) further examine IL of temporal structures, or rhythms, but rather than examining IL as a function of metrical strength, cultural familiarity with meter is manipulated. Specifically, the capacity of listeners with a lifetime’s exposure to Western tonal music to implicitly learn rhythms with culturally familiar and culturally less familiar meters is investigated. IL of IGIs and within-group intervals will be examined independently.
Chapter 4

Implicit Learning of Auditory Rhythms with Even and Uneven Meters

A manuscript based on Chapter 4 has been submitted to *Psychological Research*:

Implicit learning of auditory rhythms with even and uneven meters.

Terry, J., Stevens, C. J., & Tillmann, B.

Note: C. J. Stevens and B. Tillmann are the author’s principal and associate supervisors, respectively.
4. Implicit Learning of Auditory Rhythms with Even and Uneven Meters

4.1. Introduction

Exposure to complex sequences of auditory events (e.g. speech and music) allows listeners to learn the regularities inherent in these sequences. Consequently, expectations about upcoming events are established. These expectations can be of the identity of the upcoming event (ordinal dimension), and/or of the timing with which the event will occur (temporal dimension). In Chapter 4, two experiments investigate the development of temporal expectations via implicit learning (IL). Specifically, we examine learning of auditory rhythms (i.e. sequences of inter-onset-intervals, IOIs) without directing participants’ attention to the rhythmic structure and without giving participants an intention to learn the rhythms.

The perception and learning of rhythm is integral to our making sense of sequential structures that unfold in time, e.g. music, speech, dance, gymnastics, and other motor skills. Furthermore, temporal expectations are important for synchronising and coordinating movements with others (Bispham, 2006; Merker, et al., 2009; Phillips-Silver, Aktipis, & Bryant, 2010; Phillips-Silver & Keller, 2012; Vesper, van der Wel, Knoblich, & Sebanz, 2011; Zentner & Eerola, 2010). Often these temporal expectations are acquired without an explicit instruction to learn the rhythm, but rather are acquired via incidental exposure (Jones, 2009). Hence, to examine IL of rhythms, we employ an auditory adaptation of a Serial Reaction Time task (SRTT).
4.1.1. Implicit Learning of Temporal Structure: An Auditory Adaptation of the SRTT

The SRTT has been used primarily to demonstrate IL of the ordinal dimension of structured visual-spatial sequences (e.g. a repeating order of spatial locations of an object on a screen). Although participants show behavioural advantages from exposure to the visual sequences (e.g. faster reaction time (RT) and improved accuracy to identify the locations), participants are often unable to describe the regularities in the sequences (Boyer, et al., 2005; A. Cohen, et al., 1990; Curran & Keele, 1993; Destrebecqz & Cleeremans, 2001; Nissen & Bullemer, 1987; Perruchet, 2008; A. S. Reber, 1993; Reed & Johnson, 1994; Willingham, et al., 1989).

Research investigating IL of auditory temporal structure, or rhythm, has received less attention and while there has been some debate as to whether temporal structure can be learned independently of ordinal structure (Buchner & Steffens, 2001; Shin & Ivry, 2002), recent findings suggest that temporal structures or rhythms can be learned when the events presented in the rhythmic sequence are held constant (Salidis, 2001), or the order of events is unpredictable (Brandon, et al., 2012; Schultz, et al., 2013; Tillmann, et al., 2011). Over an exposure phase, participants become faster at detecting or discriminating auditory events (e.g. tones or syllables) when they are presented in sequences with temporal structures defined by repeating IOIs. Learning of the temporal structure is argued to have occurred when a decline in performance is elicited (i.e. slower RT) at the introduction of a sequence with a random or alternate ordering of IOIs (i.e. temporal violation) or when performance in a subsequent reproduction task is facilitated by the exposure to the temporal structure in the SRTT (Tillmann, et al., 2011).
4.1.2. The Possible Facilitatory Effect of an Even Meter on Processing Rhythms

Some preliminary findings emerging from the literature suggest that a hierarchical temporal structure typical of music - meter - may modulate learning (Brandon, et al., 2012; Schultz, et al., 2013). Meter gives rise to the perception of cyclic patterns of strong and weak beats subsumed within larger-scale cyclic patterns of strong and weak beats at longer time-scales (Lerdahl & Jackendoff, 1983). Beats are experienced as periodic and isochronous (i.e. evenly spaced) points in time (Lerdahl & Jackendoff, 1983) and are endogenous, psychological events that occur in response to an exogenous rhythm. Consequently, beats can be experienced in the absence of an event onset (Large, 2008; Large & Snyder, 2009).

When beats coincide at multiple levels in the hierarchy, they are perceived as strong and the regularity of these strong beats defines the meter of the rhythm (Jones, 1987; Palmer & Krumhansl, 1990). Although strong beats are often associated with exogenous cues, e.g. increases in amplitude, longer durations, tonally important pitches and harmonic transitions (Ellis & Jones, 2009; Hannon, Snyder, Eerola, & Krumhansl, 2004; Krumhansl, 2000a; Lerdahl & Jackendoff, 1983), they can also be perceived in the absence of these cues. Research has shown that the grouping of auditory events bounded by longer IOIs can give rise to the perception of meter (Povel & Essens, 1985). Specifically, (a) isolated tones, (b) the second tone in a group of two, (c) and the first and last tones in a group of three or more, tend to be perceived as accented.

In Western tonal music, the most common meters - even meters - have evenly spaced strong beats at all levels of the metric hierarchy. Beats at each level are related to beats at the next highest level according to fixed 2:1 binary or 3:1 ternary ratios. Duple meters are based on binary ratios and are characteristic of “march” rhythms.
(strong-weak-strong-weak). Triple meters are based on ternary ratios and are characteristic of “waltz” rhythms (strong-weak-strong-weak-weak) (London, 2002). While both duple and triple meters are common in Western tonal music, duple meters are more prevalent. Greater familiarity to duple meters, relative to triple meters, results in relatively more accurate perception and performance (Bergeson & Trehub, 2006; Desain & Honing, 2003; Drake, 1993; K. C. Smith & Cuddy, 1989).

In general, the presence of a metrical structure facilitates perception and production of rhythms. For listeners exposed primarily to Western tonal music in their cultural environment, strong even meters are particularly beneficial. Some research has examined the effect of presence, compared to absence, of metrical structure (i.e. non-metrical rhythms) in temporal processing. For instance, discriminating the pitch of a target tone is faster when the target is presented in a strong metrical rhythm context, compared to a non-metrical context (Ellis & Jones, 2010). Other research has investigated the effects of varying metrical strength on production and performance of rhythms. Strong even meter rhythms are reproduced more accurately after fewer exposures compared to weakly metrical rhythms (Grahn & Brett, 2007; Patel, et al., 2005; Povel & Essens, 1985). Furthermore, participants are more accurate at detecting temporal violations to the relatively longer interval between groups of auditory events (referred to here as inter-group-intervals, IGIs) when they are in rhythms that have a strong, compared to weak meter (Handel, 1998; Hébert & Cuddy, 2002).

One possible advantage of the presence of a strong meter, over a weak meter, or indeed no meter, is that it may facilitate the prediction of IOIs that extend beyond a beat or pulse, i.e. having durations that are multiples of the basic pulse. The endogenous regular pulse activated by a strong metrical framework provides a grid that guides temporal expectations to future points in time (Ellis & Jones, 2010).
Additionally, a more frequently encountered meter (e.g. even duple for listeners exposed to Western tonal music), relative to less frequently encountered meter (e.g. triple, or uneven) might also facilitate the prediction of the longer IOIs (Brandon, et al., 2012; Eisler, Eisler, & Hellström, 2008; Grahn & Brett, 2007).

The proposition that a regular temporal grid guides temporal expectations is consistent with the Dynamic Attending Theory. This theory proposes a mechanism that underpins the development of temporal expectations and accounts for the finding that listeners are more accurate and faster at making judgements about an event that is presented at an expected, compared to unexpected, point in time (Jones, et al., 2002; Jones & Yee, 1997; Penel & Jones, 2005; Tillmann & Lebrun-Guillaud, 2006).

Neural oscillatory processes activated by exposure to temporal regularity guide attention to points in time at which events are expected to occur; that is, at points in time that uphold the preceding temporal regularity. As a consequence, processing of events occurring at expected time points is optimized (Jones & Boltz, 1989; Large & Jones, 1999; Large & Kolen, 1994).

Evidence that a strong familiar meter promotes oscillations at longer timescales (i.e. higher time levels of the metric hierarchy), facilitating temporal prediction by guiding attention over longer IOIs, has been highlighted in recent IL research. Brandon et al. (2012) presented rhythmic sequences of syllables (randomly presented) with duple or triple meters over exposure blocks, and participants identified the syllables as quickly and accurately as possible. In the exposure condition presenting the duple meter rhythm, RT to both the short (700 ms) and longer (1400 ms and 2100 ms) IOIs increased when temporal expectations were violated at a test block introducing a new duple meter rhythm. However, in the exposure condition presenting the triple meter rhythm, RT to syllables following the
longer IOIs did not increase when a new duple meter rhythm was introduced. It was argued that the more familiar duple meter at the test block allowed participants to better anticipate the longer and more difficult-to-process IOIs (Brandon, et al., 2012; Eisler, et al., 2008) and thus counteracted the RT increase that was expected in response to the temporal violation. Hence, it appears that meter may provide a framework that enables more efficient processing of the longer IOIs (Grahn & Brett, 2007).

4.1.3. Perception of Uneven Meters: The Role of Enculturation

In the current study, the role of meter on learning the longer IOIs (i.e. IGIs) is examined further. However, rather than employing only rhythms with even meters typical of Western tonal music (i.e. duple and triple meters), we present an even meter rhythm and an uneven meter rhythm. Uneven meters are common in the music of the Balkan region (e.g. Macedonia, Bulgaria, Hungary and Greece), the Middle East, South-Asia, West Africa and Latin America. These meters have uneven spacing between strong beats at an intermediate level of the hierarchy (Fracile, 2003; London, 1995; Moelants, 2006; Singer, 1974). For instance, an anapaestic meter has a strong-weak-strong-weak-weak beat structure and a dactylic meter has a strong-weak-weak- strong-weak beat structure.

Listeners exposed primarily to Western tonal music find it relatively difficult to synchronise with and to reproduce uneven meter rhythms (Repp, et al., 2005; Snyder, et al., 2006). During synchronisation, longer IOIs tend to be shortened so that tapping is more characteristic of a rhythm with an even meter (Snyder, et al., 2006).

Research with infants and adults suggests that the ease with which rhythms with even and uneven meters are perceived and produced is a function of cultural
exposure (Hannon, et al., 2011; Hannon, Soley, et al., 2012; Hannon & Trainor, 2007; Hannon & Trehub, 2005b; Hannon, Vanden Bosch der Nederlanden, et al., 2012; Kalender, et al., 2012; Soley & Hannon, 2010; Trehub & Hannon, 2006). For instance, Hannon and Trehub (2005a) reported that North American adults were better at judging alterations in melodies with even, compared to uneven meters. However, adults from Macedonia and Bulgaria made equally accurate judgments of melodies with both even and uneven meters. Hence, the organisation and perception of a rhythm as it unfolds over time depends on previous exposure to metrical frameworks and on the resultant learned expectancies (Clayton, et al., 2004; Large & Palmer, 2002). In the current experiments, we investigated learning, via short-term exposure, of rhythms by listeners enculturated primarily to Western tonal music and we manipulated familiarity by presenting rhythms with even and uneven meters. In other words, the effect of long-term temporal expectations (via cultural exposure) on learning of specific rhythms (via short-term exposure during an experimental session) will be investigated when attention is not drawn to the rhythm and when the rhythm is incidental to the task, thus accessing the capacity of implicit learning.

The aforementioned research, using explicit discrimination and synchronisation/reproduction tasks, has demonstrated that participants enculturated to Western tonal music have difficulty processing uneven meters. However, incidental learning of a simple rhythm with an uneven meter has been demonstrated (Tillmann, et al., 2011). Participants identified randomly presented syllables in sequences with one of two temporal structures with repeating patterns of short and long IOIs: short-short-long. Participants were not informed of the temporal structures, but were given the cover story that they were performing a speeded syllable identification task. The short and long intervals in one sequence had a simple integer ratio relationship (1:2)
typical of even meters, and the short and long intervals in the other sequence had a complex ratio relationship (1:1.5), typical of uneven meters. RT to identify the syllables decreased with exposure to both the simple and complex ratio rhythms and suggested that participants learned both temporal structures. This preliminary research indicates that learning of rhythms with unfamiliar meters may benefit from implicit processes. Indeed, in the visual domain, implicit learning can be more powerful than explicit learning when the to-be-learned structures are complex (Fletcher, et al., 2005; Howard & Howard Jr, 2001; A. S. Reber, 1976).

4.1.4. Aims of Experiments 4 and 5

We explore IL of rhythms with familiar even meters and less familiar uneven meters (to listeners of primarily Western tonal music). Extending on the research of Tillmann et al. (2011), we make some important changes to the method. Firstly, complex rhythms with short, medium and long IOIs in longer temporal structures with 10 and 11 IOIs will be employed. These rhythms will have even and uneven meters, respectively, and will allow an examination of IL of temporal structures that are more typical of music. Consequently, learning of these rhythms should be sensitive to the influences of prior long-term exposure. Secondly, after exposure, test blocks with new rhythms will be introduced to ensure that the effects over exposure (i.e. RT decreases) are not simply due to task learning. In this case, RT increases at the test blocks can be attributed to the change in the rhythm and the effects of the resulting temporal violation. Of particular interest for our study will be the effect of introducing test rhythms with different meters on the processing of the longer IOIs (i.e. IGIs). Finally, post-test questionnaires and familiarity ratings to the SRTT sequences and a set of novel sequences will be examined to determine the presence of any explicit
knowledge of the rhythms acquired during the experiment.

4.1.5. Design

Using an auditory SRTT, randomly ordered syllables will be presented in rhythmic sequences with even and uneven meters. Hence, the temporal dimension (i.e. the rhythm) will be structured while the ordinal dimension (i.e. order of the syllables) will be unpredictable. Eight exposure blocks will contain syllable sequences with either even or uneven meter rhythms: Even Meter condition and Uneven Meter condition, respectively. After each exposure type, two test blocks will be presented that contain sequences with the rhythms of the alternate meter. A final block will present again the original exposure rhythm\textsuperscript{12}.

The dependent variable will be correct RT to identify syllables. Over exposure blocks, a 2 x 8 design will be employed with Meter (Even, Uneven) as the between-subjects independent variable and Block (Blocks 1 to 8) as the within-subject independent variable. The effect of violating the acquired temporal expectation at the test blocks will be determined by two 2 x 2 analyses with again, Meter as the between-subjects variable and Block as the within-subject variable. We will compare; (a) the mean RT at the two test blocks (Block 9 and 10) with the mean RT at the two adjacent exposure blocks (Block 8 and 11), and (b) RT at the first test block (Block 9) with the prior exposure block (Block 8). This second analysis (Block 8 versus Block 9) takes into account the possibility that learning of the rhythm in the second test

\textsuperscript{12} In Experiments 1 – 3, participants were exposed to seven blocks of 2 mins 10 s, totalling 15 mins and 10s of task exposure over the duration of the experiment. Experiments 4 – 6 presented blocks of approximately 1 min 20s (range: 1 min 11 s – 1 min 21 s) to reduce possible participant fatigue. To ensure that the total presentation time of exposure and test rhythms was equivalent to Experiments 1 – 3, 11 blocks were presented, totalling on average (across the three experiments) 14 mins 21 s of task exposure.
block may occur and consequently weaken the effect of comparing the two test blocks with the two adjacent exposure blocks. Finally, in line with Brandon et al. (2012), the above analyses will be conducted with RT to syllables following the short IOIs (within-group) and the medium/long IOIs (post-IGIs) examined separately.

4.1.6. Hypotheses

It is hypothesised that RT to identify syllables will decrease over Blocks 1 to 8 and that the decrease will be greater in the Even Meter, compared to the Uneven Meter condition. It is also expected that the exposure block decrease to post-IGI syllables will occur primarily in the Even Meter condition but the decrease to the easier-to-process within-group syllables will less influenced by meter. At the test blocks, it is hypothesised that RT will increase in both conditions but with a greater increase in the Even Meter condition (i.e. when the less familiar uneven meter rhythm is presented at test). In the Uneven Meter condition, we expect that the introduction of the more familiar even meter rhythm at the test blocks will benefit participants and lead to a lesser increase. It is expected that these effects at the test block will be particularly pronounced for the syllables following the more difficult medium/long IOIs (post-IGI syllables), compared to the syllables following the short IOIs (within-group syllables). Finally, it is hypothesised that learning will be implicit with participants rating exposure, test and novel sequences as equally familiar.
4.2. Experiment 4: Implicit Learning of Rhythms with Even and Uneven Meters

4.2.1. Method

4.2.1.1. Participants

Eighty-one undergraduate students from the University of Western Sydney took part in Experiment 4 in exchange for course credit. Participants were randomly assigned to either the Even Meter ($N = 44$) or Uneven Meter ($N = 37$) conditions. Z-tests were conducted to identify participants performing significantly above chance ($ps < .05$). The z-test returns the probability that the mean of all of a participant’s blocks is greater than 50%, taking into account the variability across blocks. Eighteen participants in the Even Meter condition and 12 participants in the Uneven Meter condition performed either below chance or not significantly above chance. Sub-optimal syllable identification was likely driven by the difficulty of the task, as the speed of the presentation of syllables was rapid (i.e. shortest IOI of 400 ms) (see Materials section). Data from these participants were excluded from the analyses. Furthermore, as not all participants were fully attentive and vigilant when identifying the syllables, a further criterion was set for including participants’ data in the analysis: only data from participants with RT faster at Block 8 compared to Block 1 were retained. The rationale for this criterion was that a decrease in RT over exposure blocks indicated the presence of task learning and suggested that participants were performing the task with vigilance.\(^{13}\)

\(^{13}\) Note that for participants retained in the analysis, RT decreased from 377.61 ms (Block 1) to 347.71 ms (Block 8) in the Even Meter condition, and from 384.84 ms (Block 1) to 353.79 ms (Block 8) in the Uneven Meter condition. For excluded participants, RT increased from 368.92 ms (Block 1) to 389.60 ms (Block 8) in the Even Meter condition, and from 356.36 ms (Block 1) to 372.92 ms (Block 8) in the
Applying this criterion resulted in a sample of 34 participants: 17 in each condition. The 15 female and 2 male participants in the Even Meter condition had a mean age of 20.53 years ($SD = 4.08$ years, range = 17 – 31 years). The 15 female and 2 male participants in the Uneven Meter condition had a mean age of 20.65 years ($SD = 6.11$ years, range = 17 – 40 years).

The two participant groups were equivalent in terms of years of musical training. Participants in the Even Meter condition had a mean of 2.12 years of training ($SD = 2.74$ years, median = 0) and participants in the Uneven Meter condition had a mean of 2.50 years of training ($SD = 3.14$ years, median = 2). These levels of musical training were not statistically different between the two conditions ($p = .71$).

All participants had self-reported normal hearing and had English as a first language. No participant reported exposure during childhood to music of the Balkan region, or other music characterised by uneven meters. Likewise, no participants reported that they were currently listening to this music.

4.2.1.2. Materials

4.2.1.2.1. SRTT. The rhythms were constructed by chaining short (400 ms), medium (800 ms) and long (1200 ms) IOIs. The shortest temporal unit (400 ms) was chosen as it is in the range typical of rhythms with both even and uneven meters (Moelants, 2006). This rapid presentation was also required to induce contiguity of the rhythms whilst ensuring the task remained achievable. The even meter rhythm was selected from a set of strongly metrical rhythms used by Povel and Essens (1985). An additional event was added to the end of the rhythm in order to avoid the long 1600 ms IOI at the end, as it would provide an obvious segmentation of the Uneven Meter condition. This indicated that a sub-group of participants experienced fatigue during the task. The analyses for the full set of data (i.e. all participants performing above chance) are presented in Appendix D.
rhythm at that point. The uneven meter rhythm was adapted from the even meter rhythm by altering the medium and long IOIs (i.e. IGIs) and by adding a second additional event at the end, again to avoid a 1600 ms IOI.

The two rhythms were identical in terms of grouping structure (apart from the addition of a final isolated syllable in the uneven meter rhythm). That is, the number of groups, number of events within groups, and the order of groups were identical in the two rhythms. For instance, in both rhythms, a single event was followed by two groups of three events, and so on (1-3-3-2-1-1) (Figure 4.1). To generate the even and uneven meter rhythms without altering the grouping structure, the duration of the IGIs (i.e. IOIs between syllable groups/isolated syllables) differed across the two rhythms. The duration of the first to third, and fifth IOIs were directly transposed so that medium IOIs in the even meter rhythm became long IOIs in the uneven meter rhythm and the long IOI became a medium IOIs. The fourth IOI remained a medium IOI across the two rhythms. To strengthen the meter of each rhythm, events aligning with strong beats were accented with amplitude increases (see Figure 4.1 and text below for further explanation). Amplitude, or dynamic accents have been used previously to induce the perception of meter (K. C. Smith & Cuddy, 1989). The IOI chaining in the even meter rhythm was 800-400-400-800-400-400-1200-400-800-800, and the IOI chaining in uneven meter rhythm was 1200-400-400-1200-400-400-800-400-800-1200-400 (see Figure 4.1). In the Even Meter condition, 10 IOIs formed the basic rhythm, and this rhythm was cycled 11 times in a sequence. In the Uneven Meter condition, 11 IOIs formed the basic rhythm, and this rhythm was cycled 10 times. This construction resulted in the even and uneven meter sequences having the same number of events (i.e. 110 syllables).
Figure 4.1. Experiment 4 rhythms (Even and Uneven): “X” represents a syllable, and digits indicate the serial positions of the syllables. Bold and regular overscores indicate syllable positions aligning with strong beats (accented with 6dB amplitude increases) and moderate beats (accented with 3dB amplitude increases), respectively. Horizontal arrows represent IGIs (inter-group intervals), and vertical lines represent the hypothesised metrical structure (the longer the line the stronger the perceived beat). The even meter rhythm is cycled 11 times per block and the uneven meter rhythm is cycled 10 times per block.

A measure of metrical strength (C-score) was applied (Povel & Essens, 1985) to ensure that both rhythms (Even and Uneven Meter) were strongly metrical. The C-score is based on an internal clock model of subjective accent induction and has two key principles/assumptions: (a) Rhythms have an underlying beat or pulse grid, and
(b) the grouping structure of a rhythm gives rise to the perception of subjectively accented tones. Isolated tones, the second in a group of two tones, and the first and last of a group of three or more tones are perceived as accented. A C-score is generated by considering the relationship between the hypothesised beat grid (or internal clock pulse) and the subjective accent structure. Specifically, the counter-evidence based measure considers the number of internal clock pulses that are not accompanied by an event or are accompanied by a subjectively unaccented event using the formula: $C = (W \cdot -ev) + (1 \cdot 0ev)$, where $-ev$ is the number of beats that coincide with a silence and $0ev$ is the number of beats that coincide with an unaccented auditory event. $W$ is a weight generally set at four. The lower the C-score, the stronger the meter of the sequence, with zero indicating maximal metrical strength.

With the even meter rhythm, the clock pulse was considered to occur at 1600 ms intervals (i.e. at strong beats), with four 400 ms subdivisions of the beat (4-unit). With the uneven meter rhythm, the clock pulse was considered to occur at 2000 ms intervals (i.e. at strong beats), with five 400 ms subdivisions of the beat (5-unit). The C-scores for both rhythms were zero, indicating that both rhythms were strongly metrical.

Events in the sequences were two syllables, “Pa”, and “Ta”, spoken with a male voice generated using a text-to-speech synthesizer, Mbrola. The syllables had a fundamental frequency of 120 Hz, a duration of 218 ms, and were normalized for intensity (i.e. perceived loudness).

As the first syllable in each block did not follow an IGI, it was not included in the analyses. Instead an additional syllable was added at the end of each block to create the final IGI. Hence, each block consisted of a sequence of 111 syllables
presented in a pseudo-random order. The following constraints were applied from the second to the final syllable in each sequence. There were 55 presentations of each syllable with no more than nine repetitions of a single syllable or nine alternations of the two syllables in a row. Second- and third-order repetitions were roughly equated across blocks. Second-order repetitions are instances when, for example, two Pas are interposed with Ta ("Pa Ta Pa"), and third-order repetitions are instances when, for example, two Pas are interposed with two Tas ("Pa Ta Ta Pa"). Finally, syllables were distributed equally across all serial positions in each sequence. To ensure that any effects could not be attributed to syllable order, half the participants were presented with a second syllable order that was a reversal of the order presented to the other half of participants.

For each block, AIFF files of each syllable sequence, with the defined IOI chaining were created in Matlab. The amplitude of syllables aligning with strong beats and moderately strong beats, as defined by the metrical structure of each rhythm, was increased by 6dB and 3dB, respectively (see Figure 4.1). Even and Uneven Meter sequences had durations of 1 min and 11 s and 1 min 21 s, respectively. Two Even Meter practice sequences with 4.5 cycles (28 s) of the basic rhythm were created, as were two Uneven Meter practice sequences with 4 cycles of the basic rhythm (33 s). The experiment was run in Psyscope (J. Cohen, et al., 1993), sequences were presented over Sennheiser HD 25 closed headphones, and responses were made using a Targus USB numeric keypad.

4.2.1.2.2. Post-Tests. The purpose of the post-test phase was to measure participants’ explicit knowledge of the rhythms to which they were exposed in the SRTT. Post-test sequences were one cycle of the basic even and uneven rhythms. As the rhythm was cycled multiple times in the SRTT, it was possible that participants
may have perceived the rhythm as starting at one of any of the strongly accented syllables (i.e. strong beat). Hence, four versions of each rhythm were created, each starting at a different strong beat.

In addition to the Even Meter and Uneven Meter post-test sequences, two novel rhythms with even and uneven meters were created (see Table 4.1). The Even and Uneven Meter Novel rhythms had grouping structures of 2-3-3-1-1 and 2-3-3-1-1-1, respectively. The Even Meter Novel and Uneven Meter Novel rhythms were **XX..XXX.X.X**. and **XX.XXX..XXX..X.X..X**. (“X” represents a syllable, a full stop(s) represents a 400 ms IOI, and bold font indicates a syllable aligning with a strong beat). Four versions of the two novel post-test sequences began on different strong beats. Table 4.1 displays the labels for the post-test sequence sets. For instance, the even meter rhythm presented in the SRTT became the “Old exposure” post-test sequence in the Even Meter condition and “Old test” in the Uneven Meter condition.

**Table 4.1**

*Labels for the Post-test Sequence Sets for the Even and Uneven Meter Exposure Conditions*

<table>
<thead>
<tr>
<th>Post-test Sequence Set</th>
<th>Even meter</th>
<th>Uneven meter</th>
<th>Even meter novel</th>
<th>Uneven meter novel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition</td>
<td>Even meter</td>
<td>Uneven meter</td>
<td>Even meter novel</td>
<td>Uneven meter novel</td>
</tr>
<tr>
<td>Even meter</td>
<td>Old exposure</td>
<td>Old test</td>
<td>Novel same meter</td>
<td>Novel new meter</td>
</tr>
<tr>
<td>Uneven meter</td>
<td>Old test</td>
<td>Old exposure</td>
<td>Novel new meter</td>
<td>Novel same meter</td>
</tr>
</tbody>
</table>

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Both the Even Meter and Uneven Meter novel patterns were strongly metrical with C-scores of 1 (4-unit and 5-unit respectively). As in the SRTT, all sequences were accented so that syllables aligning with strong beats had an amplitude accent of 6dB and syllables aligning with moderate beats had an amplitude accent of 3dB. The syllables used in the post-test sequences (“Pa”, “Ta”), and the method for creating the AIFF files was as per the SRTT. The post-test task was run in Psyscope (J. Cohen, et al., 1993).

4.2.1.3. Procedure

4.2.1.3.1. SRTT. To minimise awareness of the presence of a rhythm in the syllable sequences, participants were informed that the experiment was investigating the speed and accuracy of syllable identification. They were not informed that the temporal presentation of the sequences was determined by a cycling rhythm. Participants listened to the sequences of syllables and identified each syllable as quickly and accurately as possible. They made their responses using keys 7 and 1 on a USB numeric keypad. Labels identifying the appropriate response key were placed on the keys above (keys 8 and 2). Participants held the USB keypad in both hands (rotated 90°) and pressed key 7 with their left thumb and key 1 with their right thumb. Participants were instructed to not correct themselves if they made a mistake or to type in missed syllables. To minimise motor-based effects, key attributions were counterbalanced across participants.

Two practice blocks with the rhythm of the participants’ exposure sequence were presented and participants were reminded of the instructions before beginning the experimental blocks. Participants in the Even Meter condition were presented with eight exposure blocks of the Even Meter rhythm (Blocks 1 to 8). This was followed by two test blocks presenting the Uneven Meter rhythm (Blocks 9 and 10), and a final
block of the Even Meter rhythm (Block 11). Conversely, participants in the Uneven Meter condition were presented with eight exposure blocks of the Uneven Meter rhythm, followed by two test blocks presenting the Even Meter rhythm and a final block of the Uneven Meter rhythm. A short break with a minimum duration of 30 s was provided between each block.

4.2.1.3.2. Post-tests. After completing the SRTT, participants filled in a questionnaire asking them to describe any temporal regularity they noticed in the sequences. They were then informed that the sequences followed a repeating timing or rhythmic structure.

To ensure that the testing conditions were as equivalent as possible across the SRTT and post-test task (thus giving participants the best opportunity to extract any explicit knowledge), participants were instructed to identify each syllable (using the USB numeric keypad) as quickly and accurately as possible and to not correct themselves if they made a mistake or to type in missed syllables. All participants responded to all four post-test sequences from the Even Meter, Uneven Meter, Even Meter Novel and Uneven Meter Novel sets. The sequences were presented in random order.

After identifying the syllables in each post-test sequence, participants performed two rating tasks. Firstly, they were instructed to think back to the SRTT in the first part of the experiment and rate their familiarity with the timing pattern of the post-test sequence just heard using a scale: 1 = very unfamiliar, 2 = unfamiliar, 3 = somewhat unfamiliar, 4 = somewhat familiar, 5 = familiar, 6 = very familiar. They were then instructed to indicate the certainty with which they made their familiarity rating using a scale: 1 = complete guess, 2 = very uncertain, 3 = somewhat uncertain, 4 = somewhat certain, 5 = very certain, 6 = completely certain (adapted from
Destrebecqz & Cleeremans, 2001). Ratings were made using the numeric keys across the top of the computer keyboard. After the post-test task, participants completed a demographic questionnaire and were debriefed on the purpose of the experiment. The experiment took 50 minutes.

4.2.2. Results

4.2.2.1. SRTT

Correct responses were included in the analysis if they occurred 100 – 800 ms after the onset of the syllable\textsuperscript{14}. RTs less than 100 ms were assigned to the previous syllable if it was missed and, if multiple responses were made within the 100 – 800 ms window, only the first response was kept. The upper limit (800 ms) allowed us to retain longer RTs made to the syllables immediately preceding a medium and long IOI (i.e. IGIs).

It was decided that across the two conditions, an equal number of potential data points at each serial position should be included in the analyses. Hence, RT to the final syllable in each cycle of the uneven meter rhythm was excluded, as was RT to the 10 syllables in the last cycle in each block even meter condition. This meant that, in both conditions, 100 potential data points were analysed in each block. Mean accuracy to syllables was significantly above chance (50\%) for the Even meter

\textsuperscript{14} In Experiments 1 – 3, the temporal window for accepting responses was 250 ms – 900 ms. In Experiments 4 – 6, this window was adjusted to 100 – 800 ms as the base IOI between syllables was faster (400 ms) compared to Experiments 1 – 3 (600ms). The adjusted window accounts for faster responses induced by the shorter IOIs.
condition (61.41%; $SD = 5.12\%$), $t(16) = 9.20, p = .00$, and Uneven meter condition (63.05%; $SD = 6.49\%$), $t(16) = 8.30, p = .00$\textsuperscript{15}.

### 4.2.2.1.1. Mean RT to all correct responses over exposure blocks.

Only data from participants demonstrating faster RT at Block 8 compared to Block 1 were analysed (see Method section). This decrease was statistically assessed, as was any influence of the Even and Uneven Meter conditions. Therefore, RT to syllables was averaged for each block and an 8 x 2 ANOVA with Block (Blocks 1 – 8) as a within-subject factor and Meter (Even, Uneven) as a between-subjects factor was conducted (Figure 4.2). The main effect of Block was significant, $F(7, 224) = 8.59, p = .00$, partial $\eta^2 = .21$. There was no main effect of Meter, $F(1, 32) = 2.44, p = .13$, partial $\eta^2 = .07$, and no Block by Meter interaction, $F(7, 224) = 1.71, p = .11$, partial $\eta^2 = .05$. RT at Block 8 was significantly faster than at Block 1, $p = .00$.

### 4.2.2.1.2. Mean RT to all correct responses over test blocks.

To investigate the effect of changing the rhythm and consequently meter at the test blocks, a 2 x 2 ANOVA with Block (mean exposure Blocks 8 and 11, mean test Blocks 9 and 10) as a within-subject factor and Meter (Even, Uneven) as a between-subjects factor was conducted. There was no effect of Block, $F(1, 32) = 2.15, p = .15$, partial $\eta^2 = .06$, no effect of Meter, $F(1, 32) = .08, p = .78$, partial $\eta^2 = .00$, and no Block by Meter interaction, $F(1, 32) = 1.59, p = .22$, partial $\eta^2 = .05$. However, Figure 4.2 suggests some learning of the test rhythm at the second test block (Block 10). The first test block (Block 9) was compared to the immediately preceding exposure block (Block 8) with an ANOVA with Block (Block 8, Block 9) as a within-subject factor and Meter (Even, Uneven) as a between-subjects factor (Figure 4.2). This revealed a

\textsuperscript{15} Appendix D reports accuracy over blocks and correlations between RT and accuracy.
significant effect of Block, $F(1, 32) = 5.40, p = .03$, \textit{partial $\eta^2$} = .14, but no effect of Meter, $F(1, 32) = 0.01, p = .93$, \textit{partial $\eta^2$} = .00 and no Block by Meter interaction, $F(1, 32) = 1.29, p = .27$, \textit{partial $\eta^2$} = .04.

\textit{Figure 4.2.} Experiment 4: Correct RT to syllables presented as a function of Block and Pattern condition. Error bars show standard error of the mean.

4.2.2.1.3. \textit{Mean RT to post-IGI syllables over exposure blocks.} RT to syllables following IGIs was averaged for each block and an 8 x 2 ANOVA with Block (Blocks 1 – 8) as a within-subjects factor and Meter (Even, Uneven) as a between-subjects factor was conducted. The main effect of Block was significant, $F(7, 224) = 5.90, p = .00$, \textit{partial $\eta^2$} = .16. There was no main effect of Meter, $F(1, 32) = 1.89, p = .18$, \textit{partial $\eta^2$} = .06, and no Block by Meter interaction, $F(7, 224) = 1.38, p = .22$, \textit{partial $\eta^2$} = .08. RT at Block 8 ($M = 372.01$ ms, $SE = 8.01$) was significantly faster than at Block 1 ($M = 412.37$ ms, $SE = 8.92$), $p = .00$. Although the main effect of Meter did not reach significance, it was in the expected direction with overall faster RT in the
Even ($M = 380.10 \text{ ms}, SE = 10.16$), compared to Uneven Meter condition ($M = 399.65 \text{ ms}, SE = 10.16$).

4.2.2.1.4. Mean RT to post-IGI syllables over test blocks. RT to post-IGI syllables at Block 8 and Block 9 was calculated by averaging correct RT to serial positions 1, 2, 5, 8 and 10 (see Figure 4.1, and the SRTT sub-section above for information concerning the exclusion of position 11 in the Uneven meter condition). A 2 x 2 ANOVA with Block (Block 8, Block 9) as a within-subject factor and Meter condition (Even, Uneven) as a between-subjects factor was conducted. There was no effect of Block, $F(1, 32) = 1.04, p = .32$, partial $\eta^2 = .03$, Meter condition, $F(1, 32) = .03, p = .87$, partial $\eta^2 = .00$, and no Block by Meter condition interaction, $F(1, 32) = 1.86, p = .18$, partial $\eta^2 = .06$. It was hypothesised that RT to post-IGI syllables would increase in the Even Meter condition but not the Uneven Meter condition. Although this interaction was not significant, a visual inspection of Figure 4.3 indicates a trend in the expected direction.

4.2.2.1.5. Mean RT to within-group syllables over exposure blocks. RT to within-group syllables was averaged for each block and an 8 x 2 ANOVA with Block (Blocks 1 – 8) as a within-subject factor and Meter (Even, Uneven) as a between-subjects factor was conducted. The main effect of Block was significant, $F(7, 224) = 3.89, p = .00$, partial $\eta^2 = .10$. There was no main effect of Meter, $F(1, 32) = 1.76, p = .19$, partial $\eta^2 = .05$, and no Block by Meter interaction, $F(7, 224) = 1.27, p = .27$, partial $\eta^2 = .04$. RT at Block 8 ($M = 328.66 \text{ ms}, SE = 5.88$) was significantly faster than at Block 1 ($M = 346.99 \text{ ms}, SE = 7.08$), $p = .00$. Although the main effect of Meter did not reach significance, overall RT was faster in the Even ($M = 326.87 \text{ ms}, SE = 6.73$), compared to Uneven Meter condition ($M = 339.50 \text{ ms}, SE = 6.73$).
4.2.2.1.6. Mean RT to within-group syllables over test blocks. RT to within-group syllables at Block 8 and Block 9 was calculated by averaging correct RT to serial positions 3, 4, 6, 7, and 9 (See Figure 4.1). A 2 x 2 ANOVA with Block (Block 8, Block 9) as a within-subjects factor and Meter condition (Even, Uneven) as a between-subjects factor was conducted. There was a main effect of Block, $F(1, 32) = 5.78, p = .02$, partial $\eta^2 = .15$, but no effect of Meter condition, $F(1, 32) = .03, p = .88$, partial $\eta^2 = .00$, and no Block by Meter condition interaction, $F(1, 32) = .09, p = .76$, partial $\eta^2 = .00$. Introducing a new rhythm at the test block lead to a significant increase in RT to within-group syllables, and there was no influence of meter.

![Figure 4.3](image_url)

*Figure 4.3. Experiment 4: Correct RT to a) post-IGI syllables and, b) within-group syllables presented as a function of Block and Meter condition. Error bars show standard error of the mean.*

4.2.2.2. Post-tests

An open-ended question asked participants to describe any regularity in the timing of the presentation of the syllables. Of the thirty-four participants, 17 reported there were pauses between some syllables and four indicated that the speed of the
presentation of the syllables changed within a block. However, no participants were able to report the rhythm correctly. While participants were able to indicate the presence of some variation in timing within the sequences, the post-test ratings were analysed to determine the presence of awareness of the precise rhythms presented in the SRTT. Familiarity ratings to the Even Meter sequence, Uneven Meter sequence, Even Meter Novel sequence and Uneven Meter Novel sequences were compared. Ratings (1 = very unfamiliar through to 6 = very familiar) were collapsed across the four presentations of each sequence to obtain a mean rating (Table 4.2). These were analysed with a 4 x 2 ANOVA with Post-test Sequence as a within-subject factor (Old Exposure, Old Test, Same Meter Novel, Different Meter Novel) and Meter condition (Even, Uneven) as a between-subjects factor. There was a main effect of Post-test Sequence, $F(3, 96) = 5.70, p = .00$, partial $\eta^2 = .15$, but no effect of Meter and no Post-test Sequence by Meter Condition interaction. Participants were significantly more familiar with their Exposure sequence than the Novel Same Meter and Novel New Meter sequences, $ps < .01$. Familiarity ratings to Exposure and Test sequences were not significantly different and neither were ratings to Novel Same Meter and Novel New meter sequences.
Table 4.2

*Experiment 4: Post-test Familiarity (1 = very unfamiliar, through to 6 = very familiar) and Certainty (1 = complete guess, through to 6 = completely certain)*

*Mean Ratings and Standard Deviations presented as a function of Sequence Type and Exposure Condition*

<table>
<thead>
<tr>
<th>Condition</th>
<th>Exposure</th>
<th>Test</th>
<th>Same meter</th>
<th>New meter</th>
<th>Exposure</th>
<th>Test</th>
<th>Same meter</th>
<th>New meter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Even</td>
<td>4.02</td>
<td>0.66</td>
<td>3.75</td>
<td>0.69</td>
<td>3.56</td>
<td>0.69</td>
<td>3.10</td>
<td>0.79</td>
</tr>
<tr>
<td>Uneven</td>
<td>3.84</td>
<td>0.73</td>
<td>3.84</td>
<td>0.96</td>
<td>3.41</td>
<td>0.89</td>
<td>3.57</td>
<td>0.87</td>
</tr>
</tbody>
</table>

To further examine participants’ familiarity with the SRTT sequences, correlations between post-test familiarity and certainty ratings were assessed. If participants had explicit knowledge of the rhythms to which they were exposed to in the SRTT, then there would be a positive correlation between familiarity and certainty ratings to their exposure sequences (Scott & Dienes, 2008). In other words, they would rate the exposure sequences as familiar and be certain of their decision.

Each participant’s mean familiarity rating (i.e. mean rating of all post-test sequences) was subtracted from their mean rating to exposure sequences yielding a *difference score*. These were converted to *z*-scores (*z*-familiarity). Correlations between *z*-familiarity scores and the mean certainty ratings to the exposure sequences were calculated.

There was no significant correlation between familiarity and confidence, *r*(32) = .12, *p* = .51. This indicates that participants were not confident in their familiarity ratings to exposure rhythms. Nonetheless, particular participants showing awareness...
of the rhythms were identified. These participants met two criteria. Firstly, they had an exposure sequence z-familiarity score greater than zero. That is, their mean rating to the exposure sequences was greater than their overall mean familiarity rating to all post-test sequences. Secondly, their mean certainty rating to the exposure sequences was equal to, or greater than four (4 = somewhat certain, 5 = very certain, 6 = completely certain). Seventeen of the 34 participants (Even Meter condition = 8, Uneven Meter condition = 9) met both these criteria and were considered to be “aware” of their exposure rhythm. To ensure that aware participants did not drive the test block results in the SRTT, ANOVAs were conducted for post-IGI and within-group positions. RT at Block 8 (exposure) was compared with Block 9 (first test), and Meter (Even, Uneven) and Awareness (Aware, Unaware) were between-subjects factors.

4.2.2.2.1. Post-IGI syllables by awareness: test block analyses. As with the main SRTT analysis of post-IGI positions, there was no effect of Block, $F(1, 30) = 1.45, p = .24$, partial $\eta^2 = .05$, and no effect of Condition, $F(1, 30) = .03, p = .87$, partial $\eta^2 = .00$. While there was no main effect of Awareness, $F(1, 30) = .03, p = .87$, partial $\eta^2 = .00$, the interaction between Block, Awareness, and Meter approached significance, $F(1, 30) = 3.52, p = .07$, partial $\eta^2 = .11$. For participants in the Uneven Meter condition, average RTs were longer for the test block in the Unaware group (Block 8: $M = 371.09, SD = 25.55$; Block 9: $M = 393.02, SD = 15.56$) but shorter in the Aware group (Block 8: $M = 383.38, SD = 36.31$; Block 9: $M = 359.63, SD = 33.69$). For participants in the Even Meter condition, average RTs were longer for both Unaware (Block 8: $M = 363.66, SD = 67.98$; Block 9: $M = 379.17, SD = 53.45$) and Aware participants (Block 8: $M = 369.52, SD = 49.27$; Block 9: $M = 385.31, SD = 50.79$). No other interactions were significant.
4.2.2.2. Within-group syllables by awareness: test block analyses. As with the main SRTT analysis of within-group syllables, there was a main effect of Block, $F(1, 30) = 5.63, p = .02$, partial $\eta^2 = .16$. There was no influence of awareness.

4.2.3. Discussion

Listeners of primarily Western tonal music were exposed to rhythms with even and uneven meters in the context of a SRTT. For participants demonstrating decreasing RT to syllables over exposure blocks, IL of rhythms with even and uneven meters was shown for both post-IGI and within-group syllables. It was hypothesised that the decrease to post-IGI syllables in particular would be greater in the Even compared to Uneven Meter condition. While no Block by Meter interaction was found, there was a tendency for RT to be faster to post-IGI syllables in the even, compared to uneven meter rhythm. As this improvement in performance over exposure blocks could have been solely due to task learning, the effect of introducing a new rhythm at the test blocks was an indication that the specific temporal structures or rhythms were learned. RT increases were found at the introduction of the first test block and indicated that temporal expectations, acquired during exposure by means of IL, were violated. While statistically there was no interaction with meter, the increase was mainly evident in the Even Meter condition. It may have been that participants in the Even Meter condition were more strongly disadvantaged by the violation of temporal expectation at the test block because of the less familiar uneven meter. On the other hand, participants in the Uneven Meter condition may have benefited from the more familiar even meter at the test blocks.

Separating RT to post-IGI (medium and long IOIs) and within-group (short IOIs) syllables revealed that for the Uneven Meter condition the lesser increase at the
first test block (with an even meter) was driven by post-IGI syllables. This is consistent with Brandon et al.’s (2012) finding that RT did not increase at the introduction of a duple meter rhythm at a test block, after exposure to a relatively less familiar triple meter rhythm. The current experiment provides further evidence that the more familiar even meter at the test block helped participants to anticipate the longer and more difficult-to-process IOIs (Brandon, et al., 2012; Eisler, et al., 2008; Grahn & Brett, 2007).

However, additional analyses suggested, at least tentatively, that awareness might have had a further influencing role on learning the IGIs. Participants in the Uneven Meter condition without explicit knowledge of their exposure sequence demonstrated a test block increase to post-IGI syllables. Conversely, participants with awareness showed no increase. In the Even Meter condition, participants with both implicit and explicit knowledge of their exposure sequences showed the RT increase. This interaction between Block, Meter, and Awareness failed to reach significance ($p = .07$), most likely due to small participant numbers in each group. Nevertheless, it may be that for more complex stimuli (i.e. with meter as a proxy for complexity in the temporal domain), learning is more powerful when it emerges implicitly rather than explicitly, thus leading to an RT increase at the test block for the unaware participants in the Uneven Meter condition. In the visual modality, research investigating learning of ordinal structures (i.e. a repeating order of events), provided some evidence that implicit, compared to explicit, learning strategies are more successful when the stimulus is complex (Fletcher, et al., 2005; Howard & Howard Jr, 2001). However, there is no equivalent research into the roles of complexity and the implicit/explicit learning distinction in the auditory and temporal domains and this hypothesis requires further research.
It is noted that there were an unequal number of medium (800 ms) and long (1200 ms) IGIs across the two rhythms, notably with more long compared to medium IGIs in the uneven meter rhythm. It might thus be argued that the RT differences across the two meter conditions over exposure and the results at the first test block were due to a local effect, such as the foreperiod effect. According to the variable foreperiod effect (Capizzi, Sanabria, & Correa, 2012; Correa, Lupiáñez, Milliken, & Tudela, 2004; Ellis & Jones, 2010), RT should be slower following 800 ms compared to 1200 ms IGIs. Therefore, slower RT to post-IGI syllables in the Even, compared to Uneven Meter condition would have been predicted. Furthermore, faster RT at the test blocks in the Even Meter condition would have also been expected as the uneven meter test block rhythm contained more long IGIs. However, we found the opposite result, with faster RT over exposure in the Even Meter condition and with an increase at the first test block. Consequently, a variable foreperiod effect could not have elicited the results. Nonetheless, Experiment 5 eliminated any potential issue arising from differences in the number of medium and long IGIs by controlling this across exposure and test.

In Experiment 5, we also investigated learning of rhythms with uneven meters more closely by presenting uneven meter rhythms across exposure and test. This avoids the possible reduction of the effect of temporal violation observed in Experiment 4 when the more familiar even meter rhythm was introduced at the test block, which could have resulted in some benefit.

It is hypothesised that RT will increase at the test blocks compared to the mean of the adjacent exposure blocks and we expect RT to increase for both post-IGI and within-group syllables. Given the results of Experiment 4, it is possible that an increase will be evident more so in the first test block. As in Experiment 4, learning is
expected to be implicit, as measured by post-test questionnaires and familiarity ratings.

4.3. Experiment 5: Implicit Learning of an Auditory Rhythm with an Uneven Meter

4.3.1. Method

4.3.1.1. Participants

Forty-four participants from the University of Western Sydney took part in the experiment in exchange for course credit. As per Experiment 4, z-tests were conducted to determine that each participant’s performance was significantly above chance ($p < .05$). Seventeen participants performed below chance, or not significantly above chance. Therefore, data from these participants were excluded from the analyses. As per Experiment 4, only data from participants showing vigilance on the demanding task were retained (i.e. those with RT faster at Block 8 compared to Block 1). Applying this criterion resulted in a sample of 15 participants$^{16}$. The 12 female and 3 male participants had a mean age of 19.87 years ($SD = 2.53$ years, range = 17 – 25 years) and had a mean of 3.10 years of musical training ($SD = 4.73$ years, median = 0).

All participants had self-reported normal hearing and, apart from one early bilingual speaker (English and Persian), all other participants had English as a first

$^{16}$Note that for participants retained in the analysis, RT decreased from 405.52 ms (Block 1) to 369.78 ms (Block 8). For excluded participants, RT increased from 375.73 ms (Block 1) to 392.92 ms (Block 8). This indicated that this sub-group of 12 participants experienced fatigue during the task. The analyses for the full set of data (i.e. all participants performing above chance) are presented in Appendix D.
language. No participant reported exposure during childhood to music of the Balkan region, or other music characterised by uneven meters. Likewise, no participants were currently listening to this music.

4.3.1.2. Materials

4.3.1.2.1. SRTT. As in Experiment 4, the rhythms were constructed by chaining short (400 ms), medium (800 ms) and long (1200 ms) IOIs. The basic exposure and test rhythms contained 11 IOIs, and these rhythms were cycled 10 times in a sequence/block (i.e. 110 syllables per sequence).

Both the exposure and test rhythms had an equal number of medium (800 ms) and long (1200 ms) IOIs. These were directly transposed across the two rhythms so that 800 ms IOIs in the exposure rhythm became 1200 ms IOIs in the test rhythm. Likewise, 1200 ms IOIs in the exposure sequence became 800 ms IOIs in the test sequence. The IOI chaining in the exposure rhythm was 800-1200-400-400-800-400-1200-400-400-1200-800, and the IOI chaining in test rhythm was 1200-800-400-400-1200-400-800-400-400-1200-800. As in Experiment 4, the two rhythms were identical in terms of grouping structure. This is illustrated in Figure 4.4.
Figure 4.4. Experiment 5 rhythms (Exposure and Test): “X” represents a syllable, and digits indicate the serial positions of the syllables. Bold and regular overscores indicate syllable positions aligning with strong beats (accented with 6dB amplitude increases) and moderate beats (accented with 3dB amplitude increases), respectively. Horizontal arrows represent IGIs (inter-group intervals), and vertical lines represent the hypothesised metrical structure (the longer the line the stronger the perceived beat). The rhythms cycled 10 times per block.

As in Experiment 4, metrical strength of the exposure and test rhythms was calculated (see Experiment 4, Method section for more details). At the 5-unit level (clock pulse of 2000 ms with five 400 ms subdivisions), the C-scores for the exposure and test rhythms were zero and one, respectively, indicating that both rhythms were strongly metrical.

The constraints on syllable order, stimulus construction, addition of amplitude accents and experimental presentation were identical to Experiment 4. The exposure
and test sequences were 1 min and 20 s. Two practice sequences with 5 cycles (40 s) of the basic exposure rhythm were created.

4.3.1.2.2. Post-tests. Post-test sequences were one cycle of the chaining of the 11 IOIs of the exposure and test rhythms. As in Experiment 4, to account for participants potentially segmenting the SRTT sequences at different strong beats, four versions of the exposure and test rhythm were created, each starting at a different strong beat.

In addition to the Exposure and Test post-test sequences, a novel uneven meter rhythm was created. The grouping structure of the Novel sequence was 1-3-1-2-2-2; X..XXX.X..XX..XX.XX. (“X” represents a syllable, a full stop(s) represents a 400 ms IOI, and bold font indicates a syllable aligning with a strong beat). Four versions of the novel post-test sequence began on different strong beats.

The Novel pattern was strongly metrical and had a C-score comparable to the exposure and test rhythms (5-unit C-score = 1). As in the SRTT, for all sequences, syllables aligning with strong beats had an amplitude accent of 6dB and syllables aligning with moderate beats had an amplitude accent of 3dB. The syllables used in the post-test sequences (“Pa”, “Ta”), and the method for creating the AIFF files was as per Experiment 4.

4.3.1.3. Procedure

4.3.1.3.1. SRTT. The procedure was identical to that in Experiment 4. However, participants were presented with eight exposure blocks of the uneven meter exposure rhythm (Blocks 1 to 8). This was followed by two test blocks presenting the uneven meter test rhythm (Blocks 9 and 10), and a final block of the exposure rhythm (Block 11).
4.3.1.3.2. Post-tests. The procedure was identical to that in Experiment 4. Participants responded to all four randomly presented post-test sequences from the Exposure, Test, and Novel sets and completed the associated familiarity and certainty ratings.

4.3.2. Results

4.3.2.1. SRTT

The temporal window for including correct responses was as per Experiment 4. Mean accuracy to syllables was significantly above chance (50%); 65.70%, $SD = 6.52\%$, $t(14) = 9.33$, $p = .00^{17}$.

4.3.2.1.1. Mean RT to all correct responses over exposure blocks. As with Experiment 4, only data from participants demonstrating faster RT at Block 8 compared to Block 1 were analysed and consequently it was expected that RT would decrease across exposure blocks. This decrease was statistically assessed. RT to syllables was averaged for each block and an ANOVA with Block (Blocks 1–8) as a within-subject factor was conducted (Figure 4.5). The effect of block was significant, $F(7, 98) = 7.14$, $p = .00$, partial $\eta^2 = .34$. RT at Block 8 was significantly faster than at Block 1, $p = .00$.

4.3.2.1.2. Mean RT to all correct responses over test blocks. To investigate the effect of changing the uneven meter rhythm at the test blocks, a 2 x 2 ANOVA with Block (mean exposure Blocks 8 and 11, mean test Blocks 9 and 10) as a within-subject factor was conducted. The effect of Block was not significant, $F(1, 14) = 3.89$.

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17 Appendix D reports accuracy over blocks and correlations between RT and accuracy.
$p = .07$, partial $\eta^2 = .22$, but Figure 4.5 shows that some learning of the test rhythm was evident at the second test block (Block 10). The first test block (Block 9) was compared to the immediately preceding exposure block (Block 8) with an ANOVA with Block (Block 8, Block 9) as a within-subject factor (Figure 4.5). This revealed a significant effect of Block, $F(1, 14) = 5.07, p = .04$, partial $\eta^2 = .27$.

![Figure 4.5](image_url)

*Figure 4.5. Experiment 5: Correct RT to syllables over blocks. Error bars show standard error of the mean.*

**4.3.2.1.3. Mean RT to post-IGI syllables over exposure blocks.** RT to syllables following IGIs (positions 1, 2, 3, 6, 8, and 11, see Figure 4.4) was averaged for each block and an ANOVA with Block (Blocks 1 – 8) as a within-subject factor was conducted. The effect of Block was significant, $F(7, 98) = 9.24, p = .00$, partial $\eta^2 = .40$. RT at Block 8 ($M = 384.49$ ms, $SE = 10.81$) was significantly faster than at Block 1 ($M = 433.61$ ms, $SE = 11.23$), $p = .00$. 

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4.3.2.1.4. Mean RT to post-IGI syllables at the first test block. Mean RT to post-IGI syllables at Block 8 and Block 9 was calculated and an ANOVA with Block (Block 8, Block 9) as a within-subject factor was conducted. There was a significant effect of Block, \( F(1, 14) = 8.62, p = .01, \) partial \( \eta^2 = .38, \) with RT increasing at the first test block (Block 9) (Figure 4.6).

4.3.2.1.5. Mean RT to within-group syllables over exposure blocks. RT to within-group syllables (positions 4, 5, 7, 9, and 10, see Figure 4.4) was averaged for each block and an ANOVA with Block (Blocks 1–8) as a within-subject factor was conducted. The effect of Block was not significant, \( F(7, 98) = .90, p = .51, \) partial \( \eta^2 = .06. \) Although in the expected direction, RT at Block 8 (\( M = 350.83 \text{ ms}, SE = 10.11 \)) was not significantly faster than at Block 1 (\( M = 364.86 \text{ ms}, SE = 10.89 \)).

4.3.2.1.6. Mean RT to within-group syllables at the first test block. Mean RT to within-group syllables at Block 8 and Block 9 was calculated and an ANOVA with Block (Block 8, Block 9) as a within-subject factor was conducted. While RT increased at the test block, this increase was not significant, \( F(1, 14) = 1.29, p = .28, \) partial \( \eta^2 = .08 \) (Figure 4.6).
4.3.2.2. Post-tests

An open-ended question asked participants to describe any regularity in the timing of the presentation of the syllables. Of the fifteen participants, nine reported that there were pauses between some syllables. However, none of the participants were able to report the rhythm correctly. Familiarity ratings to the Exposure sequences, Test sequences, and Novel sequences were compared. Ratings (1 = very unfamiliar through to 6 = very familiar) were collapsed across the four presentations of each sequence to obtain a mean rating (Table 4.3). These were analysed with an ANOVA with Post-test Sequence as a within-subject factor (Exposure, Test, Novel). There was no effect of Post-test Sequence, $F(2, 28) = 1.00, p = .38$, partial $\eta^2 = .07$. Participants were not more familiar with their Exposure sequence than the test or novel sequences.
Nonetheless, aware participants were identified using the same criteria as in Experiment 4 (i.e. mean z-familiarity score greater than zero and mean certainty rating to the exposure sequences equal to, or greater than four; 4 = somewhat certain). Using these criteria, 5 aware participants were identified. To ensure that the result at the first test block was not due to awareness, further analyses were conducted. Given that the “aware” and “unaware” groups were highly unbalanced in size, data were re-analysed with unaware participants only. An ANOVA was conducted with Block (Block 8, Block 9) as a within-subject factor.

4.3.2.2.1. Post-IGI syllables and within-group syllables: unaware participants only. For Post-IGI syllables, there was a main effect of Block, $F(1, 9) = 13.88, p = .01$, $\eta^2 = .61$ but for within-group syllables, there was no effect of Block, $F(1, 9) = .00, p = .95$, $\eta^2 = .00$. These results are consistent with those conducted on the full sample and show that the aware participants did not drive the effects in the main test block analyses.

Table 4.3

**Experiment 5: Post-test Familiarity (1 = very unfamiliar, through to 6 = very familiar) and Certainty (1 = complete guess, through to 6 = completely certain)**

*Mean Ratings and Standard Deviations presented as a function of Sequence Type*

<table>
<thead>
<tr>
<th></th>
<th>Familiarity</th>
<th></th>
<th>Certainty</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exposure</td>
<td>Test</td>
<td>Novel</td>
<td>Exposure</td>
</tr>
<tr>
<td></td>
<td>$M$  $SD$</td>
<td>$M$  $SD$</td>
<td>$M$  $SD$</td>
<td>$M$  $SD$</td>
</tr>
<tr>
<td>Exposure</td>
<td>3.95  .90</td>
<td>3.82  0.51</td>
<td>3.57  1.01</td>
<td>4.10  0.51</td>
</tr>
</tbody>
</table>
4.3.3. Discussion

While RT decreased over exposure blocks, this decrease was primarily due to syllables following the more difficult-to-process IGIs (post-IGI syllables). There was also an overall RT increase at the first test block indicating that the uneven meter exposure rhythm in Experiment 5 was learned. As the number of medium (800 ms) and long (1200 ms) IGIs were now held constant across exposure and test blocks, this RT increase at the first test block cannot be accounted for by a discrepancy in the number of these IGIs.

Unlike the uneven exposure condition of Experiment 4, where a benefit from the even meter test block was may have contributed to the lack of RT increase, there was a significant RT increase to Post-IGI syllables at the uneven meter test block. This suggests further that in Experiment 4, the familiar even meter of the test block facilitated prediction of the longer and more difficult-to-process IGIs. Therefore, by presenting a rhythm with an uneven meter at the test block, (i.e. without the benefit of the more familiar even meter), we were able to demonstrate learning of a rhythm with an uneven meter. Finally, learning was implicit with; (a) participants in the post-test being no more familiar with their exposure and test rhythms, compared to a novel rhythm, and (b) unaware participants showing a significant test block increase to post-IGI syllables.

4.4. General Discussion

Learning of temporal structures, or rhythms, acquired via exposure to sequences of auditory events, leads to the development of temporal expectations. This facilitates prediction of the timing of upcoming events and results in faster processing of events occurring at the expected time points (e.g. Jones, et al., 2002; Tillmann &
Lebrun-Guillaud, 2006). In a laboratory setting, the current study investigated implicit learning of rhythms through short-term exposure to sequences of syllables with defined temporal structures. Importantly, the role of established expectations of meter (i.e. acquired via long-term exposure to rhythms) in learning rhythms was addressed. Listeners with lifelong experience of primarily Western tonal music were presented with rhythms with a relatively familiar even meter or a relatively unfamiliar uneven meter.

Broadly, rhythms with both metrical structures were learned. However, in Experiment 4, there was some performance advantage for an even meter. Although not significant, RT was faster in the Even, compared to Uneven Meter condition. Also in Experiment 4, RT to post-IGI and within-group syllables increased at the first test block (relative to the prior exposure block) when a rhythm with the alternate meter was presented. The exception was in the Uneven Meter condition (Experiment 4) when a rhythm with a familiar even meter was introduced at test. There was no RT increase to post-IGI syllables as the familiarity of the even meter facilitated participants’ prediction of more difficult-to-process IGIs (i.e. medium and long IOIs). This supports the findings of Brandon et al. (2012) who reported that after exposure to a rhythm with a relatively less familiar triple meter, RT to syllables following the longer IOIs did not increase at the introduction of a new rhythm with a more familiar duple meter. A familiar meter may activate a temporal grid that allows for the development of more accurate expectations of IOIs, even those extending beyond the pulse level.

A firm conclusion cannot be drawn from the additional analyses based on awareness in Experiment 4 as the three-way interaction just fell short of significance. However, differences in explicit knowledge of the uneven meter rhythms acquired
during exposure may have modulated the effect of introducing a familiar even meter at the test block. Participants *without* explicit knowledge in fact tended to show an RT increase to post-IGI syllables at the first test block when presented with the even meter rhythm, whereas it was those *with* explicit knowledge that showed no increase. The presence of the expected RT increase to these syllables in the participant group without explicit knowledge might demonstrate the benefit of implicit learning, over explicit learning of complex, and culturally less familiar rhythms. Explicit, compared to implicit, strategies have been shown to be detrimental to learning complex visual-spatial sequences (Fletcher, et al., 2005; Howard & Howard Jr, 2001; Song, et al., 2007), but it is unknown as to whether the same applies to learning complex auditory-temporal stimuli.

In Experiment 5, the role of meter at the test block was investigated further with uneven meter rhythms presented across both exposure and test blocks. In this case, when participants did not have the benefit of the even meter at test, RT increased for both the within-group and post-IGI syllables. This effect remained when a small number of participants with explicit knowledge of the exposure rhythm were excluded from the analysis. Consequently, Experiment 5 confirmed that rhythms with uneven meters can be implicitly learned.

Dynamic Attending Theory has been proposed to explain the development of temporal expectations (Jones & Boltz, 1989; Large & Jones, 1999; Large & Kolen, 1994). The evidence in support of this theory has used simple isochronous tone sequences to prime the temporal context (Jones, et al., 2002). Furthermore, using both explicit and implicit testing protocols, exposure to non-isochronous temporal structures more typical of musical rhythms have been shown induce temporal expectations (Brandon, et al., 2012; Ellis & Jones, 2010; Jones & Boltz, 1989; Jones,
et al., 1982; Schultz, et al., 2013; Tillmann, et al., 2011). Jones and colleagues (Large & Jones, 1999; Large & Kolen, 1994) propose that exogenous rhythms activate neural oscillations that drive attention to periodic time points, facilitating processing of events occurring at those time points. It is possible that recurrent neural oscillation underpins the development of long-term expectations and the learning of rhythmic structures (Jones, 2009). In Experiment 4, neural oscillatory processes may have guided temporal expectations to evenly spaced periodicities at multiple levels of the metric hierarchy, enhancing processing of events aligning with these points in time and facilitating the processing of longer IOIs in the even meter rhythms (Barnes & Jones, 2000; Jones & Boltz, 1989; Large & Jones, 1999).

Yet, it remains unclear as to how Dynamic Attending Theory can account for the development of temporal expectations (via learning) of rhythms with periodicities that are unequally spaced in time (i.e. rhythms with uneven meters). While not explaining neural oscillation to rhythms with uneven meters, a non-linear resonance model has been proposed to account for temporal processing of complex syncopated rhythms – rhythms with equally spaced strong beats but with auditory events frequently aligning with weak beats but often being absent on strong beats (Velasco & Large, 2011). How such a model might apply to rhythms with uneven meters requires further work. Neural networks, modelling learning of cross-cultural tonal structures (e.g. Indian thatа Bhairav, North Sami yoiks, Finnish folk songs), have been previously developed and highlight the importance of convergent approaches (i.e. behavioural and computational) in understanding the development of expectation (Curtis & Bharucha, 2009; Krumhansl, 2000b; Krumhansl, et al., 1999; Krumhansl, et al., 2000). In the temporal domain, it may be that oscillatory processes can allow for the perception of regular, but complex temporal structures (i.e. with uneven meters)
via long-term exposure to these rhythms, or enculturation. Indeed, listeners with a lifetime’s exposure to rhythms with uneven meters (e.g. Macedonian and Turkish adults) process these rhythms more effectively than listeners primarily exposed to Western tonal music (i.e. with mostly even meters) (e.g. Hannon, Soley, et al., 2012; Hannon & Trehub, 2005a).

Previous research has demonstrated that exposure to music with uneven meters (i.e. 2 weeks at-home listening to music presented on a CD) does somewhat improve adults’ processing of these rhythms (as measured with a similarity judgement pre- and post-exposure task). However, processing does not reach the level of those with long-term exposure to uneven meters (Hannon & Trehub, 2005b). The experiments reported here using an SRTT in an experimental setting reveal that adults without a lifetime’s exposure to uneven meters can learn rhythms with these meters. It is important to note that the purpose of our experiments was to investigate learning of particular rhythms, rather than to investigate the effects of exposure to a set of rhythms instantiated in musical pieces on the processing of uneven meters more broadly (as per Hannon and colleagues). Yet, the SRTT may provide an opportunity to examine the effects of implicit learning of particular rhythms on the subsequent learning of new uneven meter rhythms and to assess the capacity of listeners to acquire new temporal expectations of metrical structure. An important advance for research examining temporal processing would be a validation of the Povel and Essens (1985) measure of metrical strength (C-score) when applied to uneven meters. Testing this measure against perception and production performance of temporal structures with uneven meters by listeners with lifetime exposure to these meters would benefit future research.
It is possible that the motor-responses required in the SRTT may contribute to enhanced learning, over and above mere listening. The distinction between motor learning (associative learning of successive responses) and perceptual learning (associative learning of successive stimuli) has been addressed using visual SRTTs in which participants learn ordinal structures (i.e. sequences of spatial locations) (e.g. Deroost & Soetens, 2006; Mayr, 1996). Evidence suggests that perceptual learning benefits from concurrent motor learning when visual-spatial sequences are complex. While complexity in the visual-spatial domain is not directly analogous to meter - a possible proxy of complexity in the auditory-temporal domain – the distinction between perceptual and motor learning of temporal material requires further study. However, given that the performance of Balkan folk songs characterized by uneven meters is frequently associated with dance (Fracile, 2003; Singer, 1974) and that research with infants indicates that movement influences perception of duple and triple meters (Phillips-Silver & Trainor, 2005), it can be hypothesised that motor learning plays an important role. The importance of movement has implications in pedagogical and rehabilitation settings. Exposure to complex sequential structures (e.g. music, language and motor sequences that require precise timing) that engage implicit learning processes and are associated with rhythmic movements may offer an efficient way of improving task performance when explicit instructions are prohibitive. Finally, cross-cultural musical structures offer diverse opportunities to explore the applicability of current theories in the research domains music cognition, perception of meter and implicit learning (Rohrmeier & Rebuschat, 2012; Stevens, 2004) and the research reported here demonstrates the capacity of listeners to implicitly learn novel rhythms with both culturally familiar and less familiar meters.
Chapter 5 Preface

In Experiments 4 and 5 (reported in Chapter 4), listeners with a lifetime’s exposure to Western tonal music implicitly learned rhythms with culturally familiar (i.e. even) and less familiar (i.e. uneven) meters. However, there was some benefit provided by the relatively familiar even meter. In Experiment 6 (reported in Chapter 5), a direct comparison of IL of the two rhythms (i.e. even and uneven) is made over exposure blocks (and at subsequent test blocks). To ensure that any performance differences across the two rhythms are due to meter, and not to differences in the IGIs, the temporal structures will be identical. Meters will be instantiated with the appropriate placement of amplitude accents.
Chapter 5

Implicit Learning of Rhythms with Identical Temporal Structures but Culturally Less Familiar Even and Uneven Meters
5. Implicit Learning of Rhythms with Identical Temporal Structures but Culturally Familiar Even and Less Familiar Uneven Meters

5.1. Introduction

When listeners perceive complex sequences of auditory events (e.g. speech and music), they benefit from abstracting a structure from the sequence, for instance, a systematic patterning in the order of events (ordinal structures) or regularity in the timing with which events occur. Perceiving repetition or statistical regularity allows listeners to develop expectations about upcoming events and promotes faster and more accurate responses to the events (Escoffier, et al., 2010; Perruchet, 2008; Perruchet & Pacton, 2006; Tillmann & Lebrun-Guillaud, 2006). One way in which expectations are acquired is via mere exposure to event sequences and, as a consequence, repeating patterns or regularities are learned. Learning can occur implicitly, that is, without attention being directed to the structure, and without an intention to learn. In addition, the regularities are difficult for the learner to describe (Cleeremans, et al., 1998; Curran & Keele, 1993; Destrebecqz & Cleeremans, 2001; Shanks, 2005)

5.1.1. Even Meters Typical of Western Tonal Music and their Effect on Processing Rhythms

In the laboratory setting, research has demonstrated implicit learning (IL) of ordinal structures (i.e. the order of sequential events) in the visual and auditory domains (Buchner, et al., 1997; Nissen & Bullemer, 1987; Reed & Johnson, 1994; Zhuang, et al., 1998). However, less research has examined IL of auditory temporal
structures (i.e. the timing with which sequential events are presented) (see Rohrmeier & Rebuschat, 2012 for a review). The current study investigates IL of auditory temporal structures, or rhythms, that have a particular form of regularity typical of much of the world’s music, meter.

Temporal structures are defined by repeating sequences of inter-onset intervals (IOIs). When all IOIs are of equal duration, the temporal structure is isochronous, with every event being presented at equally spaced points in time. However, when multiple IOIs are present, a grouping structure is perceived. Events (e.g. musical tones) within groups are separated by relatively short IOIs, and longer IOIs form boundaries around the groups (inter-group intervals, IGIs) (see Figure 5.1). An isolated event bounded by longer IOIs (i.e. IGIs) is also considered to be a group (Handel, 1998; Lerdahl & Jackendoff, 1983).

Meter is an additional regularity that characterises a temporal structure, or rhythm, and is the perception of regular alternating patterns of strong and weak beats. A temporal structure can be organised according to its relationship to the regularity of these strong and weak beats. Beats are endogenous, psychological events that occur in response to an exogenous, or external temporal structure or rhythm (Large, 2008). Beats are internally generated and are not experienced as having a duration but are rather experienced as periodic, evenly spaced or isochronous points in time that give rise to a sense of pulse to which listeners entrain, or synchronise (Lerdahl & Jackendoff, 1983). In fact, a beat can be experienced in the absence of an event onset (Large & Snyder, 2009). Meters have hierarchical structures with the IOIs between beats extending over longer timescales at each progressive level of the hierarchy. When beats align at multiple levels in the hierarchy, they are perceived as strong (Lerdahl & Jackendoff, 1983; Palmer & Krumhansl, 1990). Research with adults and
infants has shown that temporal structures with strongly established meters are perceived and reproduced more accurately than temporal structures that are weakly metrical, or non-metrical (Bergeson & Trehub, 2006; Ellis & Jones, 2010; Grahn & Brett, 2007; Grube & Griffiths, 2009; Hébert & Cuddy, 2002; Patel, et al., 2005; Povel & Essens, 1985).

Meter can arise from the grouping structure of a rhythm. Isolated events, the second in a group of two events, and the first and last of a group of three or more events, are perceived as being accented, or louder than adjacent events (Povel & Essens, 1985; Povel & Okkerman, 1981). The strength of the emergent meter is related to (a) the number of events that align with perceived beats, and (b) whether the event aligning with a beat is subjectively accented (due to the event’s location in the grouping structure). The more accented the events aligning with beats, the stronger the perceived meter. Meter can also arise when particular events are accented with an amplitude increase, or brief increase in intensity. When amplitude-accented events regularly align with beats, these beats are perceived as strong, and the periodicity of these strong beats defines the metrical structure (Palmer & Krumhansl, 1990).

For instance, in Western tonal music strong beats at every hierarchical level are evenly spaced and, consequently, rhythms with these beat structures have even meters. Strong beats at one level align with strong beats at the next highest level according to fixed 2:1 binary or 3:1 ternary ratios. Binary ratios, or duple meters, are characteristic of “march” rhythms (strong-weak) whereas ternary ratios, or triple meters, are characteristic of “waltz” rhythms (strong-weak-weak) (London, 2002).

Although the rhythms of Western tonal music typically have duple and triple meters, duple meters are more common (Fraisse, 1982). Research with adults and infants indicates that the relative familiarity of duple, over triple, meters improves
processing of rhythms with these meters (Abecasis, et al., 2005; Bergeson & Trehub, 2006; Brandon, et al., 2012; Drake, 1993; K. C. Smith & Cuddy, 1989). Evidence that a processing advantage for a duple, over a triple meter is a consequence of early exposure comes from an infant study. Phillips-Silver and Trainor (2005) reported that 7-month old infants preferred rhythms with meters that corresponded to the way the infants were bounced during exposure to a metrically ambiguous rhythm. Infants that were bounced on every second beat preferred rhythms with duple meters and those bounced on every third beat preferred rhythms with triple meters. This result suggests that the processing advantage for duple meters evident with adult listeners is a function of early vestibular-auditory interactions. In the current study, we examine learning of rhythms that have relatively familiar and unfamiliar meters to listeners of Western tonal music. However, rather than both meters being typical of Western tonal music, we investigate IL of rhythms with culturally familiar and culturally less familiar meters; even and uneven meters, respectively.

5.1.2. Uneven Meters Processed with Difficulty by Listeners of Western Tonal Music

Uneven meters are typically present in rhythms of the Balkan region (e.g. Macedonia, Bulgaria, Hungary and Greece), the Middle East, South-Asia, West Africa and Latin America. While these meters have strong beats evenly spaced at the lowest and highest levels of the hierarchy, they have uneven spacing between strong beats at an intermediate level of the hierarchy (Fracile, 2003; Moelants, 2006; Singer, 1974). This gives rise to a perception of cycles of strong-weak-strong-weak-weak or strong-weak-weak-strong-weak patterns, being anapaestic and dactylic meters, respectively. In the current study, the influence of familiarity with meter (via a lifetime’s exposure to culturally-specific rhythms) on learning of rhythms is examined.
We investigate the capacity of listeners of primarily Western tonal music to implicitly learn rhythms with relatively familiar even and unfamiliar uneven meters.

Experiments using synchronisation and reproduction tasks, as well as rhythm discrimination tasks have revealed that long-term exposure to culturally specific meters influences processing of rhythms with culturally less familiar meters. Both non-musicians and musicians with primarily exposure to Western tonal music find it difficult to synchronise with and to reproduce rhythms with uneven meter meters (Repp, et al., 2005; Snyder, et al., 2006). Hannon and Trehub (2005a) reported that North American adults were better at detecting alterations in melodies with even, compared to uneven, meters. However, adults from Macedonia and Bulgaria, having had exposure to both even and uneven meters, were equally accurate at detecting alterations in melodies with both meters (see also Hannon, Soley, et al., 2012; Kalender, et al., 2012). These findings suggest that the relative ease with which meters are processed develops through the process of early enculturation (Clayton, et al., 2004; Large & Palmer, 2002).

Research also indicates that for adult listeners of primarily Western tonal music, the even meter bias is enduring and resistant to passive exposure. Listening passively to music with uneven meters (over a period of two weeks) facilitates perception of these meters in twelve-month old infants (Hannon & Trehub, 2005b) and younger children (5- and 7-year olds). However, older children (11-year olds) and adult listeners do not appear to benefit from exposure to uneven meters (Hannon, Vanden Bosch der Nederlanden, et al., 2012). In the current study, learning of rhythms with even and uneven meters is examined using an IL paradigm. It has previously been proposed that IL is a powerful means through which listeners develop temporal expectations (Salidis, 2001; Tillmann, et al., 2011). Therefore, in an IL
context, we examine whether listeners, primarily exposed to Western tonal music can equally learn rhythms with even and uneven meters, and whether there is a performance advantage provided by the more familiar even meter.

5.1.3. Implicit Learning of Rhythms

The IL method employed is an auditory serial reaction time task (SRTT). In these tasks, participants detect or identify auditory events presented in sequences with defined temporal structures. In previous experiments, the events themselves are either held constant (e.g. a beep, Salidis, 2001) or are presented in a random, or pseudo-random order (e.g. spoken syllables Brandon, et al., 2012; Tillmann, et al., 2011). Therefore, the only learnable structure is in the temporal presentation of events. Participants performing the task are not informed of the presence of a temporal structure, or rhythm, but are instead instructed that they are performing a detection or identification task. Typically, RT to events decreases with exposure to the temporal sequences. The rationale is that temporal expectation develops via learning of the rhythms and consequently, the perception of events is facilitated. When a new rhythm (Brandon, et al., 2012) or a random chaining of IOIs (Salidis, 2001) is presented in a test block, RT increases. In terms of the role of meter in learning rhythms, IL of both non-metrical (Salidis, 2001) and metrical rhythms has been demonstrated (Brandon, et al., 2012; Tillmann, et al., 2011). Brandon (2012) reported learning of rhythms with duple and triple even meters and demonstrated that after exposure to a rhythm with a triple meter, the more familiar duple meter rhythm presented at the test block facilitated responses to syllables following longer, and more difficult-to-process, IOIs.

Tillmann et al. (2011) investigated IL of rhythms with orderings of fixed short and long inter-onset intervals (IOIs): short-short-long. The short and long intervals in
one sequence had a simple integer ratio relationship (1:2) and thus these rhythms had an even meter. In a second sequence, the short and long intervals had a complex ratio relationship (1:1.5) and had an uneven meter. Participants, with exposure to primarily Western tonal music, identified randomly ordered syllables (“Pa”, “Ta”) presented according to these defined rhythms. In both the simple and complex ratio conditions, RT to identify the syllables decreased with exposure. Furthermore, this exposure led to reduced variability in tap timing in a subsequent production task (compared to a group of participants performing the production task without prior exposure). Over exposure, the decrease in RT was particularly evident for syllables following the long IOI in the temporal structure based on the complex 1:1.5 ratios. This suggests that participants were tending to adapt their RT to a 1:1 timing ratio between all events, and assimilating their timing to fit a familiar even meter structure. Although no test block was presented (i.e. testing the effect of the violation of temporal expectation) and the extent of awareness was not formally assessed, the overall findings suggest that temporal expectations of rhythms with culturally familiar and less familiar meters can be acquired when the temporal structures are incidental to the task.

In a previous experiment (Experiment 4 reported in Chapter 4 of this thesis), IL of rhythms with even and uneven meters was explored further. Rather than presenting repeating sequences of three IOIs (i.e. short-short-long), the rhythms were more complex, with repeating sequences of 10 and 11 IOIs in the even and uneven meter rhythms, respectively. As with Brandon et al. (2012) and Tillmann et al. (2011), participants identified pseudo-randomly presented syllables (“Pa”, “Ta”) in sequences with the defined rhythms. After exposure to the rhythm with the even meter, test blocks with the uneven meter rhythm were presented. Conversely, after exposure to the rhythm with an uneven meter, test blocks with the even meter rhythm were
presented. The introduction of the test blocks allowed for an investigation of the effects of violating temporal structure, and also permitted an examination of the influence of meter on these effects. While both even and uneven meter rhythms were learned over exposure, there was a trend for RT to the syllables in the uneven meter rhythm to be slower than in the even meter rhythm. After exposure to an even meter rhythm, RT increased when a test block with an uneven meter rhythm was presented. However, after exposure to an uneven meter rhythm, RT to syllables following the IGIs (i.e. longer IOIs) did not increase when an even meter rhythm was presented in a test block, as would have been expected with a temporal violation. Consistent with Brandon et al. (2012), it was concluded that the more familiar even meter at the test block provided an advantage for the prediction of the longer, and more difficult-to-process IGIs. However, in a follow up experiment, when an uneven meter was maintained across exposure and test block rhythms, RT increased at the test block, indicating that uneven meters can be learned.

5.1.4. Rationale of Experiment 6

In Experiment 6, two important constraints on the stimuli and design are applied. The first maintains meter across exposure and test blocks in the two meter conditions; (a) even meter exposure and even meter test; and (b) uneven meter exposure and uneven meter test. The second and most crucial constraint allows a precise comparison between the even and uneven meter rhythms over exposure blocks. This will be achieved by tightly controlling the temporal structure of the two exposure rhythms.

In the first of the two experiments reported in Chapter 4 of this thesis, the rhythms were designed so that the grouping structures across the even and uneven
meter rhythms were identical. This meant that RT differences between the even and uneven meter rhythms during exposure could not have been due to differences in the size and ordering of groups (i.e. differences in grouping structure). Neither could a change in grouping structure between exposure and test account for RT changes at the test block. However, keeping constant the grouping structures across the even and uneven meter rhythms meant that the IGIs were different between the two rhythms. While both rhythms contained two IGIs (medium: 800 ms, long: 1200 ms), the uneven meter rhythm contained three medium and three long IGIs, whereas the even meter rhythm contained four medium and only one long IGI\textsuperscript{18}. It is possible that the RT difference across the even and uneven meter exposure blocks may have been due to these local temporal features. Specifically, the greater number of long IGIs in the uneven meter rhythm, compared to the even meter rhythm, may have promoted slower RT. Likewise, the RT increase at the uneven meter test block in the Even Meter condition may have been driven by the greater number of long IGIs in the uneven meter rhythm. However, these IGI difference cannot fully account for the effects as in Experiment 5 (Chapter 4), the uneven meter exposure rhythm and uneven meter test rhythm had equal numbers of medium and long IGIs, yet an RT increase at the first test block was demonstrated.

Variable foreperiod effects (Capizzi, et al., 2012; Correa, et al., 2004; Ellis & Jones, 2010) can also not explain the results of Experiment 4 (Chapter 4). According to the variable foreperiod effect, RT slows to an event when it is preceded by a shorter, compared to longer, IOI. According to this effect, in Experiment 4, RT should have been slower to the even, compared to the uneven, meter rhythm as there were

\textsuperscript{18} Note that RT to the syllables following the last of the three long IGIs in the uneven meter rhythm was not included in the analyses. See the Results section in Experiment 4, Chapter 4 for an explanation.
more medium IGIs in the even meter rhythm. However, the reverse was found: RT was slower to the uneven meter rhythm containing more long than medium IGIs, compared to the even meter rhythm containing more medium than long IGIs.

Despite these counter-arguments the differing numbers of medium and long IGIs, and the variable foreperiod effect, can not account for the effects in Experiment 4, the purpose of the current study is nonetheless to control the duration of IGIs across rhythms to ensure a precise comparison of meter. Consequently, the even and uneven meter exposure rhythms employed in the current experiment have identical temporal structures (i.e. grouping structure, number and durations of IGIs, and the chaining of groups and IGIs) but differ only in the location of amplitude accents. Thus, RT differences between the even and uneven meter rhythms can only be accounted for by the differences in metrical structure arising from amplitude accent placement.

As a consequence of controlling the exposure sequences in this manner and by ensuring that the even and uneven meters were strong, test rhythms had different grouping structures than exposure rhythms. Specifically, while the exposure and test rhythms had the same number of groups of the same size, the chaining of the groups differed. The two test rhythms (i.e. even meter and uneven meter) were constructed according to the same principle as the exposure rhythms, having identical temporal structures but differing in the location of amplitude accents so as to elicit different metrical structures. Again, this allowed for a precise comparison across the even and uneven meter conditions at the test blocks.

5.1.5. Summary of Aims

The aims for Experiment 6 are as follows. Firstly, IL of rhythms with even and uneven meters is compared over exposure blocks. Secondly, the effect of
temporal violation at the test blocks is examined with the presentation of a rhythm with a new temporal structure, but the same meter as the exposure rhythm. Performance at the test blocks will also be compared across the even and uneven meter conditions. Thirdly, the effects of meter and temporal violation on learning the IGIs and the short IOIs between syllables within groups are examined.

Finally, the implicitness of learning will be determined. In a post-test phase, participants will rate their familiarity with their exposure and test rhythms, as well as the exposure rhythm presented in the alternate meter condition, and a novel rhythm with the same meter as during exposure.

5.1.6. Design

The within-subject variable is Block, to enable a comparison across exposure Blocks 1 to Block 8, and a comparison of the two test blocks (Block 9 and 10) with the adjacent exposure blocks (Block 8 and Block 11). The between-subject variable is Meter (Even, Uneven) and the dependent variable is correct RT to syllables. Consistent with previous research (Brandon, et al., 2012) and experiments reported in this thesis, analyses will be conducted separately for syllables following IGIs (i.e. post-IGI) and syllables immediately following another syllable (i.e. within group). These post-IGI and within-group analyses will test for the effect of a familiar meter on the relatively difficult-to-process long IOIs (measured by RT to post-IGI syllables) and the relatively easy-to-process short IOIs (measured by RT to within-group syllables).

In the post-test phase, the within-subject variable is Post-test sequence (Exposure, Test, Exposure with alternate meter, Novel), with Meter condition (Even,
Uneven) as the between-subjects variable. The dependent variable in the post-test phase is familiarity rating.

5.1.7. Hypotheses

It is hypothesised that RT to identify syllables will be slower in the Uneven compared to the Even Meter condition and while RT will decrease over Blocks 1 to 8 in both conditions, the decrease will be greater in the Even Meter, compared to the Uneven Meter condition. This is expected to be particularly the case for post-IGI syllables. At the test blocks, it is hypothesised that RT will increase with the mean RT of the two test blocks significantly slower than the mean of the two adjacent exposure blocks and it is hypothesised that this increase will be greater in the Even, compared to Uneven Meter condition. Again, these two effects are expected particularly for the post-IGI syllables. Finally, it is hypothesised that learning will be implicit with participants rating exposure, test and novel sequences as equally familiar/unfamiliar.

5.2. Experiment 6: Implicit Learning of Rhythms with Identical Temporal Structures but Culturally Familiar Even and Less Familiar Uneven Meters

5.2.1. Method

5.2.1.1. Participants

Forty-one undergraduate students and staff from the University of Western Sydney took part in exchange for course credit or were given twenty dollars.
Participants were randomly assigned to either the Even Meter ($N = 20$) or Uneven Meter condition ($N = 21$). Z-tests were conducted to identify participants performing significantly above chance ($p < .05$). The $z$-test returns the probability that the mean of all of a participant’s blocks is greater than 50%, taking into account the variability across blocks. Six participants in the Even Meter condition and seven participants in the Uneven Meter condition performed either below chance or not significantly above chance. Sub-optimal syllable identification was likely driven by the difficulty of the task, as the speed of the presentation of syllables was rapid (i.e. shortest IOI of 400 ms) (see Materials section). Data from these participants were excluded from the analyses. Applying this exclusion criterion resulted in a sample of 28 participants.

The eight females and six males in the Even Meter condition had a mean age of 20.86 years ($SD = 2.07$ years, range = 18 – 24 years), and the nine female and five males in the Uneven Meter condition had a mean age of 27.14 years ($SD = 9.32$ years, range = 18 – 51 years).

The two participant groups were equivalent in terms of years of musical training. Participants in the Even Meter condition had a mean of 2.23 years of training ($SD = 3.15$ years, median = .13) and participants in the Uneven Meter condition had a mean of 1.50 years of training ($SD = 1.99$ years, median = .5). The levels of musical training did not differ significantly across the two conditions ($p = .47$).

All participants had self-reported normal hearing and were native English speakers. Four participants were bilingual (Mandarin, Italian, Japanese, Assyrian). No participant reported exposure during childhood to music of the Balkan region, or other music characterised by uneven meters. Likewise, no participant reported having had recent exposure to music with uneven meters.
5.2.1.2. Materials

5.2.1.2.1. SRTT. The rhythms were constructed by chaining short (400 ms), and long (800 ms) IOIs. The shortest temporal unit (400 ms) was chosen as it is in the range typical of rhythms with both even and uneven meters (Moelants, 2006) and this tempo was required to induce rhythmic coherence (London, 2002) Although explicit tasks have used minimum temporal units of 200 ms (Patel, et al., 2005; Povel & Essens, 1985), this tempo would have made syllable identification unattainable in the present task.

Two rhythms were constructed (Rhythm 1 and Rhythm 2) that acted as exposure and test rhythms in a counterbalanced design. For half the participants in each meter condition, Rhythm 1 was presented during exposure blocks and Rhythm 2 was presented during test blocks. For the other half of participants in each meter condition, Rhythm 2 was presented during exposure blocks and Rhythm 1 was presented during test blocks.

The IOI chaining of Rhythm 1 was 400-800-400-400-800-400-800-400-800-800, and the IOI chaining of the Rhythm 2 was 400-400-800-400-400-800-800-400-800-400-800-800 (see Figure 5.1). The 800ms IOIs (i.e. IGIs) formed boundaries around groups of syllables and isolated syllables giving rise to grouping structures of 2-3-2-1-1-3-1 and 3-3-1-1-2-3-1 for Rhythm 1 and Rhythm 2, respectively.
Figure 5.1. Rhythm 1 and Rhythm 2 with even and uneven meter accenting: “X” represents a syllable, and digits indicate the serial positions of the syllables. Bold and regular overscores indicate syllable positions aligning with strong beats (accented with 6dB amplitude increases) and moderate beats (accented with 3dB amplitude increases), respectively. Vertical lines represent the hypothesised metrical structure (the longer the line the stronger the perceived beat). Each rhythm is cycled 10 times per block.

Across the meter conditions, the temporal structures of the exposure sequences were identical, as were the temporal structures of the test sequences. In other words, Even 1 had the same temporal structure as Uneven 1, and Even 2 had the same temporal structure as Uneven 2. This was done to ensure that any RT differences between the Even and Uneven Meter conditions could not be attributed to differences in the low-level temporal features, i.e. number of events, groups, and IGIs, or the duration of the IGIs. Therefore, to define the meter of each rhythm, accents were added by increasing the amplitude of syllables aligning with strong and moderate beats by 6dB and 3dB, respectively (Figure 5.1). For Even 1 and 2, 6dB increases were made to syllables in serial positions 1, 4, 7, 9, and 12, and 3dB increases were made to syllables in serial positions 8, 10 and 13 in Even 1 and positions 3, 6 and 8 in Even 2. For Uneven 1 and 2, 6dB increases were made to syllables in serial positions 1, 5, 8, and 11, and 3dB increases were made to syllables in serial positions 3, 7, and
13 in Uneven 1 and positions 7, 10, and 13 in Uneven 2. The temporal structures and accenting profiles were designed so that the even and uneven meter versions were both strongly metrical.

A measure of metrical strength (C-score) was applied to the rhythms (Even 1, Even 2, Uneven 1, and Uneven 2) to ensure that, based on grouping structure, all were strongly metrical (Povel & Essens, 1985). The C-score is based on an internal clock model of subjective accent induction and has two key principles/assumptions, 1) rhythms have an underlying beat or pulse grid, and 2) the grouping structure of a rhythm gives rise to the perception of subjectively accented events (i.e. isolated events, the second in a group of two events, and the first and last of a group of three or more events are perceived as accented). A C-score is generated by considering the relationship between the hypothesised beat grid (or internal clock pulse) and the subjective accent structure. Specifically, the counter-evidence based measure considers the number of internal clock pulses that are not accompanied by an event or are accompanied by a subjectively unaccented event using the formula: 

$$C = (W \times -ev) + (1 \times 0ev),$$

where $-ev$ is the number of beats that coincide with a silence and $0ev$ is the number of beats that coincide with an unaccented auditory event. $W$ is a weight generally set at four. The lower the C-score, the stronger the meter of the sequence, with zero indicating maximal metrical strength.

For the even meter rhythms, the clock pulse was considered to occur at 1600 ms intervals (i.e. at strong beats), with four 400 ms subdivisions of the beat (4-unit). In the uneven meter rhythms, the clock pulse was considered to occur at 2000 ms intervals (i.e. at strong beats), with five 400 ms subdivisions of the beat (5-unit). For Even 1 and Even 2, the C-scores were 2 and 1, respectively. For Uneven 1 and
Uneven 2, the C-scores were both 2. These scores indicate that all rhythms were strongly metrical.

The auditory events used to present the rhythms were two syllables, “Pa”, and “Ta”, spoken with a male voice generated using a text-to-speech synthesizer, Mbrola. The syllables had a fundamental frequency of 120 Hz, a duration of 218 ms and were normalized for intensity.

Each block consisted of 10 cycles of the basic rhythm. An additional syllable was added at the end of each block to create the final IGI and this resulted in a sequence of 131. As the first syllable in each block did not follow an IGI, it was not included in the analyses. The syllables were presented in a pseudo-random order with the following constraints applied from the second to the final syllable in each sequence. There were 55 presentations of each syllable with no more than nine repetitions of a single syllable or nine alternations of the two syllables. Second- and third-order repetitions were roughly equated across blocks. Second-order repetitions are instances when, for example, two Pas are interposed with Ta (“Pa Ta Pa”), and third-order repetitions are instances when, for example, two Pas are interposed with two Tas (“Pa Ta Ta Pa”). Finally, syllables were distributed equally across all serial positions in each sequence. To ensure that any effects could not be attributed to syllable order, half the participants were presented with a second syllable order that was a reversal of the order presented to the other half of participants.

AIFF files of each syllable sequence, with the defined IOI chaining were created in Matlab. All sequences had a duration of 1 min and 21 s. Eight practice sequences (two each of Even 1, Uneven 1, Even 2, and Uneven 2) with three cycles (43 s) of each basic rhythm were also created. The experiment was run in Psyscope (J.
sequences were presented over Sennheiser HD 25 closed headphones, and responses were made using a Targus USB numeric keypad.

5.2.1.2.2. Post-tests. Eight post-test sequence sets were constructed. Four of these sets were based on the rhythms presented in the SRTT: Even 1, Even 2, Uneven 1, Uneven 2. Four additional sets were based on novel rhythms: Even Novel 1, Even Novel 2, Uneven Novel 1, and Uneven Novel 2. The Even Novel 1 and Uneven Novel 1 sets had the same temporal structures but differed according to the accenting. Likewise, the Even Novel 2 and Uneven Novel 2 sets were identical in terms of temporal structure but differed in terms of accenting (Table 5.1).

Table 5.1

<table>
<thead>
<tr>
<th>Post-test Sequence</th>
<th>Temporal Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Even Novel 1</td>
<td>X.X.X.X.X.X.X.X.X.</td>
</tr>
<tr>
<td>Uneven Novel 1</td>
<td>X.X.X.X.X.X.X.X.X.</td>
</tr>
<tr>
<td>Even Novel 2</td>
<td>X.X.X.X.X.X.X.X.X.X.</td>
</tr>
<tr>
<td>Uneven Novel 2</td>
<td>X.X.X.X.X.X.X.X.X.X.X.</td>
</tr>
</tbody>
</table>

Novel 1 and Novel 2 rhythms had the same number of events, (i.e. 13 syllables), the same number of groups (i.e. 7 groups), and the group sizes as the SRTT exposure rhythms (i.e. two groups of 3, two groups to two, and 3 isolated syllables). However, the order of the groups was changed and the grouping structures of the
Novel 1 and Novel 2 rhythms were 1-1-3-3-2-2-1 and 1-1-2-2-3-3-1, respectively. The Even Novel 1 and Uneven Novel 1 sequences were designed to be as maximally different from the Even 1 and Uneven 1 SRTT rhythms, while still maintaining strong metricality across both meters. Similarly, the Even Novel 2 and Uneven Novel 2 sequences were designed to be as maximally different from the Even 2 and Uneven 2, again being both strongly metrical. Therefore, the Even Novel 1 and Uneven Novel 1 post-test sequences were presented to participants exposed to the Even 1 and Uneven 1 rhythms in the SRTT, and the Even Novel 2 and Uneven Novel 2 post-tests sequences were presented to participants exposed to the Even 2 and Uneven 2 rhythms in the SRTT, respectively (Table 5.2).

A measure of metrical strength was applied to the Novel rhythms (Povel & Essens, 1985). The Even Novel 1 and Even Novel 2 rhythms both had C-scores of 1 and the Uneven Novel 1 and Uneven Novel 2 rhythms had C-scores of 2 and 1, respectively. All sequences were accented so that syllables aligning with strong beats had an amplitude increase of 6dB and syllables aligning with moderate beats had an amplitude increase of 3dB.

Each post-test sequence was one cycle of the basic rhythm. As the exposure and test rhythms were cycled in the SRTT, it was possible that participants may have perceived the rhythm as starting at one of any of the strongly accented syllables (i.e. strong beat). As a result, four versions of each of the eight basic rhythms were created, each starting at one of the first four strong beats.

The syllables used in the post-test sequences (“Pa”, “Ta”), and the method for creating the AIFF files was as per the SRTT. The post-test task was run in Psyscope (J. Cohen, et al., 1993).
5.2.1.3. Procedure

5.2.1.3.1. SRTT. To promote implicit learning, participants were informed that the experiment was investigating how quickly and accurately syllables could be identified. They were not informed that the sequences had a rhythmic presentation. Participants listened to the syllable sequences and identified each syllable as quickly and accurately as possible. Responses were made using keys 7 and 1 on the USB numeric keypad and labels identifying the appropriate response keys were placed on the keys above (keys 8 and 2). Participants held the keypad in both hands (rotated 90°) and pressed key 7 with their left thumb and key 1 with their right thumb. Participants were instructed to not correct themselves if they made a mistake or to type in any syllables that they missed. Key-to-syllable mappings were counterbalanced across participants (i.e. Pa = 7 and Ta = 1, Ta = 7 and Pa = 1).

Two practice blocks with the rhythm of the participants’ exposure sequence was completed and participants were reminded of the instructions before beginning the experimental blocks. In the main SRTT, eight blocks of the exposure sequence were presented, followed by two blocks of the test sequence, with a final block returning to the exposure sequence. In counterbalanced conditions, exposure to Even 1 was followed by two test blocks of Even 2, and exposure to Even 2 was followed by two test blocks of Even 1. Likewise, exposure to Uneven 1 was followed by two test blocks of Uneven 2, and exposure to Uneven 2 was followed by two test blocks of Uneven 1. A short break with a minimum duration of 30 s was provided between each block.

5.2.1.3.2. Post-tests. After completing the SRTT, participants responded to the questionnaire asking them to describe any temporal regularity they noticed in the
sequences. They were then informed that the sequences followed a repeating timing or rhythmic pattern.

In the post-test rating task, participants were presented the four post-test sequences from the corresponding Exposure, Test, Exposure with alternate meter, and Novel sets (Table 5.2).

Table 5.2

Post-test Sequence Presentation for each SRTT Meter Condition

<table>
<thead>
<tr>
<th>SRTT Meter condition</th>
<th>Post-test Sequence Set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Even 1 exposure</td>
<td>Even 1        Even 2</td>
</tr>
<tr>
<td>Even 2 exposure</td>
<td>Even 2        Even 1</td>
</tr>
<tr>
<td>Uneven 1 exposure</td>
<td>Uneven 1      Uneven 2</td>
</tr>
<tr>
<td>Uneven 2 exposure</td>
<td>Uneven 2      Uneven 1</td>
</tr>
</tbody>
</table>

Participants were instructed to identify each syllable as quickly and accurately as possible and not correct themselves if they made a mistake or type in responses to syllables they missed. After identifying the syllables in each post-test sequence, participants made two ratings. Firstly, they were instructed to think back to the SRTT in the first part of the experiment and rate their familiarity with the timing pattern of the post-test sequence just heard using a scale from 1 = very unfamiliar, 2 = unfamiliar, 3 = somewhat unfamiliar, 4 = somewhat familiar, 5 = familiar, 6 = very familiar. They were then instructed to indicate the certainty with which they made their familiarity rating using a scale from 1 = complete guess, 2 = very uncertain, 3 = somewhat uncertain, 4 = somewhat certain, 5 = very certain, 6 = completely certain.
(adapted from Destrebecqz & Cleeremans, 2001). Responses were made using the numeric keys across the top of the computer keyboard. After responding to the 16 post-test sequences, participants completed a demographic questionnaire and were debriefed on the purpose of the experiment. The experiment took 50 minutes.

5.2.2. Results

5.2.2.1. SRTT

Correct responses were included in the analysis if they occurred 100 – 800 ms after the onset of the syllable. RTs less than 100 ms were assigned to the previous syllable if it was missed and, if multiple responses were made within the 100 – 800 ms window, only the first response was kept. The upper limit (800 ms) allowed us to retain longer RTs made to the syllables immediately preceding an IGI. Mean accuracy to syllables was significantly above chance (50%) for the Even meter condition (62.07%; SD = 6.57%), t(13) = 6.88, p = .00, and Uneven meter condition (59.53%; SD = 4.77%), t(13) = 7.46, p = .00\textsuperscript{19}.

No hypotheses were made concerning the counterbalanced rhythm conditions, and for all analyses, the Even 1 and Even 2 counterbalanced conditions were collapsed, as were the Uneven 1 and Uneven 2 counterbalanced conditions in all analyses\textsuperscript{20}.

5.2.2.1.1. Mean RT to all syllables over exposure blocks. RT to syllables was averaged for each block and an 8 x 2 ANOVA with Block (Blocks 1 – 8) as a within-

\textsuperscript{19} Analyses of accuracy over blocks and correlations between RT and accuracy were conducted and are reported in Appendix E.

\textsuperscript{20} In an additional step, to ensure that effects were equivalent across counterbalanced conditions, all reported analyses were conducted with Rhythm (Rhythm 1, Rhythm 2) as a between-subjects factor was conducted. In general, there was no effect of the counterbalanced condition. These analyses are presented in Appendix E.
subject factor and Meter (Even, Uneven) as a between-subjects factor was conducted (Figure 5.3). The main effect of Block was significant, $F(7, 182) = 2.11, p = .049$, partial $\eta^2 = .08$. There was no main effect of Meter, $F(1, 26) = 1.30, p = .27$, partial $\eta^2 = .05$, and no Block by Meter interaction, $F(7, 182) = 1.38, p = .22$, partial $\eta^2 = .05$. However, RT at Block 8 ($M = 386.49$ ms, $SE = 5.61$) was not significantly faster than at Block 1 ($M = 396.68$ ms, $SE = 5.66$). Therefore, with post-IGI and within-group syllables combined in one analysis, RT did not appear to improve with exposure.

5.2.2.1.2. Mean RT to all syllables over test blocks. To investigate the effect of changing the rhythm at the test block, a 2 x 2 ANOVA with Block (mean exposure Blocks 8 and 11, mean test Blocks 9 and 10) as a within-subject factor and Meter (Even, Uneven) as a between-subjects factor was conducted. There was a main effect of Block, $F(1, 26) = 10.88, p = .00$, partial $\eta^2 = .30$, but no effect of Meter, $F(1, 26) = 2.40, p = .13$, partial $\eta^2 = .08$, and no interaction, $F(1, 26) = .44, p = .51$, partial $\eta^2 = .02$. As Figure 5.2 shows, the RT increase was only at the second test block. Consequently, Block 8 (exposure) was compared to Block 9 (first test) and Block 9 (first test) with Block 10 (second test), with Meter (Even, Uneven) as a between-subjects factor. There was no significant difference between Block 8 and Block 9, $F(1, 26) = .56, p = .46$, partial $\eta^2 = .02$, no effect of Meter, $F(1, 26) = 1.63, p = .21$, partial $\eta^2 = .06$, and no Block by Meter interaction, $F(1, 26) = .77, p = .39$, partial $\eta^2 = .03$. However, RT at Block 10 was significantly slower than at Block 9, $F(1, 26) = 44.92, p = .00$, partial $\eta^2 = .63$, but there was no effect of Meter, $F(1, 26) = 1.40, p = .25$, partial $\eta^2 = .05$, and no Block by Meter interaction, $F(1, 26) = 2.49, p = .13$, partial $\eta^2 = .09$. Unexpectedly, the hypothesised RT increases did not occur at the first test block, but rather there appears to have been a delayed response to temporal
violation, with the RT increase emerging at the second test block. To examine the effect of re-introducing the exposure rhythm in the final block, RT was compared at Block 10 (second test) and Block 11 (final exposure). By examining this final exposure block, it can be determined that the RT increase at the second test block was not due to fatigue. A significant RT decrease in the final exposure block would indicate the benefit of returning to the expected temporal structure (acquired over the first eight exposure blocks). Meter (Even, Uneven) was a between-subjects factor.

There was a main effect of Block, $F(1, 26) = 57.86, p = .00, \text{partial } \eta^2 = .69$, but no effect of Meter, $F(1, 26) = 2.65, p = .12, \text{partial } \eta^2 = .09$, and no Block by Meter interaction, $F(1, 26) = .01, p = .92, \text{partial } \eta^2 = .00$. RT significantly decreased at the return of the final exposure block and although there was no significant effect of Meter, mean RT was slower in the Uneven Meter condition that in the Even Meter condition (Figure 5.2).

Figure 5.2. RT to correct responses presented as a function of Block and Meter condition. Error bars show standard error of the mean.
5.2.2.1.3. Mean RT to post-IGI syllables over exposure blocks. RT to syllables that followed IGIs was averaged for each block and an 8 x 2 ANOVA with Block (Blocks 1 – 8) as a within-subject factor and Meter (Even, Uneven) as a between-subjects factor was conducted. The main effect of Block was significant, $F(7, 182) = 4.23, p = .00, partial \eta^2 = .14$. There was no main effect of Meter, $F(1, 26) = 2.91, p = .10, partial \eta^2 = .10$, but Meter interacted with Block, $F(7, 182) = 2.25, p = .04, partial \eta^2 = .08$. During the first blocks, RT in the Even and Uneven Meter conditions did not differ (Blocks 1 - 3), but then from Block 4 to Block 8, RT was faster in the Even, compared to Uneven Meter condition. In regards to the expected decrease over exposure blocks, pairwise comparisons revealed that RT at Block 1 was significantly slower than at Blocks 4, 5, 7, and 8 in the Even meter condition, $ps < .05$, and RT at Block 1 was significantly slower than at Blocks 2, 3, 5, and 8 in the Uneven meter condition, $ps < .05$. Both conditions showed the expected learning effect with RT decrease over exposure, and although there was no main effect of Meter, RT was slower in the Uneven Meter compared to the Even Meter condition after the first three blocks (Figure 5.3a).

5.2.2.1.4. Mean RT to post-IGI syllables at the test blocks. To investigate the effect of changing the rhythm at the test block, a 2 x 2 ANOVA with Block (mean exposure Blocks 8 and 11, mean test Blocks 9 and 10) as a within-subject factor and Meter (Even, Uneven) as a between-subjects factor was conducted. There was a main effect of Block, $F(1, 26) = 12.21, p = .00, partial \eta^2 = .32$, and the effect of Meter approached significance, $F(1, 26) = 3.52, p = .07, partial \eta^2 = .12$. There was no Block by Meter interaction, $F(1, 26) = .08, p = .78, partial \eta^2 = .00$. As Figure 5.3a shows, the RT increase was only at the second test block. Therefore, in two additional analyses, Block 8 (exposure) was compared to Block 9 (first test block), and Block 9
(first test block) was compared to Block 10 (second test block), with Meter as a between-subjects factor (Even, Uneven). RT at Block 9 was not slower than at Block 8, $F(1, 26) = .13, p = .73$, $\text{partial } \eta^2 = .01$. Although there was a trend for RT to be slower in the Uneven, compared to Even Meter condition, this did not reach significance, $F(1, 26) = 2.93, p = .10$, $\text{partial } \eta^2 = .10$. There was no Block by Meter interaction, $F(1, 26) = .07, p = .80$, $\text{partial } \eta^2 = .00$.

RT at Block 10 was significantly slower than at Block 9, $F(1, 26) = 25.88, p = .00$, $\text{partial } \eta^2 = .50$, and again while RT tended to be slower in the Uneven compared to Even meter condition, this did not reach significance, $F(1, 26) = 2.53, p = .12$, $\text{partial } \eta^2 = .09$. There was no interaction between Block and Meter, $F(1, 26) = .13, p = .72$, $\text{partial } \eta^2 = .01$.

With post-IGI syllables, there appeared to be a delay in the response to temporal violation with RT increasing at the second test block. Furthermore, although not reaching significance, RT was slower in the Uneven Meter, compared to the Even Meter condition.

To assess the effect of presenting a final exposure block, RT to post-IGI positions at Block 10 (second test) and Block 11 (final exposure). Meter (Even, Uneven) was a between-subjects factor. There was a main effect of Block, $F(1, 26) = 42.35, p = .00$, $\text{partial } \eta^2 = .62$, with RT faster at the final exposure block compared to the preceding test block. The main effect of Meter approached significance, $F(1, 26) = 3.58, p = .07$, $\text{partial } \eta^2 = .12$ but there was no Block by Meter interaction, $F(1, 26) = .61, p = .44$, $\text{partial } \eta^2 = .02$. RT tended to be slower in the Uneven, compared to Even Meter condition (Figure 5.3a).

5.2.2.1.5. Mean RT to within-group syllables over exposure blocks. RT to syllables within groups was averaged for each block and an 8 x 2 ANOVA with Block
(Blocks 1 – 8) as a within-subject factor and Meter (Even, Uneven) as a between-subjects factor was conducted (Figure 5.3b). The main effect of Block was significant, $F(7, 182) = 2.56, p = .02$, partial $\eta^2 = .09$. There was no main effect of Meter, $F(1, 26) = .03, p = .87$, partial $\eta^2 = .00$, and no Block by Meter interaction, $F(7, 182) = .67, p = .70$, partial $\eta^2 = .03$. Significantly faster RT at Block 3 compared to Blocks 2, 6, 7, and 8 drove the effect of Block. RT in Block 1 was not slower than in Block 8. Therefore, the same learning effect over exposure blocks evident with post-IGI syllables was not evident with within-group positions. RT was fast at the first test block and did not decrease at Block 8. Furthermore, there was no RT difference between the Even and Uneven Meter conditions over exposure (Figure 5.3b).

5.2.2.1.6. Mean RT to within-group syllables at the test blocks. To investigate the effect of changing the rhythm at the test block, a 2 x 2 ANOVA with Block (mean exposure Blocks 8 and 11, mean test Blocks 9 and 10) as a within-subject factor and Meter (Even, Uneven) as a between-subjects factor was conducted. There was no effect of Block, $F(1, 26) = 1.80, p = .19$, partial $\eta^2 = .07$, or Meter, $F(1, 26) = .31, p = .59$, partial $\eta^2 = .01$, and no Block by Meter interaction, $F(1, 26) = .47, p = .50$, partial $\eta^2 = .02$. As Figure 5.3b shows, while there was a small increase at the first and second test block in the Even Meter condition, the RT increase was primarily at the second test block in the Uneven Meter condition. Therefore, in two additional analyses, Block 8 (exposure) was compared to Block 9 (first test block), and Block 9 (first test block) was compared to Block 10 (second test block), with Meter as a between-subjects factor (Even, Uneven). RT at Block 9 was not slower than at Block 8, $F(1, 26) = .62, p = .44$, partial $\eta^2 = .02$ and there was no effect of Meter, $F(1, 26) = .00, p = .97$, partial $\eta^2 = .00$, and no Block by Meter interaction, $F(1, 26) = 2.63, p = .12$, partial $\eta^2 = .09$. RT at Block 10 was significantly slower than at Block 9, $F(1,
26) = 20.46, \( p = .00 \), partial \( \eta^2 = .44 \), and while there was no effect of Meter, \( F(1, 26) = .02, p = .90 \), partial \( \eta^2 = .00 \), there was a significant interaction, \( F(1, 26) = 6.28, p = .02 \), partial \( \eta^2 = .19 \). The increase was not significant in the Even meter condition, \( p = .12 \), but reached significance in the Uneven meter condition, \( p = .00 \). Thus, as with post-IGI positions, there was a delayed response to the temporal violation but only in the Uneven Meter condition.

To assess the effect of presenting a final exposure block, RT to within-group positions at Block 10 (second test) and Block 11 (final exposure). Meter (Even, Uneven) was a between-subjects factor. There was a main effect of Block, \( F(1, 26) = 20.72, p = .00 \), partial \( \eta^2 = .44 \), with RT faster at the final exposure block compared to the preceding test block. The main effect of Meter was not significant, \( F(1, 26) = .74, p = .40 \), partial \( \eta^2 = .03 \), and there was no Block by Meter interaction, \( F(1, 26) = .163, p = .21 \), partial \( \eta^2 = .06 \) (Figure 5.3b).

Figure 5.3. Correct RT to a) Post-IGI and, b) Within-group syllables across blocks and plotted as a function of meter condition (even and uneven). Error bars show standard error of the mean.
5.2.2.2. Post-tests

An open-ended question asked participants to describe any regularity in the timing of the presentation of the syllables. Of the twenty-eight participants, 10 reported that there were fluctuations in the speed of presentation of the syllables and two participants reported the presences of pauses between some syllables. Seven participants attempted to describe a temporal structure (e.g. X.X.XXX) but none reported it correctly. To determine if participants had developed awareness of the rhythms presented in the SRTT, familiarity ratings to Exposure, Test, Exposure with alternate meter, and Novel sequences were analysed. Ratings (1 = very unfamiliar through to 6 = very familiar) were collapsed across the four presentations of each sequence to obtain a mean rating (Table 5.3). These were analysed with a 4 x 2 ANOVA with Post-test Sequence as a within-subject factor (Exposure, Test, Exposure with alternate meter, Novel) and Meter (Even, Uneven) as a between-subjects factor. There was a main effect of Post-test Sequence, \( F(3, 78) = 2.80, p = .046, \) partial \( \eta^2 = .10, \) but no effect of Meter, \( F(1, 26) = .55, p = .46, \) partial \( \eta^2 = .02, \) and no Post-test Sequence by Meter interaction, \( F(3, 78) = 2.08, p = .11, \) partial \( \eta^2 = .07. \) Participants rated the sequences with the alternate meter of their exposure rhythm as significantly more familiar than the test and novel sequences, \( ps < .05. \) Exposure sequences were not rated as more familiar than the other sequences.
Table 5.3

Post-test Familiarity (1 = very unfamiliar, through to 6 = very familiar) and Certainty (1 = complete guess, through to 6 = completely certain) Mean Ratings and Standard Deviations presented as a function of Sequence Type and Exposure Condition

<table>
<thead>
<tr>
<th>Familiarity</th>
<th></th>
<th></th>
<th></th>
<th>Certainty</th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exposure</td>
<td>with</td>
<td>alternate</td>
<td>Exposure</td>
<td>with</td>
<td>alternate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Exposure</td>
<td>Test</td>
<td>meter</td>
<td>Novel</td>
<td>Exposure</td>
<td>Test</td>
<td>meter</td>
</tr>
<tr>
<td>Condition</td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>Even</td>
<td>3.34</td>
<td>0.83</td>
<td>3.39</td>
<td>0.59</td>
<td>3.80</td>
<td>1.02</td>
<td>3.21</td>
</tr>
<tr>
<td>Uneven</td>
<td>3.82</td>
<td>0.73</td>
<td>3.25</td>
<td>0.77</td>
<td>3.70</td>
<td>0.65</td>
<td>3.61</td>
</tr>
</tbody>
</table>

To further examine participants’ familiarity with the SRTT sequences, the correlation between familiarity and certainty ratings to exposure sequences was assessed. Explicit knowledge would be evident if there was a positive correlation between familiarity and certainty ratings to their exposure sequences (Scott & Dienes, 2008). Participants would rate their exposure sequences as familiar and be certain of their decision.

Each participant’s mean familiarity rating (i.e. mean rating of all post-test sequences) was subtracted from their mean rating to exposure sequences yielding a difference score. These were converted to z-scores (z-familiarity). The correlation between z-familiarity scores and the mean certainty ratings to the exposure sequences...
was not significant, $r(26) = .17, p = .40$, and indicates that participants were not confident in their familiarity ratings to exposure sequences$^{21}$.

5.2.3. Discussion

The aim of the current experiment was to investigate IL, by listeners of Western tonal music, of tightly controlled rhythms with culturally familiar even and culturally less familiar uneven meters. The even and uneven meter rhythms presented over the exposure blocks had identical temporal structures but it was the placement of amplitude accents that elicited the two metrical structures. The control of the grouping structure, and the number and duration of IOIs over exposure rhythms allowed for a precise examination of the effects of a relatively familiar meter (i.e. even) and unfamiliar meter (i.e. uneven) on the learning of rhythms by listeners of primarily Western tonal music. Apart from investigating differences in learning of the even and uneven meter rhythms over exposure, we also examined the effect of violating temporal expectations, acquired during learning, by introducing new rhythms in two test blocks. The test rhythm presented to participants had the same meter as the exposure rhythm, but the chaining of the event groups was modified. Of particular interest was the effect of meter on RT to syllables following IGIs (i.e. long IOIs), both over exposure and at the test blocks. Previous research has indicated that, for listeners of primarily Western tonal music, an even duple, compared to an even triple meter, facilitates processing of longer IOIs because duple meters are somewhat more common (Brandon, et al., 2012; Eisler, et al., 2008). Therefore, we hypothesised that

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$^{21}$ In an additional step, participants indicating familiarity with their exposure sequence were identified and the post-IGI and within-group ANOVAs were conducted again with “Awareness” as a between subjects factor. For completion, these analyses are reported in Appendix E.
learning of the IGIs in the culturally familiar even meter rhythms would be more evident that in the culturally less familiar uneven meter rhythms.

Using an SRTT, learning of IGIs in both the even and uneven meter rhythms was evident over exposure blocks. RT was slower at the first block, compared to the last block in both meter conditions. However, while RT over the first three blocks was equivalent across the meter conditions, RT was faster in the Even, compared to the Uneven Meter condition from Block 4 onwards. Therefore, the hypothesis that a familiar meter facilitates learning of the more difficult-to-process IOIs was supported.

For within-group syllables (i.e. following the short IOIs), RT was not faster at Block 8 compared to Block 1 and there was no influence of meter. In both conditions, RT was relatively fast at the first test block and remained so throughout exposure. The shorter IOIs preceding these syllables aligning with the beat level of the even and uneven meter temporal grids might have enabled participants to respond efficiently to these syllables from the start of exposure. While IL of non-metrical (Salidis, 2001) and weakly metrical structures (see Chapter 2 of this thesis) has been demonstrated, the benefit of a temporal grid elicited by the presence of a strong meter requires investigation with a direct comparison between learning of metrical and non-metrical temporal structures.

A key aim of this experiment was to establish the role of meter in learning rhythms when all other aspects of the rhythms were controlled. The previously reported experiment (Experiment 4 of Chapter 4) demonstrated learning of rhythms with even and uneven meters, with some benefit of an even meter, using rhythms that had identical grouping structures, but changes to the IGIs. The uneven meter rhythm had a greater number of long IGIs (1200 ms) than the even meter rhythm. It might be argued that this temporal feature may have given rise to slower RT even though this
hypothesis is not consistent with the variable foreperiod effect (Capizzi, et al., 2012; Correa, et al., 2004; Ellis & Jones, 2010), which predicts slower RT to shorter intervals. The current experiment was designed to ensure that the durations of the IGIs were not underpinning the RT differences across even and uneven meter rhythms. The results confirm that meter, instantiated with amplitude accents, was a successful manipulation and modulated RT to the post-IGI syllables in the exposure rhythms. In other words, because the basic temporal structures (i.e. chainings of event groups and IOIs) were identical in the even and uneven meter rhythms, performance on the task was not driven by low level temporal features but rather by the higher level metrical structure.

When temporal expectations were violated at the test blocks with the introduction of a new rhythm, RT increases were expected particularly to post-IGI syllables, and more so in the Even compared to Uneven Meter condition. However, contrary to this hypothesis, there were no increases at the first test block to either post-IGI or within-group syllables. This is inconsistent with a previous experiment (Experiment 5 reported in Chapter 4 of this thesis) that demonstrated RT increases to both post-IGI and within-group syllables at the first test block presentation of a new uneven meter rhythm. In the current experiment, RT increases to post-IGI syllables in both meter conditions and to within-group syllables in the Uneven Meter condition appeared at the presentation of the second test block and this suggests that there was some delayed response to the temporal violation.

A key difference between the test block violation in the current experiment and in those previously reported (see Chapter 4 of this thesis) was that the grouping structure, rather than the IOIs between groups, was altered. It is plausible that the

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22 The increase to within-group syllables fell short of significance, ($p = .28$) but was in the expected direction.
grouping structure change, and consequently the nature of the specific violations, resulted in particular patterns of RT that may have differed across the counterbalanced conditions (i.e. Even 1 and Even 2, Uneven 1 and Uneven 2). For instance, if a participant was expecting a group of three syllables at a particular point in the repeating sequence, but was instead presented with a group of two, the next syllable after the two-group would have been temporally violated. It would have been presented later-than-expected. Conversely, if a participant was expecting a group of two syllables but was presented with a group of three, that third syllable would have been presented earlier-than-expected. Using simple isochronous sequences, previous research has shown that a temporal violation can lead to a number of possible effects. Firstly, RT can be slower to events presented earlier and later than expected, compared to events presented on time. This has been referred to as an expectancy effect (Barnes & Jones, 2000; Penel & Jones, 2005) and is consistent with the current investigations of IL of temporal structure reported in this thesis and elsewhere (Brandon, et al., 2012; Salidis, 2001). Secondly, RT has been shown to be faster to events presented earlier and later than expected, compared to events presented on time. This has been referred to as a capture effect and is thought to occur when a temporal violation to an event leads to an increase in its salience. Attention is drawn to that event and consequently responses are facilitated (Penel & Jones, 2005). Finally, a more specific effect arising from the temporal orienting literature is that RT is slower to events (e.g. visual targets and chords) presented earlier than expected compared to events presented later than expected (e.g. Correa, Lupiáñez, Milliken, Tudela, 2004; Correa, Lupiáñez, Tudela, 2006; Tillmann & Lebrun-Guillaud, 2006). It is possible that one or other of these effects was at play in the current experiment. Specifically, some violations may have led to RT increases while others may have led
to RT decreases, in effect cancelling each other out when collapsed in the analyses. Importantly, the absence of an RT increase at the first test block, perhaps driven by the above mentioned temporal violations, only occurred in Experiment 6 where, for the first time in this series of experiments, the grouping structure was violated at the test blocks.

Regardless of the possibility that divergent RT patterns to particular temporal violations led to an overall lack of RT increase in the first test block, the increase at the second test block was obtained. Such an increase indicated, that during exposure, participants had acquired temporal expectations via learning and that the violation slowed responses. Furthermore, the analyses of the RT increase at the second test block revealed that there was an effect of meter. The RT increase to post-IGI syllables was equivalent across the Even and Uneven Meter conditions but, although the main effect of meter fell short of significance, RT tended to be slower in the Uneven, compared to the even Meter condition. RT to within-group syllables was also modulated by meter with a significant increase evident in the Uneven Meter condition only. This finding suggests that the prediction of the easier-to-process short IOIs in the familiar Even Meter Condition was least disturbed by the temporal violation at the test block.

The return of the exposure rhythm at the final block was an important additional feature to measure learning over exposure and to ensure that the RT increase at the second test block was not due to fatigue. If fatigue drove the RT increase at Block 10 (i.e. second test block), then it would be expected that RT would remain stable or would increase further at Block 11. However, if the rhythms were learned over exposure then an RT decrease would be expected at the return of a final exposure block (i.e. Block 11), as the previously acquired temporal expectations...
would be upheld. Consistent with this latter prediction, RT decreases were found at Block 11 for both post-IGI and within-group syllables. While there was no significant influence of meter, RT tended to be slower to post-IGI positions in the Uneven, compared to Even Meter condition. The faster RT at the return of the exposure rhythm indicates that participants had developed temporal expectations over exposure and that when these were confirmed during the final block, RT decreased.

With some caution, it can be concluded that despite the absence of the expected effect at the first test block, rhythms with even and uneven meters can be learned, with an even meter providing some benefit, particularly for the longer and more difficult-to-process IGIs. Potentially, the temporal grid activated by the strong, familiar even meter, allowed participants to better predict and learn these IGIs (i.e. long IOIs spanning two beats). Furthermore, the results indicate that the learning was implicit. Participants did not rate their exposure rhythm as more familiar than their test rhythm, the exposure rhythm of the alternate meter condition, or a novel rhythm.

Previous experimental work has shown that adult listeners, primarily exposed to Western tonal music, are able to discriminate rhythms with temporal violations when those rhythms have even meters. However, adults have difficulty with the task when the rhythms have uneven meters. By contrast, listeners with a lifetime’s exposure to rhythms with uneven meters perform the task equally well across even, and uneven meter conditions (Hannon & Trehub, 2005a; Kalender, et al., 2012). Furthermore, with relatively short-term (i.e. 2 weeks) incidental exposure to music with uneven meter rhythms, listeners of primarily Western tonal music fail to improve their discrimination performance with uneven meter rhythms (Hannon & Trehub, 2005b). These studies suggest that the activation of metrical frameworks develop via a long-term process of enculturation. While it was not within the scope of the current
study, an obvious extension would be to investigate IL of rhythms with even and uneven meters by listeners with prior long-term exposure to uneven meters. This would complement the work of Hannon and colleagues (Hannon & Trainor, 2007; Hannon & Trehub, 2005a, 2005b; Hannon, Vanden Bosch der Nederlanden, et al., 2012; Kalender, et al., 2012) and further test the hypothesis that learning is modulated by a culture-specific familiarity with meter.

In the current experiment, it appears that participants can develop temporal expectations of rhythms with culturally less familiar uneven meters. It may be that the implicit nature of the task supports learning. In the visual domain, studies have shown that if the to-be-learned material (visual-spatial sequences and letter strings) is complex, learning is hindered when an explicit instruction is given (Fletcher, et al., 2005; Howard & Howard Jr, 2001). The authors interpret these results as indicating that a highly complex stimulus, combined with the engagement of an explicit hypothesis-testing strategy to learn a sequential pattern, leads to cognitive overload and consequently, learning is impeded. Implicit learning, on the other hand, appears to be influenced less by stimulus complexity and may be a powerful means with which to develop temporal expectations (Curran & Keele, 1993; Jiménez & Méndez, 1999; Stefaniak, et al., 2008; Willingham & Goedert-Eschmann, 1999; Willingham, et al., 2002).

Alternatively, the nature of the SRTT, requiring a motor response to every event may promote learning. Again, not investigating temporal learning but rather learning of sequences of visual spatial locations, research has shown that perceptual learning benefits from concurrent motor learning of complex stimuli (Deroost & Soetens, 2006; Mayr, 1996). In the auditory temporal domain, learning of complex stimuli, perhaps defined by metrical strength, or cultural familiarity with a meter,
might benefit from a motor component. Indeed, performance of music with uneven meters is frequently integrated with dance (Fracile, 2003; Singer, 1974). Infant research also indicates that movement is an important aspect of modulating temporal processing (Phillips-Silver & Trainor, 2005). The issue of the role of movement in learning rhythms with unfamiliar meters requires further investigation.

A further extension of this research would be an investigation of the reciprocal relationship between meter and sensorimotor synchronisation or joint action with human partners. While co-ordinated movement has been investigated using simple temporal materials (e.g. isochronous pacing signals), it may be that simultaneously performing a movement-based task with a partner facilitates learning of rhythms with uneven meters via additional visual movement cues (Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006; Jäncke, Loose, Lutz, Specht, & Shah, 2000; Lucas, Clayton, & Leante, 2011; Merker, et al., 2009; Phillips-Silver & Keller, 2012).

Indeed, uneven meters and other cross-cultural rhythms provide a means with which to investigate the cognitive capacity of the learner to adapt to unfamiliar temporal framework.
Chapter 6 Preface

Over six experiments (reported in Chapters 2 to 5), IL of auditory temporal structures, independent of ordinal structure (i.e. the ordinal structures were pseudo-random), was demonstrated. The temporal structures had features typical of musical rhythms: (a) the temporal relationships between events were based on a serial ordering of IOIs; and (b) the rhythms had metrical structures with even and uneven meters. Experiments 1 to 3 revealed that IGIs and controlled within-group intervals were learned. However, reduced metrical strength and an explicit instruction to learn the rhythms moderated the learning effect. Experiments 4 to 6 showed that listeners of primarily Western tonal music implicitly learned rhythms with even and uneven meters and there was some benefit from the presence of a relatively familiar even meter. Chapter 6 (General Discussion) will provide (a) a summary of the findings, (b) a discussion of the implications of these findings for current theories of temporal processing and IL, and (c) suggestions for future directions in this area of research.
Chapter 6

General Discussion
6. General Discussion

6.1. Prelude

Expectations of musical structure are established over a lifetime’s exposure to the music of one’s own culture (Creel, 2011; Huron, 2006). These expectations can be acquired unintentionally, or implicitly and do not require formal musical training (Bigand & Poulin-Charronnat, 2006; Rohrmeier & Rebuschat, 2012). Previous research using explicit tasks has demonstrated that these long-term, or schematic expectations influence the perception and production of tonal and rhythmic structures. Specifically, the processing of tonal (Curtis & Bharucha, 2009; Krumhansl, 2000b; Krumhansl, et al., 1999; Krumhansl, et al., 2000) and rhythmic (Creel, 2011; Hannon & Trainor, 2007; Hannon & Trehub, 2005a; Repp, et al., 2005; Snyder, et al., 2006; Trehub & Hannon, 2009) structures is facilitated when these structures uphold established, and culturally familiar musical expectations. However, perception and production of tonal and rhythmic structures are difficult if these structures are less familiar. The current program of research examined the power of implicit processes in the development of temporal expectations.

The broad aim was to investigate the capacity of listeners of Western tonal music to implicitly learn rhythms with culturally familiar, and culturally less familiar meters. While a large body of research has demonstrated IL of ordinal structures in both the visual (e.g. A. Cohen, et al., 1990; Nissen & Bullemer, 1987) and auditory (Buchner, et al., 1997; Jonaitis & Saffran, 2009; Saffran, et al., 1999; Tillmann, et al., 2000; Tillmann & McAdams, 2004) modalities, there have been fewer demonstrations of IL of temporal structures, or rhythms, in either modality (Visual: Lee, 2000; Shin
Some research employing temporal structures based on repeating RSI sequences has shown that these structures are not learned when the events that instantiate the rhythms are unpredictable (i.e. the order of event identities is random) (Buchner & Steffens, 2001; Shin & Ivry, 2002, Experiment 1). However, some more recent research (Brandon, et al., 2012; Tillmann, et al., 2011) has demonstrated IL of auditory temporal structures when they have features typical of musical rhythms: (a) serial orderings of inter-onset intervals (IOIs) with simple integer ratios relationship, and (b) the presence of hierarchical beat structures, or meters. Therefore, the current program of research has drawn on theories of temporal processing and meter perception with particular reference to research investigating the processing of rhythms with both culturally familiar, and culturally less familiar meters (e.g. Hannon & Trehub, 2005a; Hannon, Vanden Bosch der Nederlanden, et al., 2012; Trehub & Hannon, 2009). Six experiments have demonstrated IL of music-like temporal structures, or rhythms, with culturally familiar and culturally less familiar meters.

The remainder of this chapter will present; (a) a summary of the findings from each experiment, (b) interpretations of these findings with reference to earlier experimental results and in light of current theories of temporal processing and IL, (c) a discussion of the implications of the present findings, and (d) suggestions for future research.
6.2. Principal Findings

6.2.1. Experiments 1 to 3: Implicit and Explicit Learning of IGIs in Weakly Metrical Rhythms

6.2.1.1. Experiment 1

Two published studies reported IL of temporal structures, or rhythms, when the ordinal structure was either held constant (i.e. sequence of beeps; Salidis, 2001), or was unpredictable (i.e. pseudo-random sequence of syllables; Brandon, et al., 2012). In these studies, RT to events increased at the test block when temporal expectations were violated. It remained unclear however as to whether these RT increases were due solely to changes in the grouping structure at test. Therefore, the primary aim of Experiment 1 was to investigate IL of the timing between auditory groups (i.e. IGIs) in order to establish that learning extends beyond grouping structure.

In previous research using explicit tasks, it has been shown that grouping structure is the primary cue that listeners use to organise rhythm over time (Handel, 1998). It appears that IGIs are not encoded, particularly when the rhythms are weakly, compared to strongly, metrical (Hébert & Cuddy, 2002; Ross & Houtsma, 1994). Therefore, Experiment 1 examined IL of IGIs in weakly metrical rhythms. It was hypothesised that the benefit of implicit processes engaged in the SRTT would facilitate learning of IGIs. As expected, learning of IGIs in a weakly metrical rhythm was found, as was learning of certain within-group intervals. This result indicated that learning went beyond IGIs and was of the global temporal structure. However, IL was evident in only one of the two weakly metrical conditions – the condition presenting
the relatively stronger meter over exposure. As suggested by Hébert and Cuddy (2002), metrical strength modulated processing of IGIs.

In terms of the learned rhythm, IL of the IGIs might have benefited from the engagement of implicit processes. The use of an SRTT requiring a motor response to every event over multiple exposure blocks may have also facilitated learning. Indeed, motor processes are closely associated with temporal processing (Chen, Zatorre, & Penhune, 2006; Grahn & Brett, 2007; Kung, Chen, Zatorre, & Penhune, 2013; Zatorre, Chen, & Penhune, 2007). The motor response, in combination with the slightly stronger meter may have facilitated the development of temporal expectations via the activation of neural oscillations. As proposed by the Dynamic Attending Theory (Barnes & Jones, 2000; Jones & Boltz, 1989; Large & Jones, 1999), coupling of oscillations at multiple timescales may have guided oscillatory attention to future time points aligning with the established temporal framework, thus permitting increasingly faster responses to syllables over exposure. With the temporal violation of the IGIs at the test block, RT to the immediately following syllable increased, therefore providing evidence of learning of IGIs in a weakly metrical rhythm. Post-tests revealed that this learning was implicit.

6.2.1.2. Experiment 2

In Experiment 1, measures of metrical strength (e.g. Povel & Essens, 1985) indicated that although both exposure rhythms were weakly metrical, the rhythm not showing evidence of learning (i.e. no test block increase) had a slightly weaker meter than the rhythm that was learned. Therefore, Experiment 2 was similar to Experiment 1 but an accented woodblock pulse was added to the sequences in order to cue the meter of the rhythms in both conditions. Consistent with Experiment 1, IL of the IGIs was apparent in the condition that presented the rhythm with the slightly stronger
meter over exposure. In the exposure condition with the slightly weaker meter, evidence of learning emerged for within-group intervals that maintained their global location across exposure and test blocks. The addition of the woodblock pulse, likely increasing the metrical strength of the weaker of the two rhythms, led to some learning. Yet, it remains unclear as to why the expected RT increase at the test block to syllables immediately following the IGI change was not elicited in the weaker of the two rhythms. Local temporal factors such as changes in metric location (i.e. from strong to weak beats) or the direction of the change (i.e. earlier or later than expected) may have jointly contributed to the lack of RT increase to the post-IGI positions. In other words, it may not have been that the rhythm with the relatively weaker meter was not learned but rather, the particular temporal changes at the test block masked the expected RT increase. Hence, the RT increase to the controlled within-group positions provided the best measure of learning as these positions maintained their global position and their status within the metrical structure across exposure and test.

In Experiment 2, post-tests revealed that participants had acquired some awareness of the rhythms, particularly of the slightly stronger meter exposure rhythm. This was most likely due to the presence of the woodblock pulse. However, both “aware” and “unaware” participants showed the same effects in the SRTT, indicating that learning was not driven by explicit knowledge.

6.2.1.3. Experiment 3

The issue of awareness motivated Experiment 3. More specifically, the aim of Experiment 3 was to examine the effect of an explicit instruction to learn the exposure rhythms on IL across rhythm conditions. Two competing hypotheses were proposed. On the one hand, if attending to the temporal structure of the sequence is required for meter to be abstracted then the explicit instruction should facilitate learning in both
conditions. This result would be consistent with neurophysiological evidence suggesting that the direction of attention to the temporal dimension is necessary for the processing of temporal regularity (Schwartze, et al., 2011) and meter, particularly in syncopated rhythms (Chapin, et al., 2010). On the other hand, if an explicit search for regularity leads to cognitive overload, as has been demonstrated in the visual-ordinal domain (Fletcher, et al., 2005; Howard & Howard Jr, 2001), then learning should be impeded, particularly for the rhythm with the slightly weaker meter. Using the stimuli from Experiment 2 (syllable sequences presented concurrently with the woodblock pulse), support was found for the second hypothesis. The slightly stronger meter rhythm was learned with an explicit instruction. While a statistical comparison was not made between the two experiments, the evidence of learning of the slightly weakly rhythm reported in Experiment 2 was not replicated in Experiment 3 when an explicit instruction to learn was given. Contrary to expectation, despite the explicit instruction to learn the rhythms, participants did not show any awareness of the temporal structures. Therefore, at least in the condition presenting the slightly stronger meter rhythm over exposure, implicit learning persisted in the presence of an explicit learning strategy.

6.2.1.4. Interim summary

Experiments 1 to 3 examined learning of IGIs in weakly metrical rhythms under different conditions (see Table 6.1). With grouping structure as the only cue to meter (Experiment 1), IL was evident for the slightly stronger metrical rhythm. Increasing the metrical strength of the rhythms with an accented pulse elicited evidence of learning of the slightly less metrical rhythm (Experiment 2). However, learning did not occur when an explicit instruction to learn the rhythm was given. The
strategic search for a temporal structure may have reduced the cognitive capacity for learning the rhythm with the slightly weaker meter (Experiment 3).
Table 6.1

Summary of Experimental Factors and Results in Experiments 1 to 3 (Pattern condition: 1 = slightly stronger meter, 2 = slightly weaker meter)

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Pattern condition</th>
<th>Cue to meter</th>
<th>Instruction</th>
<th>Learning of IGIs (RT increase at test block)</th>
<th>Learning of controlled within-group intervals (RT increase at test block)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Grouping structure</td>
<td>Implicit</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Grouping structure</td>
<td>Implicit</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>Grouping structure and accented pulse</td>
<td>Implicit</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>accented pulse</td>
<td>Implicit</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>Grouping structure and accented pulse</td>
<td>Explicit</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>accented pulse</td>
<td>Explicit</td>
<td>×</td>
<td>×</td>
</tr>
</tbody>
</table>
6.2.2. Experiments 4 to 6: Implicit Learning of Rhythms with Even and Uneven Meters

Experiments 1 to 3 established that IL of temporal structures, or rhythms, extended from learning of grouping structures to the duration of the interval between auditory groups (i.e. IGIs). However, meter played a modulating role with an increase in the relative strength of the meter facilitating learning. Therefore the purpose of Experiments 4 to 6 was to investigate IL of rhythms with relatively more familiar even meters and less familiar uneven meters by listeners enculturated to primarily Western tonal music (see Table 6.2 for a summary of Experiments 4 to 6).
<table>
<thead>
<tr>
<th>Experiment</th>
<th>Exposure</th>
<th>Test</th>
<th>Features maintained at test blocks</th>
<th>Features changed at test blocks</th>
<th>Learning of IGIs (RT increase at test block)</th>
<th>Learning of within-group intervals (RT increase at test block)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Even</td>
<td>Uneven</td>
<td>Grouping structure</td>
<td>Number &amp; duration of IGIs</td>
<td>✓ (First test block)</td>
<td>✓ (First test block)</td>
</tr>
<tr>
<td></td>
<td>Uneven</td>
<td>Even</td>
<td>Grouping structure</td>
<td>Number &amp; duration of IGIs</td>
<td>× (Some increase for “unaware” participants)</td>
<td>✓ (First test block)</td>
</tr>
<tr>
<td>5</td>
<td>Uneven</td>
<td>Uneven</td>
<td>Grouping structure &amp; number of medium/long IGIs</td>
<td>Exchange of medium &amp; long IGIs</td>
<td>✓ (First test block)</td>
<td>× (Although trend in expected direction)</td>
</tr>
<tr>
<td>6</td>
<td>Even</td>
<td>Even</td>
<td>Temporal structure</td>
<td>Grouping structure</td>
<td>✓ (Second test block)</td>
<td>× (Second test block)</td>
</tr>
<tr>
<td></td>
<td>Uneven</td>
<td>Uneven</td>
<td>Temporal structure</td>
<td>Grouping structure</td>
<td>✓ (Second test block)</td>
<td>✓ (Second test block)</td>
</tr>
</tbody>
</table>
6.2.2.1. Experiment 4

Experiment 4 examined IL of rhythms with both even and uneven meters. Learning was tested via exposure to an even or uneven meter rhythm followed by the introduction of a new test rhythm with the alternate meter. That is, a test block of the uneven meter rhythm followed exposure to the even meter rhythm, and a test block of the even meter rhythm followed exposure to the uneven meter rhythm. RT decreased significantly over exposure blocks to both the even and uneven meter rhythms. In addition, there was a tendency for RT to be slower to the uneven, compared to the even meter rhythm. Furthermore, the meter of the test rhythm also appeared to modulate the RT effect at the test block. After exposure to an even meter rhythm, RT to all syllable positions (i.e. post-IGI, within-group) increased at the uneven meter test block. After exposure to an uneven meter rhythm, RT also increased to within-group syllable positions at the even meter test block. However, in this same condition, RT did not increase to syllable positions following IGIs. The interpretation of this finding is that the relatively more familiar even meter at the test block facilitated the prediction of the IGIs. This is consistent with Brandon et al. (2012) who found that an even duple meter facilitated prediction of IGIs after exposure to a less familiar even triple meter.

Additional analyses indicated that RT at the test block to post-IGI syllable positions was partly a function of awareness of the exposure rhythms. Participants without explicit knowledge of the uneven meter exposure rhythm demonstrated an RT increase to post-IGI syllable positions at the even meter test block. However, participants with awareness did not show this increase. There was no modulating effect of awareness
in the even meter condition. There is no known published reports of the relative effectiveness of implicit and explicit learning of rhythms. However, the findings here are consistent with demonstrations that IL of visual-spatial/ordinal sequences is more powerful than explicit learning when the stimulus is complex or cognitive capacity is reduced (Fletcher, et al., 2005; Howard & Howard Jr, 2001; A. S. Reber, 1976).

6.2.2.2. Experiment 5

The purpose of Experiment 5 was to further examine IL of culturally less familiar uneven meters by firstly controlling the number of IGIs of different durations across exposure and test, and secondly, by presenting an uneven meter rhythm at both exposure and test blocks. With these additional controls, RT increased to both post-IGI and within-group syllable positions at the first test block demonstrating learning of an uneven meter rhythm. Post-tests revealed that learning was implicit.

6.2.2.3. Experiment 6

Experiment 6 returned to comparing learning of even and uneven meter rhythms as in Experiment 4, but presenting an even meter exposure rhythm with an even meter test rhythm, and an uneven meter exposure rhythm with an uneven meter test rhythm. Some other additional controls of the rhythms were made. In Experiment 4, there was a greater number of longer IGIs in the uneven, compared to even meter exposure rhythm and this may have led to the slower RT in the uneven meter condition. Therefore, the temporal structures across the even and uneven meter exposure rhythms in Experiment 6 were made identical to control the number and duration of IGIs. In order to give rise to the different metrical structures, amplitude accents were used. Meter was maintained
across the exposure and test blocks but the test block rhythms then had different grouping structures to the exposure rhythms. This manipulation allowed for a measure of grouping structure learning but the most important comparison was across the meter conditions. As with Experiment 4, learning of both the even and uneven meter rhythms was evident over exposure, and in particular for the post-IGI positions. RT tended to be slower in the uneven, compared to the even meter condition. As the temporal structures were identical, this effect can only have been due to meter.

Unexpectedly, there was no RT increase at the first test block with the change in the grouping structure but there was a significant increase to post-IGI positions at the second test block in both conditions. The reason for the delayed response to the violation of temporal expectation over the two test blocks is unclear. Perhaps particular grouping structure changes led to capture effects, reducing the expected RT increase (Penel & Jones, 2005). However, the strong RT increase at the second test block showed clearly that temporal expectations acquired over exposure blocks were violated. Furthermore, the RT decrease at the return of the exposure rhythm demonstrated that the RT increase at the second test block was not due to fatigue. Post-tests again revealed that learning of the rhythms was implicit.

6.2.2.4. Interim summary

In Experiments 4 to 6, listeners of primarily Western tonal music implicitly learned rhythms with even and uneven meters. There was a weak effect of long-term temporal expectations on learning the rhythms with RT tending to be slower in response to the uneven, compared to even meter rhythms. Experiment 6 confirmed that metrical structure, rather than specific temporal features (i.e. durations of IGIs) drove slower RT
in the uneven, compared to the even meter condition, as both the even and uneven meter rhythms had identical temporal structures. In Experiment 4, processing the IGIs in the even meter test block after exposure to an uneven meter rhythm also seemed to benefit from the familiar even meter. In this instance, RT did not increase at the test blocks, perhaps because the even meter facilitated prediction of the IGIs. However, awareness of the rhythms acquired over exposure also played a role with RT increasing at the even meter test block for participants not showing awareness of the exposure rhythm (i.e. implicit learners). It is possible that obtaining awareness of the more complex uneven meter rhythm during exposure impeded learning, as indicated by the lack of RT increase at the test blocks for these “aware” participants. Nonetheless, Experiments 4 to 6 demonstrated that rhythms with relatively familiar even and less familiar uneven meters were learned.

6.3. Relevance of the Findings to Different Research Fields: IL of Temporal Structure, Development of Temporal Expectations, and Cross-cultural Rhythm Processing

6.3.1. IL of Temporal Structures

Evidence of IL of ordinal structures (i.e. the sequential ordering of event identities) in both the visual and auditory modalities is well established (see Cleeremans, et al., 1998; Perruchet, 2008 for reviews). However, there has been less reported evidence of learning of temporal structures in either modality. The experiments reported in the current thesis extend the phenomenon of IL into the auditory temporal domain and
provide evidence that temporal structures, or rhythms, can be implicitly learned. Previous research has demonstrated, in both the visual (Shin & Ivry, 2002) and auditory (Buchner & Steffens, 2001) modalities, that learning of temporal structures occurs only when they are correlated with an ordinal structure. In other words, temporal structures are learned only when concurrent learning of the ordinal structure aids in the prediction of upcoming temporal intervals. A reason cited (Ullén & Bengtsson, 2003) as to why independent learning of temporal structures (i.e. in the presence of a random ordinal structure) cannot be demonstrated using an SRTT is that it is impossible for the learner to predict the identity of the upcoming event. This uncertainty impedes or masks evidence of learning.

Salidis (2001) reported independent learning of auditory temporal structures but the SRTT she used required simple event detection, not identification. Furthermore, learning was only of the shorter intervals. A potential reason for the lack of evidence of independent temporal structure learning in the presence of a random ordinal structure (and the absence of learning of the longer intervals reported by Salidis) is the use of RSIs (i.e. response-stimulus intervals). RSIs inevitably introduce variability into the temporal presentation of events and might weaken the learning effect.

In the visual modality, Shin and Ivry (2002, Experiment 2) presented sequences with temporal structures based on IOIs (inter-onset intervals) rather than RSIs, thus reducing temporal variability. However, independent temporal structure learning was still not elicited. It appears therefore, that IL of temporal structures, defined by serial orderings of IOIs (inter-onset intervals), is most readily attained in the auditory modality. Indeed, recent research using auditory SRTTs has employed such structures and has exploited the benefits of meter, an important temporal feature of musical rhythms.
In two of these studies (Brandon, et al., 2012; Tillmann, et al., 2011) IL of rhythms in the presence of a random ordinal structure (i.e. syllables) was demonstrated. The experiments reported in the current thesis provide further evidence for the independent learning of rhythms and highlight the benefits of metrical structure in the development of temporal expectations.

Building on the work of Tillmann et al. (2011) and Brandon et al. (2012) a number of further contributions are made in the present thesis. Firstly, IL of IGIs in complex rhythms was demonstrated using an exposure/test block design and confirms that learning goes beyond that of just the grouping structure. In fact, the timing between event groups can be learned. It appears, at least to some degree, that the strength and familiarity of a meter facilitates learning of these longer, and more difficult to predict intervals (see also Brandon, et al., 2012; Eisler, et al., 2008; Grahn & Brett, 2007). But nevertheless, these intervals can be learned even when the rhythms have a weak, or culturally less familiar meter.

Secondly, the use of culturally diverse meters allowed for an investigation of the effects of long-term knowledge-based temporal expectations on IL of rhythms in a laboratory setting. Tillmann et al. (2011) investigated IL of simple temporal structures with IOIs typical of the intervals between strong beats in even and uneven meters. In the experiments reported in this thesis (Experiments 4 to 6), IL of even and uneven meters

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23 Schultz et al. (2013) compared learning using a 3-alternative forced-choice (3AFC) SRTT, requiring identification of three spatial locations of tones, with learning using a stimulus detection task. Learning was found to be stronger in the detection task, suggesting that the uncertainty of the stimulus identities (i.e. spatial locations) in the 3AFC weakened learning of the temporal structures. Nonetheless, Tillmann et al. (2011) and Brandon et al. (2012) found independent temporal structure learning using a pseudo-random syllable presentation.
was examined but using more complex rhythms and by introducing a test block to provide further evidence that the exposure rhythms were learned. These experiments showed that, while rhythms with familiar and less familiar meters can be learned, there is a benefit provided by a familiar even meter. Therefore, it appears that long-term temporal expectations acquired with extensive exposure to culturally specific rhythms influence IL of novel rhythms.

Thirdly, the set of post-tests (i.e. questionnaires, post-test sequence familiarity and certainly ratings, correlations between familiarity and certainty) used in the experiments reported in this thesis, allowed for a comprehensive measure of awareness of the temporal structures of the exposure rhythms. In order to maximise the opportunity for participants to demonstrate potential explicit knowledge, the post-test familiarity-rating task was as close a reproduction of the SRTT as possible. Furthermore, the confidence (i.e. measured with the certainty rating) with which participants rated their familiarity with a rhythm allowed for the identification of ratings that either represented guesses (low certainty ratings), or if fact, indicated awareness (high certainty ratings). Therefore, participants with awareness could be classified and where necessary, (a) the SRTT results re-analysed, with “aware” and “unaware” groups considered as a between-subjects factor, or (b) with “aware” participants removed, to ensure that learning was implicit. Across all IL experiments (Experiments 1, 2, 4, 5, and 6), these subsequent analyses revealed that learning of the rhythms was indeed implicit, and furthermore, awareness of the uneven meter exposure rhythms was associated with reduced evidence of learning (Experiment 4).
Finally, and consistent with the finding that awareness impeded learning of the uneven meter rhythm (Experiment 4), giving an explicit instruction also appeared to impede learning of a rhythm with a relatively weak meter (Experiment 3). Interestingly, for the exposure rhythm that was learned in Experiment 3, the explicit learning strategy was not associated with participants’ awareness of that rhythm. Learning of the slightly stronger meter rhythm in Experiment 3 proceeded implicitly and persisted in the presence of an explicit strategy to learn. This is consistent with findings from visual-spatial research with IL proceeding unhindered by attentional load (Curran & Keele, 1993; Jiménez & Méndez, 1999; Stefaniak, et al., 2008; Willingham & Goedert-Eschmann, 1999; Willingham, et al., 2002). However, sequence complexity appears to interact with IL. A hypothesis-testing strategy to learn a repeating visual sequence impedes learning more so when the sequence is relatively complex, compared to simple (Fletcher, et al., 2005). As this thesis did not manipulate instruction (i.e. implicit, explicit) within a single experiment, the effects of metrical strength (a possible analogue of complexity) and instruction on learning auditory sequences require further investigation. However, the findings of Experiment 3 suggest the presence of parallel implicit/explicit learning systems in the auditory temporal domain.

In summary, six experiments provide evidence that, with the benefits of employing rhythms typical of music, temporal structures can be learned independently of ordinal structures. In addition, the results suggest that IL is a powerful means of learning complex rhythms with culturally familiar and less familiar metrical structures.
6.3.2. Temporal Processing and the Development of Temporal Expectations of Rhythms with Even and Uneven Meters

Apart from informing the IL literature with the current demonstration of independent temporal structure learning, this thesis informs the research field of temporal processing. Specifically, using an SRTT, development of temporal expectations of complex (i.e. non-isochronous) rhythms with even and uneven meters was demonstrated. The benefit of the SRTT, requiring a response to every event, allowed for an examination not only of learning over exposure blocks, but also of the effects of violating temporal expectations at the test blocks. In general terms, - as in previous SRTT research - the experiments in this thesis showed that RT to identify syllables decreased with exposure but then increased when expectations were violated at the test block.

The data obtained with an SRTT in an IL context provides further evidence for the Dynamic Attending Theory (DAT). According to this theory, non-linear neural oscillations, coupled at multiple timescales, entrain to an external rhythm. These neural oscillations drive attention to future time points that are temporally consistent with the external rhythm (Jones & Boltz, 1989; Large & Jones, 1999; Large & Kolen, 1994). Attentional oscillations facilitate the processing of events aligning with these time points (i.e. faster RT and/or higher accuracy) but impede processing of events (i.e. slower RT and/or lower accuracy) presented earlier or later than expected (Jones, et al., 2002; Jones & Yee, 1997; Penel & Jones, 2005; Tillmann & Lebrun-Guillaud, 2006). Thus, the results reported in this thesis support DAT by demonstrating faster RT to events occurring at expected points in time (established with short-term exposure to a prior temporal context) and slower RT to temporally unexpected events (violating the established expectations).
Neurophysiological studies using ERPs (Geiser, Ziegler, Jancke, & Meyer, 2009; Iversen, Repp, & Patel, 2009; Ladinig, Honing, Háden, & Winkler, 2009), Electroencephalography (EEG) and magnetoencephalography (MEG) also provide support for the DAT, showing that temporal expectations arise from dynamic neural processes (see Grahn, 2012; Zanto, Snyder, & Large, 2006 for reviews). Specifically, MEG and EEG studies show that Gamma band activity, originating from the auditory cortex, time-locks to sound onsets. The high-frequency bursts of neural activity arise in response to auditory rhythms and these oscillatory processes activate at different periodicities entraining to the different metrical hierarchical levels (Grahn, 2012; Large & Snyder, 2009). These multiple activations give rise to the perception of meter (Snyder & Large, 2005). Large and Snyder (2009) suggest that these rhythmic bursts allow communication between the auditory and motor cortices, and drive attention to points in time that align with the metrical structure of the rhythm. These neural processes underpin temporal expectancy and processing of meter (Grahn, 2012; Large & Kolen, 1994; Large & Snyder, 2009; Snyder & Large, 2005; Zanto, et al., 2006).

It is proposed that neural oscillations drove the development of temporal expectations in the current set of studies. As shown using an auditory SRTT, expectations were acquired via implicit learning. Furthermore, the reported experiments provided evidence that metrical structure facilitated prediction of the IGIs. That is, neural oscillations at multiple timescales, driven by metrical structure, enhanced processing of the relatively difficult-to-process longer IOIs that extended over multiple beats (see also Eisler, et al., 2008; Grahn & Brett, 2007). Previous research using explicit discrimination tasks has indicated that listeners give precedence to grouping structure over IGIs when
organising temporal information (Handel, 1998). However, IGIs are abstracted and integrated into the organised temporal structures when the meter of the rhythms is strong (Hébert & Cuddy, 2002; Ross & Houtsma, 1994). In the current thesis, learning of IGIs occurred in weakly metrical rhythms and in rhythms with culturally less familiar meters. It is argued that in addition to the benefits provided by implicit processes, the learning of IGIs was facilitated by the motor responses required in the SRTT. While the role of a motor response requires further research in the auditory/temporal domain, visual/ordinal SRTTs have shown an advantage of concurrent motor learning when sequences are complex (e.g. Deroost & Soetens, 2006; Mayr, 1996).

A question that remains to be addressed is how the Dynamic Attending Theory might account for processing of complex (i.e. syncopated) rhythms and rhythms with uneven meters (Velasco & Large, 2011). It is possible that consistent neural oscillation in response to culturally specific rhythms to which a listener is frequently exposed, underpins the development of long-term expectations and the learning of rhythmic structures (Jones, 2009). In fact, with long-term exposure, oscillators may couple in such a way that accounts for the accurate perception and production of rhythms with uneven meters. When perceiving a rhythm, there may be an attempt to fit its temporal structure with these neural oscillatory patterns, established via extensive exposure to music of one’s environment and culture. If the fit is successful, and temporal expectations are upheld, processing of the rhythm is enhanced (i.e. faster and more accurate responses to events). If a successful fit is not made, and expectations are violated, then processing is impeded (i.e. slower and less accurate responses to events).
An additional question concerns the accuracy of the Povel and Essens (1985) measure of metrical strength (C-score) when applied to temporal structures with uneven meters. Indeed, when applied to temporal structures with even meters, it is unknown whether the score predicts meter perception of rhythms with varying tempos, and with varying lengths (i.e. number of beats/events). Furthermore, it is unclear whether two strongly metrical rhythms with a particular C-score difference would be perceived as metrically dissimilar as two weakly metrical rhythms with an equivalent C-score difference. Apart from these issues, a program of research would be required to test this measure against perception and production performance of temporal structures with uneven meters. This research would employ participants with lifetime exposure to uneven meters in order to validate the applicability of the C-score to temporal structures with non-Western tonal meters. Future research investigating temporal processing of uneven meters would benefit from a well-validated measure of metrical strength.

In summary, this thesis provides evidence that temporal expectations of complex (i.e. non-isochronous) rhythms with culturally familiar and culturally less familiar meters can be implicitly learned in a time-limited laboratory setting. The evidence is explained by the proposition that via exposure, listeners develop expectations of musical structures without necessarily having an intention to do so (Bigand & Poulin-Charronnat, 2006; Huron, 2006). Elsewhere, evidence has shown that unfamiliar tonal structures can be implicitly learned (Loui & Wessel, 2008; Rohrmeier & Rebuschat, 2012; Saffran, et al., 1999; Tillmann & Poulin-Charronnat, 2010). For temporal structures, or rhythms, the SRTT used in this thesis has provided a method with which to examine the development of temporal expectations via IL.
6.3.3. The Effect of Long-term Exposure to Culturally Specific Rhythms and Meters on Temporal Processing

One of the key aims of the research presented in this thesis was to examine IL, by listeners enculturated to Western tonal music, of rhythms with culturally familiar (i.e. even) and less familiar meters (i.e. uneven). A lifetime’s exposure to Western tonal music affects the perception and processing of new, unfamiliar tonal structures (Curtis & Bharucha, 2009; Krumhansl, 2000b; Krumhansl, et al., 1999; Krumhansl, et al., 2000). Likewise, familiarity with rhythms typical of Western tonal music also affects processing of rhythms with less familiar uneven meters (Hannon, Soley, et al., 2012; Hannon & Trainor, 2007; Hannon & Trehub, 2005a; Hannon, Vanden Bosch der Nederlanden, et al., 2012; Kalender, et al., 2012; Repp, et al., 2005; Snyder, et al., 2006; Trehub & Hannon, 2009). For instance, North American adults are better at detecting temporal alterations in melodies with even, compared to uneven, meters. However, adults from Macedonia and Bulgaria are equally accurate at detecting alterations in melodies with both even and uneven meters (Hannon & Trehub, 2005a). Furthermore, exposure to music with uneven meter rhythms (i.e. 2 weeks passive listening to a CD of Bulgarian music) does not enhance adults’ performance on the temporal alteration detection tasks (Hannon & Trehub, 2005b; Hannon, Vanden Bosch der Nederlanden, et al., 2012).

The experiments reported in this thesis demonstrated that listeners of Western tonal music implicitly learned rhythms with less familiar uneven meters. There was however, a benefit of a familiar even meter on learning, with a tendency for RT to be faster to even, compared to uneven meter rhythms. A key difference between the experiments conducted in this thesis and those conducted by Hannon and colleagues is
that the current experiments aimed to investigate IL of particular rhythms across a single SRTT. Hannon and colleagues rather investigated the effects of passive at-home exposure to uneven meters in Bulgarian music on the processing of melodies with uneven meters rhythms in a subsequent laboratory testing session. A further key difference is that the SRTT demanded motor responses to each event whereas the exposure phase in the experiments conducted by Hannon and colleagues involved passive listening. Therefore, the additional motor engagement with the rhythms in the current experiments may have facilitated processing of the uneven meters. As performance of music with uneven meters is frequently integrated with dance (Fracile, 2003; Shehan, 1984; Singer, 1974), movement might be an important element in learning rhythms. Indeed, movement (i.e. patterns of bouncing) has been shown to influence infants’ preferences for particular meters, indicating that multi-sensory processes drive the relationship between movement and auditory rhythms (Phillips-Silver & Trainor, 2005).

Neurophysiological evidence supports this proposition that movement and rhythm processing are closely related. Research using neuroimaging shows activation of the sensorimotor cortex (SMC), supplementary motor area (SMA) premotor cortex, and cerebellum, areas implicated in temporal and ordinal sequencing (Janata & Grafton, 2003). In particular, functional magnetic resonance imaging (fMRI) reveals a strong relationship between the basal ganglia and the supplementary motor area (SMA), brain regions associated with beat induction and motor prediction (Grahn & Brett, 2007; Kung, et al., 2013).

In summary, using an SRTT, rhythms with uneven meters were implicitly learned. The reported experiments highlight the value of employing culturally diverse stimuli in
order to examine the flexibility of temporal processing. Furthermore, use of these cross-cultural materials can expand and further develop theories of temporal cognition (Huron, 2008, 2012; Rohrmeier & Rebuschat, 2012; Stevens, 2004, 2012).

6.4. Practical Implications

In everyday life, listeners process the temporal structures inherent in complex auditory sequences (e.g. music, speech) in order to facilitate prediction of the timing of upcoming events (e.g. musical tones, syllables). Often these temporal expectations are acquired implicitly. In the series of experiments here, IL of temporal structures, or rhythms, has been demonstrated in a laboratory setting. The results of these experiments also have relevance for other tasks that require temporal prediction, e.g. dance, gymnastics, sports, and other complex motor tasks. As rhythm and movement are closely related (Chen, et al., 2006; Grahn & Brett, 2007; Kung, et al., 2013), accurate temporal expectations are extremely important for the execution of motor tasks (Molinari, Leggio, De Martin, Cerasa, & Thaut, 2003). In the auditory modality, the current research demonstrates that developing these expectations implicitly facilitates reaction time to respond to events.

With music in particular, the relationship between temporal and motor processing is crucial for performance (Chen, et al., 2006; Zatorre, et al., 2007). Musical performance is a complex and cognitively demanding task that requires significant practice, benefiting both motor performance and processing of the produced auditory feedback. Precise timing, as well as accurate pitch production is required and must be achieved through the sequencing of complex motor processes (Drake & Palmer, 2000; Palmer, 2005).
Therefore, auditory-motor interactions are crucial for performance (Phillips-Silver & Trainor, 2005; Zatorre, et al., 2007). Using a task that required a motor response to every event, the program of research presented in this thesis demonstrates that the representation of precise timing in complex familiar and less familiar temporal structures can develop implicitly. This has relevance to music pedagogy and implications for music education. Introducing students to cross-cultural materials is a goal of many music educators (Shehan, 1984; Skelton, 2002; C. Smith, 1997). Yet, the traditional educative tools for teaching Western tonal music (e.g. via Western music notation) may not be the most appropriate and useful means of teaching cross-cultural rhythms. Walking in time to music (C. Smith, 1997), performing movement or dance, and the assignment of words to particular movements are alternative methods used (Shehan, 1984). In these methods, students develop temporal expectations incidentally through performance and without formal, and traditional music instruction. The experiments in the current thesis demonstrate in a laboratory setting, that implicit learning, necessitating a motor response, is a useful means through which temporal expectations can develop and culturally familiar and less familiar rhythms can be learned.

With speech perception and production, expectations of temporal structure and meter are also important for lexico-semantic processing (Rothermich & Kotz, 2013; Rothermich, Schmidt-Kassow, & Kotz, 2012). Implicit learning of temporal structures may also be an important component of acquiring a second language, allowing a learner to develop expectations of stress patterns and the temporal cues involved in word segmentation (Schön, et al., 2008).

Emerging research is highlighting the relationship between aspects of music and
language processing, and exploring the shared neural underpinnings of music and language (Patel, 2006; Patel & Daniele, 2003; Patel, Iversen, & Rosenberg, 2006; Peretz & Coltheart, 2003). Therefore, music, with its sequential and temporal structures, is an important tool for understanding perceptual, cognitive and motor processes relevant for speech production and language acquisition (Overy, 2000; Tillmann, 2012).

Given that temporal processing is important in speech perception and production (Cutler, 1994; Patel, 2006; Patel & Daniele, 2003; Patel, et al., 2006; Tillmann, 2012), the demonstrations of IL of rhythms have implications for rehabilitation of brain-injured patients. While rehabilitation of motor skills that require temporal processing including speech production often involves explicit instructions, these instructions may hinder learning particularly of complex sequential tasks (Fletcher, et al., 2005; Howard & Howard Jr, 2001; Pohl & McDowd, 2006).

Implicit learning appears to remain intact in stroke patients (Pohl & McDowd, 2006), Alzheimer’s disease patients (Grafman, et al., 1990) and patients with closed-head injuries (Nissley & Schmitter-Edgecombe, 2002). Therefore, implicit strategies may aid in the administration of rhythm-based interventions. For instance, entrainment to rhythmic auditory stimulation (RAS) has been shown to improve gait (Hayden, Clair, Johnson, & Otto, 2009; Thaut, McIntosh, & Rice, 1997; Thaut, et al., 1996) in stroke patients. Similarly, metrical pacing (Brendel & Ziegler, 2007), and melody and rhythm interventions (Melodic Intonation Therapy, MIT) (see Hurkmans, et al., 2012 for a review) have been used to treat patients with various language disorders, including non-fluent aphasia (i.e. impaired speech production) and apraxia (i.e. impaired planning of speech movements). For instance, singing and rhythm training has been shown to
improve production of formulaic phrases in patients with non-fluent aphasia, (Stahl, Henseler, Turner, Geyer, & Kotz, 2013). Rhythm training appears to be particularly important for patients with lesions in the basal ganglia (Stahl, Kotz, Henseler, Turner, & Geyer, 2011).

Temporal processing difficulties have also been associated with children with language impairments (Corriveau & Goswami, 2009) and dyslexia (Overy, 2000; Overy, Nicolson, Fawcett, & Clarke, 2003) and this research has also shown that music training improves phonological and spelling skills. The benefits provided by meter, presented within the context of a regular temporal prime, also appear to assist syntax processing in children with specific language impairments and dyslexia (Przybylski, et al., 2013).

As implicit learning has been shown to be an effective motor skills training strategy for brain injured patients (Pohl & McDowd, 2006), IL of rhythm may be a particularly effective strategy for improving not only gait but also speech. Furthermore, IL of rhythm may also facilitate language skills in children with language impairments and dyslexia. Research addressing this proposition can only proceed if indeed IL of rhythms has been demonstrated and the results reported in this thesis contribute to this preliminary research goal.

6.5. Future Directions

A contribution of the experiments reported in this thesis is the demonstration of IL of rhythms that goes beyond the learning of grouping structures. In fact, temporal intervals between groups can be learned (i.e. IGIs). In Experiments 1 and 2, it was found that meter modulated this learning, with the emergence of IL for only the stronger of the
two weakly metrical rhythms. Future research is required to determine the precise role of metrical strength in the IL of rhythms. Firstly, the benefit of meter more broadly could be examined by directly comparing IL of metrical and non-metrical temporal structures. Previous research has failed to demonstrate independent learning of auditory rhythms without metrical structure (Buchner & Steffens, 2001). However, additional work directly comparing IL of non-metrical rhythms with metrical rhythms of various strengths would further elucidate the benefits of meter in IL of temporal structure. IL of metrical and non-metrical rhythms has been addressed by Schultz et al. (2013) and it was found that learning was equivalent across the metrical and non-metrical conditions. This may have been because the non-metrical manipulation was not strong enough to prevent participants accommodating this structure into a metrical framework. Schultz et al (2013) did not report analyses according to interval length as Salidis (2002) did, so it is unknown as to whether participants learned the longer IOIs (i.e. IGIs). Hence, examining the possible benefits of metrical structure on learning the longer IOIs between groups of auditory events would be a next step.

The current research program also demonstrated that rhythms with uneven meters can be learned. Furthermore, it appears that long-term temporal expectations moderate learning. Namely, listeners enculturated to Western tonal music were faster at responding to events presented in rhythms with relatively familiar even meters, compared to less familiar uneven meters. A further examination of the proposition that cultural-familiarity with particular meters moderates learning could be achieved by examining IL in listeners with long-term exposure to rhythms with uneven meters (e.g. adults of Macedonian, Bulgarian, or Turkish origin), or other complex cross-cultural rhythmic structures (e.g.
Indian *ragas*). Future research could also be conducted with trained musicians with exposure to a broad range of meters and syncopated rhythms. Some recent research (Kalender, et al., 2012) has shown that listeners with prior exposure to Indian music (i.e. music featuring rhythms with non-metrical structures, and a variety of complex meters) were more accurate than listeners with exposure only to Western tonal music at detecting temporal violations in Turkish melodies with uneven meters. This finding suggests that long-term exposure to a diversity of metrical structures facilitates processing of cross-cultural rhythms. Comparing IL of uneven meters across participants groups with varying degrees of familiarity with uneven meters or experience with syncopated rhythms would further probe the roles of enculturation and exposure to cross-cultural musical styles on learning.

The current paradigm employed in this program of research allowed for an examination of IL of particular rhythms. The effect of exposure to rhythms with uneven meters on subsequent learning of novel rhythms with the same metrical framework was not examined. This would be somewhat analogous to the research conducted by Hannon and colleagues (e.g. Hannon & Trehub, 2005b; Hannon, Vanden Bosch der Nederlanden, et al., 2012) who examined the effect of passive exposure to Bulgarian music on the processing of new melodies with uneven meters. A further extension of the research presented in this thesis would be to employ the SRTT as a means of exposing listeners to a variety of rhythms over a number of learning sessions. Via this exposure, the development of temporal expectations not only of a particular rhythm, but also of metrical structure more broadly, could then be examined.
A matter arising from the results of Experiments 3 and 4 concerns the potential benefit of implicit, over explicit learning. Previous research using the SRTT in the visual/ordinal domain has demonstrated that an explicit instruction impedes learning, particularly for complex structures (Fletcher, et al., 2005; Howard & Howard Jr, 2001). However, there appears to be no published literature comparing explicit and implicit learning of auditory temporal structures. For listeners of Western tonal music, uneven meters may act as an analogue of complexity. Direct comparisons between the effects of explicit and implicit instructions on learning rhythms with even (less complex) and uneven meters (more complex) would further our understanding of these potentially multiple learning systems. This research could also be applied to clinical populations (e.g. stroke patients, Alzheimer patients, patients with specific language impairment) in order to investigate the development of temporal expectations via IL when an explicit instruction may be untenable, or may interfere with learning.

Finally, it is noted that the SRTT in the current program of research was quite difficult for participants. Accuracy was somewhat low (approximately 65% accuracy rate) and in Experiment 4, for example, over 30% of participants performed significantly below chance and had to be removed from the analysis. This was most likely due to the speed of syllable presentation as the syllables themselves were clearly distinguishable (see the pilot study/perceptual test in Tillmann, et al., 2011). The speed of presentation was chosen as the shortest temporal unit (400 ms) in Experiments 4 to 6 is in the range typical of rhythms with both even and uneven meters (Moelants, 2006). This rapid presentation was also required to induce contiguity of the rhythms (London, 2002). Future research needs to address the issue of low accuracy by perhaps employing a
substantial training phase during which time participants acclimatise to the task. Additionally, alternative stimuli other than syllables (e.g. musical tones) might be employed. However, syllables were chosen as the events to which responses were made as participants are naturally well practiced at discriminating speech sounds, and the syllables acted as a “cover story” (i.e. syllable identification task) in order to direct attention away from the temporal structure, and to promote IL. To maintain this benefit and to allow for a fast tempo, a future adaptation might require identification or detection of particular syllables (i.e. rather than of all syllables), with these syllables located in temporal positions of interest (e.g. positions aligning with strong beats). This method would allow for an investigation of learning of hierarchical structures in contexts of varying metrical strength or relative familiarity with meter. Nonetheless, while accuracy remains an issue to be addressed, the auditory SRTT provided an effective tool for examining IL of rhythms.

6.6. Conclusions

Music is a universal human endeavour (Clayton, Herbert, & Middleton, 2003). Musical rhythms are structured in ways to enhance listeners’ capacity to synchronise their movements to the beat. Specifically, rhythms have metrical structures, or meters, that give rise to the perception of cycling strong and weak beats to which listeners entrain. While meter can be perceived in rhythms of most cultures, the nature of the perceived meter can differ cross-culturally (Clayton, et al., 2004; London, 1995; Magill & Pressing, 1997; Nettl, 1983). Temporal expectations crucial for engaging with musical rhythms can develop implicitly; expectations of a particular rhythm can be acquired with short-term
exposure and expectations of meter can be acquired over a lifetime’s exposure to culturally specific rhythmic structures. In this program of research, an SRTT was used to examine IL of rhythms when the order of events (i.e. syllables) presented in the rhythmic sequences was unpredictable. The findings demonstrate that listeners of Western tonal music can implicitly learn rhythms with culturally familiar (i.e. even) and culturally less familiar (i.e. uneven) meters. While rhythms with both meters were learned, there was an advantage provided by a familiar even meter. When the meter was familiar (i.e. even) and weakly metrical, there was also a benefit from a slightly stronger meter. This research has demonstrated the capacity of listeners to acquire temporal expectations implicitly and brings together the research fields of temporal processing, music perception and cognition, and implicit learning (Hallam, Cross, & Thaut, 2009). The findings also establish the value of employing diverse cross-cultural materials to investigate implicit learning of unfamiliar musical rhythms. In particular the strength of implicit learning has been shown promote the development of temporal expectations of complex rhythms.
References


*Memory and Cognition, 29*(8), 1111-1119.


Implicit Learning of Complex Auditory Temporal Structures with Even and Uneven Meters

Volume 2

Appendices

Josephine A. Terry
BA (Psychology) Honours

A thesis submitted for the degree of Doctor of Philosophy

The MARCS Institute
University of Western Sydney, Australia

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Appendix A: Povel and Essens (1985) Internal Clock Measure of Metrical Strength

A C-score is generated by considering the relationship between the hypothesised beat grid (or internal clock pulse) and the subjective accent structure. Specifically, the counter-evidence based measure considers the number of internal clock pulses that are not accompanied by an event or are accompanied by a subjectively unaccented event using the formula: $C = (W \cdot -ev) + (1 \cdot 0ev)$, where $-ev$ is the number of beats that coincide with a silence and $0ev$ is the number of beats that coincide with an unaccented auditory event. $W$ is a weight generally set at four. The lower the C-score, the stronger the meter of the sequence, with zero indicating maximal metrical strength.

The rhythms (Pattern 1, Pattern 2) employed in Experiments 1 to 3 are presented in Figure A1.

![Pattern 1 and Pattern 2](image_url)

**Figure A1.** Temporal structures used in Experiments 1 to 3 (Pattern 1 and Pattern 2): “X” represents a syllable, “.” Represents a silent interval, “|” represents a 1200 ms beat unit. Bold font indicates a grouping accent. Events (i.e. syllable and silent interval) are 600 ms subdivisions of the beat unit.
The calculation of the C-scores is as follows:

\[ C = (W \times -ev) + (1 \times 0ev) \]

-ev is the number of clock pulses that coincide with a silence (“.” in Figure A1) and 0ev is the number of clock pulses that coincide with an unaccented auditory event (non-bolded “X” in Figure A1). \( W \) is a weight generally set four.

Pattern 1:

\[ C = (4 \times 3) + (1 \times 3) \]

\[ C = 15 \]

Pattern 2:

\[ C = (4 \times 4) + (1 \times 3) \]

\[ C = 19 \]
Appendix B: Additional Analyses of Experiments 1 and 2 Reported in Chapter 2

B.1. Analyses of Accuracy over Blocks

B.1.1. Post-IGI Positions

B.1.1.1. Experiment 1

B.1.1.2. Experiment 2

B.1.2. Controlled Within-group Positions

B.1.2.1. Experiment 1

B.1.2.2. Experiment 2

B.2. Correlations between Post-IGI Accuracy and Reaction Time (RT)

B.2.1. Experiment 1

B.2.2. Experiment 2

B.3. Main effect of IGI and the Role of the Preceding Syllable Group Size

B.3.1. Exposure Blocks (mean of Blocks 5 and 7)

B.3.1.1. Experiment 1

B.3.1.2. Experiment 2

B.3.2. Test Block

B.3.2.1. Experiment 1

B.3.2.2. Experiment 2

B.4. Correlations between Post-test Familiarity and Certainty Ratings

B.4.1. Experiment 1

B.4.2. Experiment 2

B.5. Experiment 2 Analyses by Awareness

B.5.1. Post-IGI Positions

B.5.1.1. Exposure

B.5.1.2. Test Block

B.5.2. Controlled Within-group Positions

B.5.2.1. Exposure

B.5.2.2. Test Block
B.1. Analyses of Accuracy over Blocks

B.1.1. Post-IGI Positions

Examining accuracy (% correct) to post-IGI positions over exposure blocks, an ANOVA with Block (Blocks 1 – 5) as a within-subjects factor, and Pattern condition (Pattern 1, Pattern 2) as a between-subjects factor was conducted for Experiments 1 and 2 respectively. To assess accuracy at the test block, we conducted an ANOVA with Block as a within-subjects factor (Block 6 vs. mean of Blocks 5 and 7) and Pattern condition as a between-subjects factor (Pattern 1, Pattern 2) for Experiments 1 and 2, respectively.

B.1.1.1. Experiment 1

Over exposure, there was no effect of Block, $F(4, 164) = 1.60, p = .18, \eta^2 = .04$, no effect of Pattern condition, $F(1, 41) = .00, p = .99, \eta^2 = .00$, and no Block by Pattern Condition interaction, $F(4, 164) = .47, p = .75, \eta^2 = .01$. At the test block, there was no effect of Block, $F(1, 41) = 0.04, p = .84, \eta^2 = .00$ or Pattern condition, $F(1, 41) = 1.38, p = .25, \eta^2 = .03$, but there was a significant interaction, $F(1, 41) = 4.24, p = .05, \eta^2 = .09$. Accuracy decreased at the test block in the Pattern 1 condition (Test block: $M = 66.58\%, SD = 15.70$; mean adjacent exposure blocks, $M = 69.31\%, SD = 14.43$) but increased at the test block in the Pattern 2 condition (Test block: $M = 73.57\%, SD = 10.49$; mean adjacent exposure blocks, $M = 71.34\%, SD = 11.62$). However, when the two conditions were assessed separately, these differences were not significant.

B.1.1.2. Experiment 2

Over exposure blocks, there was no effect of Block, $F(4, 172) = 1.33, p = .26, \eta^2 = .03$, no effect of Pattern condition, $F(1, 43) = .39, p = .56, \eta^2 = .01$, and no Block by
Pattern condition interaction, $F(4, 172) = .28, p = .89, \eta^2 = .01$. At the test block, comparing Block 6 (test) and the mean of Blocks 5 and 7 (exposure), there was a main effect of Block (Block 6, Mean Blocks 5 & 7), $F(1, 43) = 9.12, p = .01, \eta^2 = .18$, no effect of Pattern condition (Pattern 1, Pattern 2), $F(1, 43) = .23, p = .63, \eta^2 = .01$, but there was a significant Block by Pattern condition interaction, $F(1, 43) = 12.48, p = .00, \eta^2 = .23$. Analysing by condition, there was a significant decrease at the test block (Block 6) in the Pattern 1 condition, $F(1, 21) = 15.59, p = .00, \eta^2 = .43$ (Test block: $M = 70.46\%, SD = 11.95$; mean adjacent exposure blocks, $M = 77.15\%, SD = 8.99$). However, there was no significant difference in the Pattern 2 condition, $F(1, 22) = .20, p = .66, \eta^2 = .00$ (Test block: $M = 75.52\%, SD = 11.25$; mean adjacent exposure blocks, $M = 75.00\%, SD = 10.66$). The results at the test block for Pattern 1 are consistent with the RT data, indicating that in the Pattern 1 condition, performance deteriorated (significantly in Experiment 2) at the introduction of the new temporal structure (at Block 6).

**B.1.2. Controlled Within-Group Positions**

For analysing accuracy over exposure blocks, an ANOVA with Block (Blocks 1 – 5) as a within-subjects factor, and Pattern condition (Pattern 1, Pattern 2) as a between-subjects factor was conducted for Experiments 1 and 2, respectively. To assess accuracy at the test block, an ANOVA with Block as a within-subjects factor (Block 6 vs. mean of Blocks 5 and 7) and Pattern condition as a between-subjects factor (Pattern 1, Pattern 2) was conducted for Experiments 1 and 2, respectively.
B.1.2.1. Experiment 1

Over exposure, there was a main effect of Block, $F(4, 164) = 3.44, p = .01, \eta^2 = .08$, no effect of Pattern condition, $F(1, 41) = .68, p = .41, \eta^2 = .02$, and no Block by Pattern Condition interaction, $F(4, 164) = 1.08, p = .37, \eta^2 = .03$. Accuracy at Block 5 was significantly higher than at Block 1, $p = .00$ (Block 1: $M = 60.03\%$, $SD = 19.69$; Block 5, $M = 67.61\%$, $SD = 16.17$), indicating that syllable identification improved with exposure. At the test block, there was no effect of Block, $F(1, 41) = 0.50, p = .48, \eta^2 = .04$, or Pattern condition, $F(1, 41) = .25, p = .62, \eta^2 = .01$, nor was there an interaction, $F(1, 41) = .43, p = .51, \eta^2 = .01$.

B.1.2.2. Experiment 2

Over exposure blocks, there was no effect of Block, $F(4, 172) = 1.98, p = .10, \eta^2 = .04$, no effect of Pattern condition, $F(1, 43) = .01, p = .91, \eta^2 = .00$, and no Block by Pattern Condition interaction, $F(4, 172) = .84, p = .50, \eta^2 = .02$. Assessing accuracy at the test block, there was no effect of Block, $F(1, 43) = 0.17, p = .69, \eta^2 = .00$, no effect of Pattern condition, $F(1, 43) = .20, p = .89, \eta^2 = .00$, and no interaction, $F(1, 43) = .02, p = .88, \eta^2 = .00$.

B.2. Correlations between Post-IGI Accuracy and Reaction Time (RT)

Correlations between accuracy and RT to post-IGI positions at each block were conducted in order to determine whether participants followed the instructions (to respond as fast and as accurately as possible) or adopted a speed/accuracy trade-off. Table B1 shows the correlations between post-IGI RT and accuracy for Experiment 1 and Experiment 2 (Pearson’s $r$).
B.2.1. Experiment 1

In both the Pattern 1 and Pattern 2 conditions, negative correlations for the first six blocks were significant (ps < .05) and approached significance at Block 7 (ps ≤ .07). These negative correlations reveal that the faster the RT, the higher the accuracy and indicate the absence of a speed/accuracy trade-off.

B.2.2. Experiment 2

In the Pattern 1 condition, negative correlations at Block 2 to Block 6 were significant (ps ≤ .03) and approached significance at Block 1 and Block 7 (ps ≤ .08). All negative correlations were significant in the Pattern 2 condition (ps ≤ .03). As per Experiment 1, the negative correlations reveal that the faster the RT, the higher the accuracy and indicate the absence of a speed/accuracy trade-off.
Table B1

Experiments 1 and 2: Correlations (Pearson’s r) between post-IGI RT and accuracy in each condition (Pattern 1, Pattern 2). * indicates significance at p < .05 and ** indicates significance at p < .01

<table>
<thead>
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<th>Experiment</th>
<th>Condition</th>
<th>Block</th>
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<td></td>
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<td>-.55**</td>
</tr>
</tbody>
</table>

B.3. Main effect of IGI and the Role of the Preceding Syllable Group Size

According to the variable foreperiod effect (e.g. Ellis & Jones, 2010), RT to syllables should be slower following 1200ms IGIs than 1800ms IGIs. However, over exposure blocks the reverse was found; RT was faster following 1200ms IGIs compared to 1800ms IGIs. This finding may be due to the size of the group preceding each IGI. In the Pattern 1 exposure pattern, positions 1, 3 and 7 followed long IGIs (1800ms), but two of these three positions (1 and 7) were preceded by a larger group of four syllables whereas one position (position 3) was preceded by a smaller group of two. Positions 8, 9, and 12 follow short IGIs. Two of these positions (8 and 9) were preceded by a smaller group (single syllable), while one position (position 12) was preceded by a larger group of three syllables. It may be that slower RT to post-IGI positions following the larger
groups of 3 or 4 syllables (see x below), compared to smaller groups of syllables (or single syllable), reflected a carry-over performance decrement due to the difficulty in responding to these larger groups.

Pattern 1 condition (Exposure)  

B.3.1. Exposure Blocks (mean of Blocks 5 and 7)  

To examine the hypothesis that RT is slower to post-IGI positions following larger, compared to smaller, groups, a paired samples t-test was conducted on RT of the mean of Blocks 5 and 7. Positions that followed a larger group of 3 or 4 syllables (positions 1, 7, and 12) were compared with those following a smaller group of 1 or 2 syllables.

B.3.1.1. Experiment 1  

RT was significantly slower to syllables following a larger group (\(M = 589.33\)ms) compared to a smaller group (\(M = 509.58\)ms), \(t(20) = 7.40, p = .00, SE = 10.78\).

B.3.1.2. Experiment 2  

RT was also significantly slower to syllables following a larger group (\(M = 575.55\)ms) compared to a smaller group (\(M = 492.32\)ms), \(t(21) = 9.39, p = .00, SE = 8.86\). Therefore, it appears that slower RT to syllables following the 1800ms IGIs, compared to the 1200ms IGI, might be a consequence of the preceding larger syllable groups.
B.3.2. Test Block

To ensure that the observed RT increase at the test block was independent of the size of the preceding syllable group, ANOVAs were conducted for Experiments 1 and 2, respectively. RT at the test block, compared to the mean of adjacent exposure blocks (Block 6, mean Block 5 and 7) was examined. Block and Preceding Group Size (larger, smaller) were within-subjects factors.

B.3.2.1. Experiment 1

There was a main effect of the Preceding Group Size with RT to syllables following a larger group significantly slower than those following a smaller group, $F(1, 20) = 73.13, p = .00, \eta^2 = .78$. There was also a main effect of Block with RT at the test block (Block 6) significantly slower than at the adjacent exposure blocks (mean Blocks 5 and 7), $F(1, 20) = 9.10, p = .01, \eta^2 = .31$. However, there was no Preceding Group Size by Block interaction.

B.3.2.2. Experiment 2

There was a main effect of Preceding Group Size with RT to syllables following a larger group significantly slower than those following a smaller group, $F(1, 21) = 106.80, p = .00, \eta^2 = .84$, and a main effect of Block with RT at the test block (Block 6) significantly slower than at the adjacent exposure blocks (mean Blocks 5 and 7), $F(1, 21) = 18.49, p = .00, \eta^2 = .47$. Again, there was no interaction.

Together these analyses confirm the hypothesis that the size of the preceding group influences RT to the following post-IGI position but also reveals that the increase at the test block occurred irrespective of the size of the group preceding each IGI.
B.4. Correlations between Post-test Familiarity and Certainty Ratings

To further examine awareness of the temporal structures presented in the SRTT, correlations between post-test familiarity and certainty ratings were calculated. The rationale is that if knowledge of the temporal structure is explicit, then a positive correlation between familiarity and certainty ratings to the exposure sequences is expected (Scott and Dienes, 2008). In other words, explicit knowledge is evident if participants rate the exposure sequences as familiar and they are certain of their decision. In addition, a negative correlation between familiarity and certainty ratings to the Novel sequences also indicates explicit knowledge. In this case, participants with explicit knowledge rate the Novel sequences as unfamiliar and are certain of their decision.

To calculate the correlations between Familiarity and Certainty, each participant’s mean familiarity rating (i.e. mean rating of all patterns) was subtracted from their ratings to each exposure and novel sequence, yielding a difference score. For each participant, a mean difference score was calculated for each sequence set (Exposure, Novel) and these were converted to z-scores (z-familiarity). Correlations between z-familiarity scores and certainty ratings to the exposure and novel sequences were calculated. These correlations were computed separately for each condition (Pattern 1, Pattern 2).

B.4.1. Experiment 1

There were no significant correlations between z-familiarity and certainty for either the exposure or novel sequences (Table B2), indicating that neither the Pattern 1 nor Pattern 2 group had explicit knowledge of the temporal structure presented in the SRTT.
Table B2

*Experiment 1: Correlations between z-familiarity and certainty ratings to Exposure and Novel patterns in each condition (Pattern 1, Pattern 2)*

<table>
<thead>
<tr>
<th>Condition</th>
<th>Pattern</th>
<th>$r$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pattern 1 (N = 21)</td>
<td>Exposure</td>
<td>.13</td>
<td>.57</td>
</tr>
<tr>
<td></td>
<td>Novel</td>
<td>.33</td>
<td>.14</td>
</tr>
<tr>
<td>Pattern 2 (N = 22)</td>
<td>Exposure</td>
<td>-.02</td>
<td>.95</td>
</tr>
<tr>
<td></td>
<td>Novel</td>
<td>.26</td>
<td>.24</td>
</tr>
</tbody>
</table>

*B.4.2. Experiment 2*

There was a significant positive correlation between z-familiarity and certainty ratings to exposure sequences in the Pattern 1 condition. There was no correlation between z-familiarity and certainty ratings to Novel sequences. This is in accordance with higher ratings of familiarity to the exposure, compared to test and novel sequences. In the Pattern 2 condition, there were no significant correlations (Table B3).
Table B3

*Experiment 2: Correlations between z-familiarity and certainty ratings to Exposure and Novel patterns in each condition (Pattern 1, Pattern 2)*

<table>
<thead>
<tr>
<th>Condition</th>
<th>Pattern</th>
<th>r</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pattern 1 (N = 22)</td>
<td>Exposure</td>
<td>.45</td>
<td>.04</td>
</tr>
<tr>
<td></td>
<td>Novel</td>
<td>-.07</td>
<td>.74</td>
</tr>
<tr>
<td>Pattern 2 (N = 23)</td>
<td>Exposure</td>
<td>.31</td>
<td>.15</td>
</tr>
<tr>
<td></td>
<td>Novel</td>
<td>.39</td>
<td>.07</td>
</tr>
</tbody>
</table>

B.5. Experiment 2 Analyses by Awareness

In sum, for the Pattern 1 condition of Experiment 2, the familiarity ratings and correlations indicated the presence of some explicit knowledge. Consequently, the full Pattern 1 condition data set of Experiment 2 was re-analysed with “Awareness” as a between-subjects factor with two levels (Aware, Unaware), and RT as the dependent variable. Participants in the “Aware” condition met two criteria. Firstly, they had an exposure sequence z-familiarity scores greater than zero. That is, their mean rating to the exposure sequences was greater than their overall mean familiarity rating. Secondly, their certainty ratings to the exposure sequences were equal to, or greater than four (4 = Somewhat certain, 5 = Very certain, 6 = Completely certain). Thirteen of the 22 participants in the Pattern 1 condition met both these criteria and were considered to be “aware” of the temporal structure of their exposure sequence.
As with the full data set, ANOVAs were conducted on post-IGI and controlled within-group positions across exposure blocks (Blocks 1 to 5), and assessing the change at the test block (Mean over Block 5 and 7 vs. Block 6). These ANOVAs revealed no effect of awareness. The same pattern of results reported with the full sample was evident for both the Aware ($N = 13$) and Unaware group ($N = 9$).

**B.5.1. Post-IGI positions**

**B.5.1.1. Exposure**

There was no main effect of group (Aware, Unaware), $F(1, 20) = 2.24$, $p = .15$, $\text{partial } \eta^2 = .10$, and no Group by Block interaction, $F(4, 80) = .51$, $p = .71$, $\text{partial } \eta^2 = .03$.

**B.5.1.2. Test Block**

There was no main effect of group (Aware, Unaware), $F(1, 20) = 1.16$, $p = .29$, $\text{partial } \eta^2 = .06$, and no Group by Block interaction, $F(1, 20) = .32$, $p = .58$, $\text{partial } \eta^2 = .02$.

**B.5.2. Controlled within-group positions**

**B.5.2.1. Exposure**

There was no main effect of group (Aware, Unaware), $F(1, 20) = .15$, $p = .70$, $\text{partial } \eta^2 = .01$, and no Group by Block interaction, $F(4, 80) = .44$, $p = .78$, $\text{partial } \eta^2 = .02$. 
B.5.2.2. Test Block

There was no main effect of group (Aware, Unaware), $F(1, 20) = .21, p = .65$, $\textit{partial } \eta^2 = .01$, and no Group by Block interaction, $F(1, 20) = .00, p = .95, \textit{partial } \eta^2 = .00$.

In summary, these results examining RT over blocks (exposure and test) as a function of “awareness” reveal that explicit knowledge of the temporal structure was not necessary for learning to occur.
Appendix C: Additional Analyses of Experiment 3 Reported in Chapter 3

C.1. Analyses of Accuracy over Blocks

C.1.1. Mean Accuracy to Post-IGI Positions
C.1.1.1. Exposure Blocks
C.1.1.2. Test Block

C.1.2. Mean Accuracy to Controlled Within-group Position
C.1.2.1. Exposure Blocks
C.1.2.2. Test Block

C.2. Correlations between Post-IGI Accuracy and Reaction Time (RT)

C.3. Individual Post-IGI and Controlled Within-group Positions at Exposure and Test Block

C.4. Effects of the Violation of Global Temporal Expectations

C.5. Analyses by Awareness

C.5.1. Post-IGI Positions
C.5.1.1. Exposure Blocks
C.5.1.2. Test Block

C.5.2. Controlled Within-group Positions
C.5.2.1. Exposure Blocks
C.5.2.2. Test Block
C.1 Analyses of Accuracy over Blocks

C.1.1 Mean Accuracy to Post-IGI Positions

C.1.1.1 Exposure Blocks

Examining accuracy (% correct) to post-IGI positions over exposure blocks, an ANOVA with Block (Blocks 1 to 5) as a within-subjects factor, and Pattern condition (Pattern 1, Pattern 2) as a between-subjects factor was conducted.

There was no effect of Block, $F(4, 180) = 2.03$, $p = .09$, $\eta^2 = .04$, no effect of Pattern condition, $F(1, 45) = .10$, $p = .75$, $\eta^2 = .00$, and no Block by Pattern Condition interaction, $F(4, 180) = .04$, $p = 1.00$, $\eta^2 = .00$. Although there was no main effect of Block, accuracy tended to be lower at Block 1 compared to Block 5 in the Pattern 1 condition (Block 1: $M = 73.11\%$, $SD = 10.72$; Block 5: $M = 75.36\%$, $SD = 11.52$), and in the Pattern 2 condition (Block 1: $M = 73.38\%$, $SD = 13.34$; Block 5: $M = 76.16\%$, $SD = 11.87$).

C.1.1.2 Test Block

To assess accuracy at the test block, we conducted an ANOVA with Block as a within-subjects factor (Block 6 vs. mean of Blocks 5 and 7) and Pattern condition as a between-subjects factor (Pattern 1, Pattern 2). Accuracy decreased in the Pattern 1 condition (Test block: $M = 70.93\%$, $SD = 13.23$; mean adjacent exposure blocks: $M = 75.16\%$, $SD = 11.32$) but not in the Pattern 2 condition (Test block: $M = 75.85\%$, $SD = 10.06$; mean adjacent exposure blocks: $M = 75.88\%$, $SD = 11.19$). However, these effects were not significant. There was no effect of Block, $F(1, 45) = 2.92$, $p = .10$, $\eta^2 = .06$ or
Pattern condition, $F(1, 45) = .82, p = .37, \eta^2 = .02$. There was also no Block by Pattern condition interaction, $F(1, 45) = 2.81, p = .10, \eta^2 = .06$.

C.1.2. Mean Accuracy to Controlled Within-group Positions

C.1.2.1. Exposure Blocks

For analysing accuracy over exposure blocks, an ANOVA with Block (Blocks 1 to 5) as a within-subjects factor, and Pattern condition (Pattern 1, Pattern 2) as a between-subjects factor was conducted. There was a main effect of Block, $F(4, 180) = 5.22, p = .00, \eta^2 = .10$, no effect of Pattern condition, $F(1, 45) = .20, p = .66, \eta^2 = .00$, and no Block by Pattern Condition interaction, $F(4, 180) = .40, p = .80, \eta^2 = .01$. Accuracy at Block 5 was significantly higher than at Block 2, $p = .00$ (Block 1: $M = 62.37\%$, $SE = 2.87$; Block 5: $M = 71.05\%, SD = 2.40$), but not at Block 1, $p = .97$ (Block 1: $M = 71.13\%, SE = 2.42$).

C.1.2.2. Test Block

To assess accuracy at the test block, an ANOVA with Block as a within-subjects factor (Block 6 vs. mean of Blocks 5 and 7) and Pattern condition as a between-subjects factor (Pattern 1, Pattern 2) was conducted. There was no effect of Block, $F(1, 45) = 1.80, p = .19, \eta^2 = .04$, or Pattern condition, $F(1, 45) = .08, p = .77, \eta^2 = .00$, nor was there an interaction, $F(1, 45) = .02, p = .89, \eta^2 = .00$.

C.2. Correlations between Post-IGI Accuracy and RT

Correlations between accuracy and RT to post-IGI positions at each block were conducted in order to determine whether participants followed the instructions to respond
as fast and as accurately as possible or adopted a speed/accuracy trade-off. Apart from a non-significant positive correlation (but close to 0) at Block 4 in the Pattern 1 condition, all correlations in the Pattern 1 and Pattern 2 conditions were negative (see Table C1 for Pearson’s $r$ and significance values). These negative correlations reveal that the faster the RT, the higher the accuracy and indicate that a speed/accuracy trade-off was not adopted.

Table C1

Correlations (Pearson’s $r$) between post-IGI RT and accuracy in each condition (Pattern 1, Pattern 2). * indicates significance at $p < .05$ and ** indicates significance at $p < .01$

<table>
<thead>
<tr>
<th>Condition</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>
<th>Block 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pattern 1</td>
<td>-.61**</td>
<td>-.58**</td>
<td>-.33</td>
<td>.01</td>
<td>-.36</td>
<td>-.52*</td>
<td>-.42*</td>
</tr>
<tr>
<td>Pattern 2</td>
<td>-.47**</td>
<td>-.33</td>
<td>-.52**</td>
<td>-.62**</td>
<td>-.58**</td>
<td>-.43*</td>
<td>-.62**</td>
</tr>
</tbody>
</table>

C.3. Individual Post-IGI and Controlled Within-group Positions at Exposure and Test Block

Results of individual post-IGI and controlled within-group positions are plotted in Figure C1. Descending black bars indicate faster RT over exposure (i.e. Block 5 compared to Block 1), and ascending grey bars indicate slower RT at the test block (Block 6) compared to the adjacent exposure blocks (mean of Blocks 5 and 7). As the figure shows, there was learning over exposure blocks in both the Pattern 1 (Figure C1a)
and Pattern 2 (Figure C1b) conditions but primarily of the controlled within-groups positions. RT increases at the test block occurred mainly in the Pattern 1 condition.

**Figure C1.** a) For the Pattern 1 condition and b) Pattern 2 condition, the RT differences between Block 1 and Block 5 (black bars) and between Block 6 and the mean of adjacent exposure Blocks 5 and 7 (grey bars) are shown. Descending black bars indicate faster RT at Block 5 compared to Block 1. Ascending grey bars indicate slower RT at the test block (Block 6) compared to the adjacent exposure blocks (Blocks 5 and 7).

C.4. Effects of the Violation of Global Temporal Expectations

For post-IGI syllables, it is possible that violations at the test block to the global temporal location (i.e. within each cycle of the temporal structure) modulated RT and may partially explain the difference between the Pattern 1 and Pattern 2 conditions. At the test block in the Pattern 1 condition (see Figure C2, Pattern 2), positions 3, 7, and 8 are presented *earlier* than expected and position 12 is presented *later* than expected. Conversely, at the test block in the Pattern 2 condition (see Figure C2, Pattern 1), position 12 is presented *earlier* than expected and positions 3, 7, and 8 are presented *later* than
Previous research on temporal expectations (e.g. Capizzi, et al., 2012; Correa, et al., 2006; Correa, et al., 2004; Tillmann & Lebrun-Guillaud, 2006) has demonstrated that RT is slower to events presented earlier than expected compared to events presented later than expected. In the present experiment, expectations about the temporal location of events within the global structure were developed during the exposure blocks and were violated at the test block. In the Pattern 1 condition, more post-IGI syllables were
presented earlier, compared to later than expected at the test block thus potentially leading to slower overall RT. On the other hand, more post-IGI syllables were presented later than expected at the test block in the Pattern 2 condition, thus diminishing the expected RT increase.

To investigate the hypothesis that RT would increase to earlier-than-expected syllables and decrease to later-than-expected syllables, additional analyses of post-IGI positions presented earlier and later than expected were conducted. For each Pattern condition, the mean of positions 3, 7, and 8 (earlier than expected at the test block in the Pattern 1 condition, and later than expected at the test block in the Pattern 2 condition) was calculated at the test block (Block 6) and at the two adjacent exposure blocks (Blocks 5 and 7). These means were compared to RT at position 12 (later than expected at the test block in the Pattern 1 condition, and earlier than expected at the test block in the Pattern 2 condition). An ANOVA was conducted with Block (Block 6 vs. mean of Blocks 5 and 7) and Violation (Early, Late) as within-subjects factors, and Pattern condition (Pattern 1, Pattern 2) as a between-subjects factor.

The interaction between Block, Violation, and Pattern condition was not significant, $F(1, 45) = .31, p = .58, \eta^2 = .01$. Neither was the Block by Violation interaction significant, $F(1, 45) = 2.61, p = .11, \eta^2 = .06$. However, it was in the expected direction. For earlier than expected syllables, RT increased at Block 6 ($M = 546.07$ ms, $SE = 7.69$) compared to the mean of Blocks 5 and 7 ($M = 527.13$ ms, $SE = 8.20$). For later than expected syllables, there was no increase (Block 6: $M = 549.92$, $SE = 8.40$, mean Blocks 5 and 7: $M = 547.98$ ms, $SE = 8.61$).
In Experiment 2, reported in Chapter 2 of this thesis, these same analyses yielded a significant interaction between Violation (Early, Late), and Block (mean of Blocks 5 and 7, Block 6). For earlier than expected positions, there was a significant ($p = .01$) increase in RT at Block 6, ($M = 554.08\text{ms}, SD = 75.20$) compared to the mean of Blocks 5 and 7 ($M = 526.85\text{ms}, SD = 62.20$). As in the current experiment, there was no effect for later than expected position, (Block 6: $M = 532.50$, $SD = 74.64$, mean Blocks 5 and 7: $M = 536.70\text{ms}, SD = 63.41$).

While both the implicit (Experiment 2 in Chapter 2) and explicit (current experiment) tasks yielded similar results for earlier and later than expected syllables, the effect was significant only with an implicit instruction.

C.5. Analyses by Awareness

All analyses were conducted again with “Awareness” as a between-subjects factor with two levels (Aware, Unaware), and RT as the dependent variable. Participants in the “Aware” condition met two criteria. Firstly, they had an exposure sequence z-familiarity scores greater than zero. That is, their mean rating to the exposure sequences was greater than their overall mean familiarity rating. Secondly, their certainty ratings to the exposure sequences were equal to, or greater than four ($4 = \text{Somewhat certain}, 5 = \text{Very certain}, 6 = \text{Completely certain}$). Eight participants in each condition met both these criteria and were considered to be “aware” of the temporal structure of their exposure sequence.
C.5.1. Post-IGI Positions

C.5.1.1. Exposure Blocks

There was no main effect of Group (Aware, Unaware), $F(1, 43) = 1.58, p = .22$, partial $\eta^2 = .04$, no Group by Condition interaction, $F(1, 43) = .21, p = .65$, partial $\eta^2 = .01$, no Group by Block interaction, $F(4, 172) = .58, p = .68$, partial $\eta^2 = .01$, and no interaction between Group, Condition and Block, $F(4, 172) = 1.19, p = .32$, partial $\eta^2 = .03$.

C.5.1.2. Test Block

There was no main effect of Group (Aware, Unaware), $F(1, 43) = .54, p = .47$, partial $\eta^2 = .01$, no Group by Condition interaction, $F(1, 43) = 1.03, p = .32$, partial $\eta^2 = .02$, no Group by Block interaction, $F(1, 43) = 1.67, p = .20$, partial $\eta^2 = .04$, and no interaction between Group, Condition and Block, $F(1, 43) = .07, p = .80$, partial $\eta^2 = .00$.

C.5.2. Controlled Within-group Positions

C.5.2.1. Exposure Blocks

There was no main effect of Group (Aware, Unaware), $F(1, 43) = .38, p = .54$, partial $\eta^2 = .01$, no Group by Condition interaction, $F(1, 43) = .51, p = .48$, partial $\eta^2 = .01$, no Group by Block interaction, $F(4, 172) = .37, p = .83$, partial $\eta^2 = .01$, and no interaction between Group, Condition and Block, $F(4, 172) = .76, p = .55$, partial $\eta^2 = .02$.

C.5.2.2. Test Block

There was no main effect of Group (Aware, Unaware), $F(1, 43) = .12, p = .73$, partial $\eta^2 = .00$, no Group by Condition interaction, $F(1, 43) = 1.14, p = .29$, partial $\eta^2 =$
.03, no Group by Block interaction, $F(1, 43) = .00, p = 1.00$, partial $\eta^2 = .00$, and no interaction between Group, Condition and Block, $F(1, 43) = .41, p = .52$, partial $\eta^2 = .01$. 
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D.1. Analyses of Accuracy to All Syllables over Blocks

D.1.1. Experiment 4

To assess accuracy over exposure blocks, an ANOVA with Block (Blocks 1 – 8) as a within-subject factor and Meter condition as a between-subjects factor was conducted. While there was an increase in accuracy from Block 1 ($M = 59.71\%, \ SD = 1.50$) to Block 8 ($M = 64.74\%, \ SE = 1.44$), there were no significant main effects and no interaction. To assess any change in accuracy at the test blocks, an ANOVA with Block
(Mean Blocks 8 and 11, Mean Blocks 9 and 10) as a within-subject factor and Meter condition as a between-subjects factor was conducted. There were no main effects and no interaction. The mean accuracy of the two test blocks ($M = 63.19, SE = 1.30$) was not significantly different from the mean accuracy at the two adjacent exposure blocks ($M = 65.22, SE = 1.33$).

### D.1.2. Experiment 5

To assess accuracy over exposure blocks, an ANOVA with Block (Blocks 1 – 8) as a within-subject factor was conducted. There was a main effect of Block, $F(7, 98) = 5.04, p = .00$. Accuracy was higher at Block 8 ($M = 67.09, SE = 2.38$) compared to Block 1 ($M = 60.30, SE = 1.86$), $p = .01$. To assess any change in accuracy at the test blocks, an ANOVA with Block (Mean Blocks 8 and 11, Mean Blocks 9 and 10) as a within-subject factor was conducted. Accuracy at the test blocks ($M = 67.79, SD = 7.83$) was not different from accuracy at the two adjacent blocks ($M = 67.49, SD = 8.06$).

### D.2. Correlations between Post-IGI Accuracy and Reaction Time (RT)

#### D.2.1. Experiment 4

To ensure that there were no speed/accuracy tradeoffs, RT and accuracy at each block were correlated separately for the Even and Uneven meter conditions. In the Even meter condition, the only significant correlation was at Block 7 ($r(15) = -.55, p = .02$). In the Uneven meter condition, significant correlations were at Block 5 ($r(15) = -.61, p =$
.01) and Block 6 \((r(15) = -.49, p = .05)\). These correlations were negative with faster RT associated with higher accuracy. Hence, no speed/accuracy tradeoffs were evident.

### D.2.2. Experiment 5

To ensure that there were no speed/accuracy tradeoffs, RT and accuracy at each block were correlated. All correlations were negative, however these were only significant at Block 1 \((r(13) = -.52, p = .05)\), Block 2 \((r(13) = -.80, p = .00)\), Block 4 \((r(13) = -.53, p = .05)\), and Block 10 \((r(13) = -.59, p = .02)\). These correlations were negative with faster RT associated with higher accuracy. Hence, no speed/accuracy tradeoffs were evident.

### D.3. Analyses of All Participants Performing Above Chance: Experiment 4

#### D.3.1. Participants

Eighty-one undergraduate students from the University of Western Sydney took part in Experiment 4 in exchange for course credit. Participants were randomly assigned to either the Even Meter \((N = 44)\) or Uneven Meter \((N = 37)\) conditions. Z-tests were conducted to identify participants performing significantly above chance \((ps < .05)\). The z-test returns the probability that the mean of all of a participant’s blocks is greater than 50%, taking into account the variability across blocks. Eighteen participants in the Even Meter condition and 12 participants in the Uneven Meter condition performed either below chance or not significantly above chance. Sub-optimal syllable identification was likely driven by the difficulty of the task, as the speed of the presentation of syllables was
rapid (i.e. shortest IOI of 400 ms). Data from these participants were excluded from the
analyses.

The remaining 26 participants in the Even Meter condition had a mean age of 22.12 years ($SD = 7.46$ years, range = 17 – 52 years, 24 females). The 25 participants in the Uneven Meter condition had a mean age of 21.68 years ($SD = 6.95$ years, range = 17 – 40 years, 22 females).

The two participant groups were equivalent in terms of years of musical training. Participants in the Even Meter condition had a mean of 2.02 years of training ($SD = 2.87$ years, median = 0) and participants in the Uneven Meter condition had a mean of 1.94 years of training ($SD = 2.81$ years, median = .50). These levels of musical training were not statistically different between the two conditions ($p = .92$).

All participants had self-reported normal hearing and had English as a first language. No participant reported exposure during childhood to music of the Balkan region, or other music characterised by uneven meters. Likewise, no participants reported that they were currently listening to this music.

D.3.2. Results

D.3.2.1. SRTT

Correct responses were included in the analysis if they occurred 100 – 800 ms after the onset of the syllable. RTs less than 100 ms were assigned to the previous syllable if it was missed and, if multiple responses were made within the 100 – 800 ms window, only the first response was kept. The upper limit (800 ms) allowed us to retain
longer RTs made to the syllables immediately preceding a medium and long IOI (i.e. IGIs).

It was decided that across the two conditions, an equal number of potential data points at each serial position should be included in the analyses. Hence, RT to the final syllable in each cycle of the uneven meter rhythm was excluded, as was RT to the 10 syllables in the last cycle in each block even meter condition. This meant that, in both conditions, 100 potential data points were analysed in each block. Mean accuracy to syllables was significantly above chance (50%) for the Even meter condition (60.90%; $SD = 6.19\%$), $t(25) = 10.90, p = .00$, and Uneven meter condition (62.00%; $SD = 5.88\%$), $t(24) = 12.00, p = .00$.

**D.3.2.1.1 Accuracy over blocks.** To assess accuracy over exposure blocks, an ANOVA with Block (Blocks 1 – 8) as a within-subject factor and Meter condition as a between-subjects factor was conducted. While there was an increase in accuracy from Block 1 ($M = 59.82\%, SE = 1.40$) to Block 8 ($M = 63.56\%, SE = 1.22$), there were no significant main effects and no interaction. To assess any change in accuracy at the test blocks, an ANOVA with Block (Mean Blocks 8 and 11, Mean Blocks 9 and 10) as a within-subject factor and Meter condition as a between-subjects factor was conducted. There were no main effects and no interaction. The mean accuracy of the two test blocks ($M = 64.07\%, SE = 1.14$) was not significantly different from the mean accuracy at the two adjacent exposure blocks ($M = 62.40\%, SE = 1.15$).
D.3.2.1.2. Correlations between accuracy and reaction time (RT). To ensure that there were no speed/accuracy tradeoffs, RT and accuracy at each block were correlated separately for the Even and Uneven meter conditions. In the Even meter condition, significant correlations were at Block 7 \((r(25) = -.44, p = .03)\), Block 9 \((r(25) = -.49, p = .01)\), and Block 10 \((r(25) = -.42, p = .03)\). In the Uneven meter condition, significant correlations were at Block 5 \((r(25) = -.44, p = .03)\) and Block 8 \((r(25) = -.41, p = .04)\). These correlations were negative with faster RT associated with higher accuracy. Hence, no speed/accuracy tradeoffs were evident.

D.3.2.1.3. Mean RT to all correct responses over exposure blocks. RT to syllables was averaged for each block and an 8 x 2 ANOVA with Block (Blocks 1 – 8) as a within-subject factor and Meter (Even, Uneven) as a between-subjects factor was conducted (Figure D1). The main effect of Block was not significant, \(F(7, 343) = 1.93, p = .07, \text{partial } \eta^2 = .04\). However, the pattern of results was in the expected direction, with RT decreasing over blocks. There was no main effect of Meter, \(F(1, 49) = 2.44, p = .63, \text{partial } \eta^2 = .01\), and no Block by Meter interaction, \(F(7, 343) = .62, p = .73, \text{partial } \eta^2 = .01\).

D.3.2.1.4. Mean RT to all correct responses over test blocks. To investigate the effect of changing the rhythm and consequently meter at the test blocks, a 2 x 2 ANOVA with Block (mean exposure Blocks 8 and 11, mean test Blocks 9 and 10) as a within-subject factor and Meter (Even, Uneven) as a between-subjects factor was conducted. There was no effect of Block, \(F(1, 49) = .29, p = .59, \text{partial } \eta^2 = .01\), and no effect of
Meter, $F(1, 49) = .55, p = .46$, partial $\eta^2 = .01$. While the Block by Meter interaction was not significant, $F(1, 49) = 3.53, p = .07$, partial $\eta^2 = .07$, RT increased at the test blocks in the Even Meter condition, but decreased in the Uneven Meter condition.

Figure D1. Experiment 4 (All participants above chance): Correct RT to syllables presented as a function of Block and Pattern condition. Error bars show standard error of the mean.

D.3.2.1.5. Mean RT to post-IGI syllables over exposure blocks. RT to syllables following IGIIs (serial positions 1, 2, 5, 8 and 10) was averaged for each block and an 8 x 2 ANOVA with Block (Blocks 1 – 8) as a within-subject factor and Meter (Even, Uneven) as a between-subjects factor was conducted. The main effect of Block was significant, $F(7, 343) = 3.31, p = .00$, partial $\eta^2 = .06$. There was no main effect of Meter,
\[ F(1, 49) = .03, p = .86, \text{partial } \eta^2 = .00, \] and no Block by Meter interaction, \[ F(7, 343) = 1.10, p = .37, \text{partial } \eta^2 = .02. \] RT at Block 8 \((M = 382.81 \text{ ms, } SE = 7.48)\) was significantly faster than at Block 1 \((M = 407.26 \text{ ms, } SE = 7.90), p = .00. \) The results are presented in Figure D2.

**D.3.2.1.6. Mean RT to post-IGI syllables over test blocks.** To investigate the effect on post-IGI syllables of changing the rhythm and consequently meter at the test blocks, mean RT to post-IGI syllables at exposure blocks 8 and 11, and test blocks 9 and 10 was calculated. A 2 x 2 ANOVA with Block (mean exposure Blocks 8 and 11, mean test Blocks 9 and 10) as a within-subjects factor and Meter (Even, Uneven) as a between-subjects factor was conducted. There was no effect of Block, \[ F(1, 49) = 1.04, p = .31, \text{partial } \eta^2 = .02, \] or Meter condition, \[ F(1, 49) = .61, p = .44, \text{partial } \eta^2 = .01. \] However, there was a significant Block by Meter condition interaction, \[ F(1, 49) = 10.30, p = .00, \text{partial } \eta^2 = .17. \] RT at the test blocks was not significantly different from RT at the adjacent exposure blocks in the Even Meter Condition, \[ F(1, 25) = 2.29, p = .13, \text{partial } \eta^2 = .08. \] However, RT significantly decreased at the test blocks in the Uneven Meter condition, \[ F(1, 24) = 9.44, p = .01, \text{partial } \eta^2 = .28. \]

**D.3.2.1.7. Mean RT to within-group syllables over exposure blocks.** RT to within-group syllables (serial positions 3, 4, 6, 7, and 9) was averaged for each exposure block and an 8 x 2 ANOVA with Block (Blocks 1 – 8) as a within-subject factor and Meter (Even, Uneven) as a between-subjects factor was conducted. There was no main effect of Block, \[ F(7, 343) = 1.189, p = .31, \text{partial } \eta^2 = .02, \] no main effect of Meter, \[ F(1, 49) = \]
.52, \( p = .48 \), \( \text{partial } \eta^2 = .01 \), and no Block by Meter interaction, \( F(7, 343) = .62, p = .74, \) \( \text{partial } \eta^2 = .01 \). The results are presented in Figure D2.

D.3.2.1.8. Mean RT to within-group syllables over test blocks. To investigate the effect on within-group syllables of changing the rhythm and consequently the meter at the test blocks, mean RT to within-group syllables at exposure blocks 8 and 11, and test blocks 9 and 10 was calculated. A 2 x 2 ANOVA with Block (mean exposure Blocks 8 and 11, mean test Blocks 9 and 10) as a within-subject factor and Meter (Even, Uneven) as a between-subjects factor was conducted. There was no effect of Block, \( F(1, 49) = .08, p = .78, \) \( \text{partial } \eta^2 = .00 \), no effect of Meter condition, \( F(1, 49) = .23, p = .63, \) \( \text{partial } \eta^2 = .01 \), and no Block by Meter condition interaction, \( F(1, 49) = .09, p = .77, \) \( \text{partial } \eta^2 = .00 \).

Figure D2. Experiment 4 (All participants above chance): Correct RT to a) post-IGI syllables and, b) within-group syllable positions, presented as a function of Block and Meter condition. Error bars show standard error of the mean.
D.3.2.2. Post-tests

An open-ended question asked participants to describe any regularity in the timing of the presentation of the syllables. Of the fifty-one participants, 21 reported there were pauses between some syllables and 13 indicated that the speed of the presentation of the syllables changed within a block. However, no participants were able to report the rhythm correctly. While participants were able to indicate the presence of some variation in timing within the sequences, the post-test ratings were analysed to determine the presence of awareness of the precise rhythms presented in the SRTT. Familiarity ratings to the Even Meter sequence, Uneven Meter sequence, Even Meter Novel sequence and Uneven Meter Novel sequences were compared. Ratings (1 = very unfamiliar through to 6 = very familiar) were collapsed across the four presentations of each sequence to obtain a mean rating (Table D1). These were analysed with a 4 x 2 ANOVA with Post-test Sequence as a within-subject factor (Old Exposure, Old Test, Same Meter Novel, Different Meter Novel) and Meter condition (Even, Uneven) as a between-subjects factor. There was a main effect of Post-test Sequence, $F(3, 147) = 6.82, p = .00$, partial $\eta^2 = .12$, but no effect of Meter, $F(1, 49) = .25, p = .62$, partial $\eta^2 = .01$. However, there was a Post-test Sequence by Meter Condition interaction, $F(3, 147) = 3.01, p = .03$, partial $\eta^2 = .06$. In the Even Meter condition, there was an effect of Post-test Sequence, $F(3, 75) = 7.48, p = .00$, partial $\eta^2 = .23$. Participants were significantly more familiar with their Exposure sequence than the Novel Old Meter sequence (i.e. even), $p = .04$, and the Novel New Meter sequence (i.e. uneven), $p = .00$. There was no difference in ratings between the Exposure and Test sequence, $p = .65$. In the Uneven Meter condition, the
difference in familiarity ratings across the four post-test sequences was not significant, 
\[ F(3, 72) = 2.52, p = .07, \text{ partial } \eta^2 = .10. \]

**Table D1**

*Experiment 4 (All participants above chance): Post-test Familiarity (1 = very unfamiliar, through to 6 = very familiar) and Certainty (1 = complete guess, through to 6 = completely certain) Mean Ratings and Standard Deviations presented as a function of Sequence Type and Exposure Condition*

<table>
<thead>
<tr>
<th></th>
<th>Familiarity</th>
<th>Certainty</th>
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<th></th>
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<tbody>
<tr>
<td></td>
<td>Old</td>
<td>Novel</td>
<td>Old</td>
<td>Novel</td>
</tr>
<tr>
<td>Exposure</td>
<td>Test</td>
<td>Same meter</td>
<td>New meter</td>
<td>Same meter</td>
</tr>
<tr>
<td>Condition</td>
<td>M   SD</td>
<td>M   SD</td>
<td>M   SD</td>
<td>M   SD</td>
</tr>
<tr>
<td>Even</td>
<td>3.87 0.70</td>
<td>3.80 0.77</td>
<td>3.52 0.66</td>
<td>3.09 0.92</td>
</tr>
<tr>
<td>Uneven</td>
<td>3.84 0.84</td>
<td>3.75 0.83</td>
<td>3.35 0.87</td>
<td>3.64 0.75</td>
</tr>
</tbody>
</table>

To further examine participants’ familiarity with the SRTT sequences, correlations between post-test familiarity and certainty ratings were assessed. If participants had explicit knowledge of the rhythms to which they were exposed to in the SRTT, then there would be a positive correlation between familiarity and certainty ratings to their exposure sequences (Scott & Dienes, 2008). In other words, they would rate the exposure sequences as familiar *and* be certain of their decision.

Each participant’s mean familiarity rating (i.e. mean rating of all post-test sequences) was subtracted from their mean rating to exposure sequences yielding a *difference score*. These were converted to *z*-scores (*z*-familiarity). Correlations between *z*-familiarity scores and the mean certainty ratings to the exposure sequences were
calculated. Given that there was a significant interaction between Post-test Sequence and Meter Condition in the familiarity rating analyses, correlations were conducted separately for each meter condition. There was no significant correlation between z-familiarity and confidence in either the Even Meter condition, $r(26) = .07, p = .73$, or the Uneven Meter condition, $r(25) = .27, p = .19$. This indicates that participants were not confident in their familiarity ratings to exposure rhythms.

Despite this, particular participants showing awareness of the rhythms were identified. These participants met two criteria. Firstly, they had an exposure sequence z-familiarity score greater than zero. That is, their mean rating to the exposure sequences was greater than their overall mean familiarity rating to all post-test sequences. Secondly, their mean certainty rating to the exposure sequences was equal to, or greater than four (4 = somewhat certain, 5 = very certain, 6 = completely certain). Twenty-one of the 51 participants (Even Meter condition = 8, Uneven Meter condition = 13) met both these criteria and were considered to be “aware” of their exposure rhythm. To ensure that aware participants did not drive the test block results in the SRTT, ANOVAs were conducted for post-IGI and within-group positions. Mean RT at exposure blocks 8 and 11 was compared with mean RT of test blocks 9 and 10. Meter (Even, Uneven) and Awareness (Aware, Unaware) were between-subjects factors.

D.3.2.2.1. Post-IGI syllables by awareness: test block analyses. The effects of Block, and Meter were as per the main SRTT analyses. There was no main effect of Awareness, $F(1, 47) = .09, p = .77$, partial $\eta^2 = .00$, no Meter by Awareness interaction, $F(1, 47) = .10, p = .75$, partial $\eta^2 = .00$, and no Block by Awareness interaction, $F(1, 47)$
=.61, p = .44, partial $\eta^2 = .01$. The 3-way interaction between Block, Awareness, and Meter did not reach significance, $F(1, 47) = 3.21, p = .08$, partial $\eta^2 = .06$. The difference in RT between the Test Blocks and the two adjacent Exposure Blocks tended to be greater for the aware, compared to unaware participants. In the Even Meter condition, RT increased at the test blocks more so for aware participants (Exposure Blocks 8 and 11: $M = 384.03$ ms, $SE = 16.37$; Test Blocks 9 and 10: $M = 398.05$ ms, $SE = 15.78$, $\Delta = 14.02$ ms), than the unaware participants (Exposure Blocks 8 and 11: $M = 380.27$ ms, $SE = 10.92$; Test Blocks 9 and 10: $M = 386.27$ ms, $SE = 10.52$, $\Delta = 6$ ms). Likewise, in the Uneven Meter condition the effect at the test block (i.e. RT decrease) was stronger for the aware participants (Exposure Blocks 8 and 11: $M = 389.31$ ms, $SE = 12.84$; Test Blocks 9 and 10: $M = 363.22$ ms, $SE = 12.78$, $\Delta = -26.09$ ms), compared to the unaware participants (Exposure Blocks 8 and 11: $M = 379.39$ ms, $SE = 13.37$; Test Blocks 9 and 10: $M = 373.60$ ms, $SE = 12.88$, $\Delta = -5.79$ ms).

D.3.2.2.2. Within-group syllables by awareness: test block analyses. As with the main SRTT analysis of within-group syllables, there was no main effect of Block or Meter. In addition, there was no main effect of Awareness, $F(1, 47) = .18, p = .68$, partial $\eta^2 = .00$, no Meter by Awareness interaction, $F(1, 47) = .02, p = .89$, partial $\eta^2 = .00$, and no Block by Awareness interaction, $F(1, 47) = 1.51, p = .23$, partial $\eta^2 = .03$. However, there was a significant interaction between Block, Meter, and Awareness, $F(1, 47) = 6.54, p = .01$, partial $\eta^2 = .12$. In the Even Meter condition, RT significantly increased at the test blocks for the aware group, $F(1, 7) = 13.50, p = .01$, partial $\eta^2 = .66$ (Exposure Blocks 8 and 11: $M = 323.53$ ms, $SE = 10.72$; Test Blocks 9 and 10: $M = 351.74$ ms, $SE$
= 9.71), but not for the unaware group, $F(1, 17) = 1.37, p = .26$, partial $\eta^2 = .07$

(Exposure Blocks 8 and 11: $M = 344.13$ ms, $SE = 8.37$; Test Blocks 9 and 10: $M = 335.69$ ms, $SE = 7.20$). In the Uneven Meter condition, there was no significant difference between the test blocks and the adjacent exposure blocks for either aware, $F(1, 12) = .34, p = .57$, partial $\eta^2 = .03$ (Exposure Blocks 8 and 11: $M = 336.47$ ms, $SE = 10.43$; Test Blocks 9 and 10: $M = 330.21$ ms, $SE = 5.00$), or unaware groups, $F(1, 11) = .40, p = .54$, partial $\eta^2 = .04$ (Exposure Blocks 8 and 11: $M = 334.64$ ms, $SE = 8.86$; Test Blocks 9 and 10: $M = 341.23$ ms, $SE = 11.86$).

D.4. Analyses of All Participants Performing Above Chance: Experiment 5

D.4.1. Participants

Forty-four participants from the University of Western Sydney took part in the experiment in exchange for course credit. As per Experiment 4, $z$-tests were conducted to determine that each participant’s performance was significantly above chance ($ps < .05$). Seventeen participants performed below chance, or not significantly above chance. Therefore, data from these participants were excluded from the analyses. The remaining 27 participants had a mean age of 21.15 years ($SD = 6.56$ years, range = 17 – 47 years) and had a mean of 2.74 years of musical training ($SD = 4.32$ years, median = 0).

All participants had self-reported normal hearing and, apart from one early bilingual speaker (English and Persian), all other participants had English as a first language. No participant reported exposure during childhood to music of the Balkan region, or other music characterised by uneven meters. Likewise, no participants were currently listening to this music.
D.4.2. Results

D.4.2.1. SRTT

The temporal window for including correct responses was as per Experiment 4. Mean accuracy to syllables was significantly above chance (50%); 64.17%, $SD = 6.31\%$, $t(26) = 11.67$, $p = .00$.

D.4.2.1.1. Accuracy over blocks. To assess accuracy over exposure blocks, an ANOVA with Block (Blocks 1 – 8) as a within-subject factor was conducted. There was a main effect of Block, $F(7, 182) = 6.66, p = .00$. Accuracy was higher at Block 8 ($M = 65.52$, $SE = 1.54$) compared to Block 1 ($M = 60.51$, $SE = 1.46$), $p = .00$. To assess any change in accuracy at the test blocks, an ANOVA with Block (Mean Blocks 8 and 11, Mean Blocks 9 and 10) as a within-subject factor was conducted. Accuracy at the test blocks ($M = 65.34$, $SE = 1.45$) was not different from accuracy at the two adjacent blocks ($M = 65.91$, $SD = 1.39$).

D.4.2.1.2. Correlations between accuracy and reaction time (RT).

To ensure that there were no speed/accuracy tradeoffs, RT and accuracy at each block were correlated. There were significant correlations were at Block 1 ($r(27) = -.54$, $p = .00$), Block 2 ($r(27) = -.64$, $p = .00$), Block 3 ($r(27) = -.58$, $p = .00$), Block 4 ($r(27) = -.49$, $p = .01$), Block 5 ($r(27) = -.47$, $p = .01$), Block 7 ($r(27) = -.51$, $p = .01$), Block 9 ($r(27) = -.48$, $p = .01$), Block 10 ($r(27) = -.50$, $p = .01$), and Block 11 ($r(27) = -.51$, $p = .01$).
.01). These correlations were negative with faster RT associated with higher accuracy. Hence, no speed/accuracy tradeoffs were evident.

**D.4.2.1.3. Mean RT to all correct responses over exposure blocks.** RT to syllables was averaged for each block and an ANOVA with Block (Blocks 1 – 8) as a within-subject factor was conducted (Figure D3). The effect of block was significant, $F(7, 182) = 4.73, p = .00$, $\eta^2 = .15$. RT decreased over blocks but the difference between Block 1 and Block 8 fell short of significance, $p = .06$.

**D.4.2.1.4. Mean RT to all correct responses over test blocks.** To investigate the effect of changing the uneven meter rhythm at the test blocks, a 2 x 2 ANOVA with Block (mean exposure Blocks 8 and 11, mean test Blocks 9 and 10) as a within-subject factor was conducted. The effect of Block was not significant, $F(1, 26) = 1.52, p = .23$, $\eta^2 = .06$. 
D.4.2.1.5. Mean RT to post-IGI syllables over exposure blocks. RT to syllables following IGIs (serial positions 1, 2, 3, 6, 8, and 11) was averaged for each block and an ANOVA with Block (Blocks 1 – 8) as a within-subject factor was conducted (Figure D4). The effect of Block was significant, $F(7, 182) = 6.77, p = .00$, partial $\eta^2 = .21$. RT at Block 8 ($M = 394.87$ ms, $SE = 8.13$) was significantly faster than at Block 1 ($M = 419.98$ ms, $SE = 8.44$), $p = .00$.

D.4.2.1.6. Mean RT to post-IGI syllables over test blocks. To investigate the effect on post-IGI syllables of changing the rhythm at the test blocks, mean RT to post-IGI syllables at exposure blocks 8 and 11, and test blocks 9 and 10 was calculated. An ANOVA with Block (mean exposure Blocks 8 and 11, mean test Blocks 9 and 10) as a
within-subject factor was conducted. There was no effect of Block, $F(1, 26) = 1.59, p = .22$, partial $\eta^2 = .06$.

**D.4.2.1.7. Mean RT to within-group syllables over exposure blocks.** RT to within-group syllables (serial positions 4, 5, 7, 9, and 10) was averaged for each block and an ANOVA with Block (Blocks 1 – 8) as a within-subject factor was conducted (Figure D4). The effect of Block was not significant, $F(7, 182) = .91, p = .50$, partial $\eta^2 = .03$.

**D.4.2.1.8. Mean RT to within-group syllables over test blocks.** To investigate the effect on within-group syllables of changing the rhythm at the test blocks, mean RT to within-group syllables at exposure blocks 8 and 11, and test blocks 9 and 10 was calculated. An ANOVA with Block (mean exposure Blocks 8 and 11, mean test Blocks 9 and 10) as a within-subject factor was conducted. There was no effect of Block, $F(1, 26) = .52, p = .48$, partial $\eta^2 = .02$.

*Figure D4.* Experiment 5 (All participants above chance): Correct RT to a) post-IGI syllables and, b) within-group syllable positions. Error bars show standard error of the mean.
D.4.2.2. Post-tests

An open-ended question asked participants to describe any regularity in the timing of the presentation of the syllables. Of the twenty-seven participants, 15 reported that there were pauses between some syllables. While, none of the participants were able to report the rhythm correctly, one participant provided a partially accurate description of the rhythm (“two long sounds, 3 quick, 2 longer and 3 quick”). Familiarity ratings to the Exposure sequences, Test sequences, and Novel sequences were compared. Ratings (1 = very unfamiliar through to 6 = very familiar) were collapsed across the four presentations of each sequence to obtain a mean rating (Table D2). These were analysed with an ANOVA with Post-test Sequence as a within-subject factor (Exposure, Test, Novel).

There was no effect of Post-test Sequence, $F(2, 52) = 1.19, p = .31$, partial $\eta^2 = .04$.

Participants were not more familiar with their Exposure sequence than the test or novel sequences.

Table D2

Experiment 5 (All participants above chance): Post-test Familiarity (1 = very unfamiliar, through to 6 = very familiar) and Certainty (1 = complete guess, through to 6 = completely certain) Mean Ratings and Standard Deviations presented as a function of Sequence Type

<table>
<thead>
<tr>
<th></th>
<th>Familiarity</th>
<th>Certainty</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exposure</td>
<td>Test</td>
</tr>
<tr>
<td>M</td>
<td>3.95</td>
<td>3.78</td>
</tr>
<tr>
<td>SD</td>
<td>1.00</td>
<td>0.65</td>
</tr>
</tbody>
</table>
As in Experiment 4, correlations between z-familiarity scores and the mean certainty ratings to the exposure sequences were calculated. There was no significant correlation between z-familiarity and confidence in either the Even Meter condition, \( r(26) = .07, p = .73 \), or the Uneven Meter condition, \( r(27) = .32, p = .11 \). This indicates that participants were not confident in their familiarity ratings to exposure rhythms. Nonetheless, aware participants were identified using the same criteria as in Experiment 4 (i.e. mean z-familiarity score greater than zero and mean certainty rating to the exposure sequences equal to, or greater than four; 4 = somewhat certain). Using these criteria, 9 of the 27 participants were identified as having awareness of the exposure rhythm. As there were no significant results at the test blocks with the full sample (i.e. aware and unaware), and given that the Aware and Unaware groups were highly unbalanced in size, data were re-analysed with the Aware group only. The aim was to determine if awareness of the exposure rhythm elicited the expected effect at the test blocks. Thus, ANOVAs were conducted for post-IGI and within-group positions. Mean RT at exposure blocks 8 and 11 was compared with mean RT of test blocks 9 and 10. Awareness (Aware, Unaware) was a between-subjects factor.

D.4.2.2.1. Post-IGI syllables and within-group syllables: aware participants only.

For Post-IGI syllables, there was no effect of Block, \( F(1, 8) = 2.59, p = .15 \), partial \( \eta^2 = .25 \). However, the results were in the expected direction with RT increasing from 402.81 ms (\( SE = 10.55 \)) at the exposure blocks (mean Blocks 8 and 11) to 420.60 ms (\( SE = 13.12 \)) at the test blocks (mean Blocks 9 and 10). Likewise, for within-group syllables, there was no effect of Block, \( F(1, 8) = .41, p = .54 \), partial \( \eta^2 = .05 \). While there was a
small RT increase at the test blocks (Blocks 9 and 10: $M = 373.43$ ms, $SE = 5.17$),
compared to the adjacent exposure blocks (Blocks 8 and 11: $M = 364.90$ ms, $SE = 14.38$),
overall there was no evidence of learning at the test blocks for participants who
demonstrated awareness of the exposure rhythm.
Appendix E: Additional Analyses of Experiment 6 Reported in Chapter 5

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E.1. Analyses of Accuracy to All Syllables over Blocks

E.1.1. Exposure blocks

To assess accuracy over exposure blocks, an ANOVA with Block (Blocks 1 – 8) as a within-subjects factor and Meter as a between-subjects factor was conducted. There was a significant effect of Block, $F(7, 182) = 2.34$, $p = .04$, partial $\eta^2 = .08$, but no effect of Meter and no interaction. Accuracy was significantly greater at Block 8 ($M = 62.56$, $SE = 1.42$) compared to Block 1 ($M = 59.07$, $SE = 1.57$), $p = .05$.

E.1.2. Test blocks

To assess any change in accuracy at the test blocks, an ANOVA with Block (Mean Blocks 8 and 11, Mean Blocks 9 and 10) as a within-subject factor and Meter as a between-subjects factor was conducted. There were no main effects and no interaction. The mean accuracy of the two test blocks ($M = 61.84\%$, $SE = 1.26$) was not significantly different from the mean accuracy at the two adjacent exposure blocks ($M = 61.13\%$, $SE = 1.52$). Accuracy at the first test block compared to the previous exposure block was analysed with an ANOVA with Block (Block 8, Block 9) as a within-subject factor and Meter as a between-subjects factor. There were no main effects and no interaction. Accuracy at Block 8 ($M = 62.56\%$, $SE = 1.43$) was not different Block 9 ($M = 63.27\%$, $SE = 1.80$). To account for any differences between the two test blocks, an ANOVA with Block (Block 9, Block 10) as a within-subject factor and Meter as a between-subjects factor was conducted. There was a main effect of Block, $F(1, 26) = 7.66$, $p = .01$, partial $\eta^2 = .23$, but no effect of Meter and no interaction. Accuracy at Block 9 was ($M = \ldots$)
63.27%, $SE = 1.80$) was significantly greater than at Block 10 ($M = 58.98\%, SE = 1.59$) (Figure E1). To examine the effect of returning to the exposure rhythms, accuracy at Block 10 was compared to accuracy at Block 11. An ANOVA with Block (Block 10, Block 11) as a within-subject factor and Meter as a between-subjects factor was conducted. Although there was an increase in accuracy at Block 11, this did not reach significance, $F(1, 26) = 2.43$, $p = .13$, partial $\eta^2 = .09$. There was no main effect of Meter, and no Block by Meter interaction.

**Figure E1.** Accuracy (% correct responses) presented as a function of Block and Meter condition. Error bars show standard error of the mean.
E.2. Correlations between Post-IGI Accuracy and Reaction Time (RT)

To ensure that there were no speed/accuracy tradeoffs, RT and accuracy at each block were correlated separately for the Even and Uneven Meter conditions. In the Even Meter condition, there was a significant negative correlation only at Block 2 ($r(12) = - .71, p = .01$). Faster RT was associated with higher accuracy. There were no significant correlations in the Uneven Meter condition. Hence, no speed/accuracy tradeoffs were evident.

E.3. Analyses of Counterbalanced Rhythm Conditions

Analyses investigating the influence of counterbalanced rhythm conditions (Even 1, Even 2, Uneven 1, Uneven 2) were conducted for each meter condition (see Table E1). For brevity, only the main effect of Counterbalanced rhythm, and the Block by Counterbalanced rhythm interactions are reported.

Table E1

Sequence Presentation for each Meter Condition across Exposure and Test Blocks

<table>
<thead>
<tr>
<th>Meter condition</th>
<th>Exposure blocks</th>
<th>Test blocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Even</td>
<td>1 – 8, and 11</td>
<td>9 and 10</td>
</tr>
<tr>
<td></td>
<td>Even 1</td>
<td>Even 2</td>
</tr>
<tr>
<td></td>
<td>Even 2</td>
<td>Even 1</td>
</tr>
<tr>
<td>Uneven</td>
<td>Uneven 1</td>
<td>Uneven 2</td>
</tr>
<tr>
<td></td>
<td>Uneven 2</td>
<td>Uneven 1</td>
</tr>
</tbody>
</table>
E.3.1. Mean RT to Post-IGI Syllables

E.3.1.1. Exposure Blocks

In the Even Meter condition, there was no effect of Counterbalanced rhythm, $F(1, 12) = .05, p = .83$, partial $\eta^2 = .00$, and no Block by Counterbalanced rhythm interaction, $F(7, 84) = 1.31, p = .26$, partial $\eta^2 = .10$. In the Uneven Meter condition, there was no effect of Counterbalanced rhythm, $F(1, 12) = .16, p = .70$, partial $\eta^2 = .01$, and no Block by Counterbalanced rhythm interaction, $F(7, 84) = .78, p = .60$, partial $\eta^2 = .06$.

E.3.1.2. Test Blocks

Comparing Block 8 (exposure) with Block 9 (first test): In the Even Meter condition, there was no effect of Counterbalanced rhythm, $F(1, 12) = .70, p = .42$, partial $\eta^2 = .06$, and no Block by Counterbalanced rhythm interaction, $F(1, 12) = .07, p = .80$, partial $\eta^2 = .01$. In the Uneven Meter condition, there was no effect of Counterbalanced rhythm, $F(1, 12) = .29, p = .60$, partial $\eta^2 = .02$, but the Block by Counterbalanced rhythm interaction approached significance, $F(1, 12) = 4.28, p = .06$, partial $\eta^2 = .26$. RT decreased in the Uneven 1 group (Block 8: $M = 411.47$ ms, $SD = 45.97$; Block 9: $M = 399.90$ ms, $SD = 42.33$) but increased in the Uneven 2 group (Block 8: $M = 407.59$ ms, $SD = 21.32$; Block 9: $M = 426.60$ ms, $SD = 38.99$).

Comparing Block 9 (first test) with Block 10 (second test): In the Even Meter condition, there was no effect of Counterbalanced rhythm, $F(1, 12) = .46, p = .51$, partial $\eta^2 = .04$, and no Block by Counterbalanced rhythm interaction, $F(1, 12) = .04, p = .85$, partial $\eta^2 = .00$. In the Uneven Meter condition, there was no effect of Counterbalanced rhythm, $F(1, 12) = .82, p = .38$, partial $\eta^2 = .06$, and no Block by Counterbalanced rhythm interaction, $F(1, 12) = .21, p = .66$, partial $\eta^2 = .02$. 

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Comparing Block 10 (second test) with Block 11 (final exposure): In the Even Meter condition, there was no effect of Counterbalanced rhythm, $F(1, 12) = .02, p = .91$, partial $\eta^2 = .00$, and no Block by Counterbalanced rhythm interaction, $F(1, 12) = 2.01, p = .18$, partial $\eta^2 = .14$. In the Uneven Meter condition, there was no effect of Counterbalanced rhythm, $F(1, 12) = .11, p = .75$, partial $\eta^2 = .01$, and no Block by Counterbalanced rhythm interaction, $F(1, 12) = 1.47, p = .25$, partial $\eta^2 = .11$.

E.3.2. Mean RT to Within-group Syllables.

E.3.2.1. Exposure Blocks

In the Even Meter condition, there was no effect of Counterbalanced rhythm, $F(1, 12) = .65, p = .44$, partial $\eta^2 = .05$, and no Block by Counterbalanced rhythm interaction, $F(7, 84) = .57, p = .78$, partial $\eta^2 = .05$. In the Uneven Meter condition, there was no effect of Counterbalanced rhythm, $F(1, 12) = .00, p = .97$, partial $\eta^2 = .00$, and no Block by Counterbalanced rhythm interaction, $F(7, 84) = 1.56, p = .16$, partial $\eta^2 = .12$.

E.3.2.2. Test Blocks

Comparing Block 8 (exposure) with Block 9 (first test): In the Even Meter condition, there was no effect of Counterbalanced rhythm, $F(1, 12) = .02, p = .87$, partial $\eta^2 = .00$, and no Block by Counterbalanced rhythm interaction, $F(1, 12) = 3.36, p = .09$, partial $\eta^2 = .22$. Although the interaction was not significant, RT decreased in the Even 1 group (Block 8: $M = 372.26$ ms, $SD = 29.91$; Block 9: $M = 359.26$ ms, $SD = 29.19$), but increased in the Even 2 group (Block 8: $M = 349.69$ ms, $SD = 29.05$; Block 9: $M = 385.54$ ms, $SD = 47.81$). In the Uneven Meter condition, there was no effect of
Counterbalanced rhythm, $F(1, 12) = .11, p = .74$, partial $\eta^2 = .01$, and no Block by Counterbalanced rhythm interaction, $F(1, 12) = .19, p = .67$, partial $\eta^2 = .02$.

Comparing Block 9 (first test) with Block 10 (second test): In the Even Meter condition, there was no effect of Counterbalanced rhythm, $F(1, 12) = .81, p = .39$, partial $\eta^2 = .06$, and no Block by Counterbalanced rhythm interaction, $F(1, 12) = 1.03, p = .33$, partial $\eta^2 = .08$. In the Uneven Meter condition, there was no effect of Counterbalanced rhythm, $F(1, 12) = .10, p = .76$, partial $\eta^2 = .01$, and no Block by Counterbalanced rhythm interaction, $F(1, 12) = 2.30, p = .16$, partial $\eta^2 = .16$.

Comparing Block 10 (second test) with Block 11 (final exposure): In the Even Meter condition, there was no effect of Counterbalanced rhythm, $F(1, 12) = .14, p = .71$, partial $\eta^2 = .01$, but the Block by Counterbalanced rhythm interaction was marginally significant, $F(1, 12) = 4.78, p = .049$, partial $\eta^2 = .29$. The RT decrease was greater in the Even 2 (Block 10: $M = 389.89$ ms, $SD = 34.15$; Block 11: $M = 353.19$ ms, $SD = 34.76$), compared to Even 1 group (Block 10: $M = 380.60$ ms, $SD = 46.10$; Block 11: $M = 377.44$ ms, $SD = 37.92$). In the Uneven Meter condition, there was no effect of Counterbalanced rhythm, $F(1, 12) = .50, p = .49$, partial $\eta^2 = .04$, and no Block by Counterbalanced rhythm interaction, $F(1, 12) = 1.03, p = .33$, partial $\eta^2 = .08$.

Only one Counterbalanced rhythm by Block interactions was significant, with the RT decrease to within-group syllables greater at Block 11 (last exposure), compared to Block 10 (second test) in the Even 2, compared to Even 1 group. Two other interactions approached significance: (a) There was an RT increase to post-IGI syllables at Block 9 (first test), compared to Block 8 (exposure), in the Uneven 2 group but an RT decrease in the Uneven 1 group; and (b) there was an RT increase to within-group syllables at Block
9 (first test), compared to Block 8 (exposure), in the Even 2 group but an RT decrease in the Even 1 group. These findings show that there was some increase in RT at the first test block, but only in Even 2 and Uneven 2 Counterbalanced rhythm conditions. However, the increase was inconsistent across post-IGI and within-group positions. Thus, the Counterbalanced rhythm conditions are collapsed in the analyses presented in the body of Chapter 5.

E.4. Analyses by Awareness

E.4.1. Mean RT to Post-IGI Syllables

Participants who demonstrated awareness of their exposure sequences were identified. These participants had an exposure sequence z-familiarity scores greater than zero (i.e. their mean rating to the exposure sequences was greater than their overall mean familiarity rating to all post-test sequences) and their certainty ratings to the exposure sequences were equal to, or greater than four (4 = somewhat certain, 5 = very certain, 6 = completely certain). Nine of the 28 participants (Even meter condition = 4, Uneven meter condition = 5) met both these criteria and were considered to be “aware” of the exposure rhythm. All syllables, post-IGI and within-group data sets were re-analysed with Awareness (Aware, Unaware) and Meter (Even, Uneven) as between-subjects factors.

E.4.1.1. Exposure Blocks

RT to syllables that followed IGIs was averaged for each block and an 8 x 2 x 2 ANOVA with Block (Blocks 1 – 8) as a within-subject factor and Awareness (Aware, Unaware), and Meter (Even, Uneven) as between-subjects factors was conducted. The
main effect of Block was significant, $F(7, 168) = 2.97, p = .01$, partial $\eta^2 = .11$, but there was no effect of Awareness, $F(1, 24) = .49, p = .49$, partial $\eta^2 = .02$, and no effect of Meter, $F(1, 24) = 2.70, p = .11$, partial $\eta^2 = .10$. None of the interactions were significant (Figure E2a and b).

**E.4.1.2. Test Blocks**

A set of 2 x 2 x 2 ANOVAs with Block as a within-subject factor, and Awareness (Aware, Unaware) and Meter (Even, Uneven) as between-subjects factors was conducted.

Comparing Block 8 (exposure) with Block 9 (first test block), there was no main effect of Block, $F(1, 24) = .20, p = .66$, partial $\eta^2 = .01$, no effect of Awareness, $F(1, 24) = .86, p = .36$, partial $\eta^2 = .03$, or Meter, $F(1, 24) = 2.15, p = .16$, partial $\eta^2 = .08$. While none of the interactions were significant, the Block by Awareness interaction approached significance, $F(1, 24) = 3.84, p = .06$, partial $\eta^2 = .14$. There was an RT increase in the “Aware” group (Block 8: $M = 399.31$ ms, $SD = 13.23$, Block 9: $M = 415.82$ ms, $SD = 13.72$) but an RT decrease in the “Unaware” group (Block 8: $M = 399.07$ ms, $SD = 9.06$, Block 9: $M = 388.64$ ms, $SD = 9.40$). An inspection of the four participants in the “Aware” group revealed that only two participants drove the RT increase. Therefore, it is unfeasible to make any interpretation of the near significant interaction.

Comparing Block 9 (first test) with Block 10 (second test), there was a significant effect of Block, $F(1, 24) = 25.68, p = .00$, partial $\eta^2 = .52$, and no effect of Meter, $F(1, 24) = 1.82, p = .19$, partial $\eta^2 = .07$. The main effect of Awareness approached significance, $F(1, 24) = 3.71, p = .07$, partial $\eta^2 = .13$. RT tended to be slower in the Aware group ($M = 436.40$ ms, $SE = 14.64$) compared to the Unaware group ($M = 402.23$ ms, $SE = 10.03$). None of the interactions were significant.
Comparing Block 10 (second test) with Block 11 (last exposure), there was a main effect of Block, $F(1, 24) = 52.54, p = .00$, partial $\eta^2 = .69$, but no effect of Awareness, $F(1, 24) = 2.00, p = .17$, partial $\eta^2 = .08$ or Meter, $F(1, 24) = 2.99, p = .10$, partial $\eta^2 = .11$. There was a significant Block by Awareness interaction, $F(1, 24) = 5.32, p = .03$, partial $\eta^2 = .18$, however, RT decreased significantly in both groups, $ps = .00$. No other interactions were significant (Figure E2a and b).

**E.4.2. Mean RT to Within-group Syllables**

**E.4.2.1. Exposure Blocks**

RT to within-group syllables was averaged for each block and an $8 \times 2 \times 2$ ANOVA with Block (Blocks 1 – 8) as a within-subject factor and Awareness (Aware, Unaware), and Meter (Even, Uneven) as between-subjects factors was conducted (Figure E2c and d). The main effect of Block approached significance, $F(7, 168) = 1.97, p = .06$, partial $\eta^2 = .08$. There was no effect of Awareness, $F(1, 24) = .10, p = .76$, partial $\eta^2 = .00$, or Meter, $F(7, 24) = .06, p = .80$, partial $\eta^2 = .00$. None of the interactions were significant.

**E.4.2.2. Test Blocks**

A set of $2 \times 2 \times 2$ ANOVAs with Block as a within-subject factor, and Awareness (Aware, Unaware) and Meter (Even, Uneven) as between-subjects factors was conducted (Figure E2c and d).

Comparing Block 8 (exposure) with Block 9 (first test block), there was no effect of Block, $F(1, 24) = .39, p = .54$, partial $\eta^2 = .02$, Awareness, $F(1, 24) = .01, p = .94$, partial $\eta^2 = .00$, or Meter, $F(1, 24) = .18, p = .68$, partial $\eta^2 = .01$. The only significant
interaction was between Block and Condition, \( F(1, 24) = 4.56, p = .04, \text{partial } \eta^2 = .16. \)

RT *increased* in the Even Meter condition, but *decreased* in the Uneven Meter condition.

Comparing Block 9 (first test) with Block 10 (second test), there was a main effect of Block, \( F(1, 24) = 17.28, p = .00, \text{partial } \eta^2 = .42, \) but no effect of Awareness, \( F(1, 24) = .02, p = .92, \text{partial } \eta^2 = .00, \) or Meter, \( F(1, 24) = .18, p = .67, \text{partial } \eta^2 = .01. \)

The only significant interaction was between Block and Condition, \( F(1, 24) = 6.58, p = .02, \text{partial } \eta^2 = .22. \) RT increased to a greater degree in the Uneven, compared to Even Meter condition.

Comparing Block 10 (second test) with Block 11 (last exposure), there was a main effect Block, \( F(1, 24) = 18.24, p = .00, \text{partial } \eta^2 = .43, \) but there was no effect of Awareness, \( F(1, 24) = .02, p = .88, \text{partial } \eta^2 = .00, \) or Meter, \( F(1, 24) = .30, p = .59, \text{partial } \eta^2 = .01. \) None of the interactions were significant.
Figure E2. Correct RT to a) Post-IGI positions in the Even Meter condition, b) Post-IGI positions in the Uneven Meter condition, c) Within-group positions in the Even Meter condition, and d) Within-group positions in the Uneven Meter condition, plotted as a function of Awareness (Aware and Unaware). Error bars show standard error of the mean.

Given that there were small and unequal participant numbers in each group, (Aware: Even = 4, Uneven = 5; Unaware: Even = 10, Uneven = 9), it is inappropriate to draw any conclusions based on the above results. However, we can say that the test block increase at Block 9 (second test) was not influenced by awareness.
Appendix F: Participant Instructions

F.1. Experiments 1 and 2

1. “There are 2 parts to today’s study, and it should take about 50 minutes in total. We are interested in how quickly and accurately you identify syllables, PA, TA and KA. (Experiment 2 only: “We are interested in how quickly and accurately you identify syllables, PA, TA and KA, when those syllables are in the presence of another stream of sounds”). The findings will become a part of a published research project”.

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2. “For the first part of the experiment, you will be listening to a series of syllables over headphones. (Experiment 2 only: “In the left headphone you will hear other sounds but your task is to solely focus on the syllables”). Your task is to identify which syllable you heard: PA, TA or KA (present in order consistent with the key attribution). You do this by pressing the corresponding keys on the keyboard here (point to number pad) as quickly and accurately as possible. To help you answer quickly, please keep you right index, middle, and ring fingers on the keys at ALL times”.

3. “You do not have to wait until the sound finishes before you respond. Respond as soon as you can identify the syllable. The computer will record each of your responses and measure your speed and accuracy”.

4. “The aim is to respond to each syllable before you hear the next one. It is important that you respond after every syllable with just ONE key press. Do not correct
yourself by pressing a second response. If you miss a syllable, just respond to the next one”.

5. “It is a challenging task. Please pay attention to the syllables and try to be as fast and as accurate as possible”.

6. “You will hear and respond to about 2 minutes of syllables at a time, and then you will get a break and can proceed to the next set when you are ready. We will now begin with some practice trials to be sure you understand the task. Afterwards, you will have the opportunity to ask any questions.”

Post-Tests

7. “Before we begin the second part of the experiment, I have some questions for you to answer.”

8. Present participants with the “pen and paper” questionnaire: “Answer each question before turning over to the next question”. (See Appendix I, Section I.1)

9. Inform participants that the sequences followed a temporal pattern or rhythm: “The syllables were presented according to a fixed timing pattern or rhythm. You may or may not have noticed that there were sometimes pauses in between some syllables, or that perhaps the syllable sequences followed a beat or rhythm. In this part of the experiment we are actually interested in your responses to the timing of the presentation of the syllables”.

10. “You will be presented with sequences of syllables, PA, TA and KA, only this time the sequences will be shorter than those in the first part of the experiment. You will perform the task just as you did in the first part of the experiment. (Experiment 2 only: “As in the first part of the experiment, there will be a second stream of sounds in the left
headphone but you must focus on the syllables only.” Again, you identify each syllable as quickly and accurately as possible using the corresponding keys on the keyboard”.

11. “You do not have to wait until the sound finishes to respond. Respond as soon as you can identify the syllable. It is important that you respond after every syllable with just ONE key press and do not correct yourself by pressing a second response. If you miss a syllable, just respond to the next one”.

12. “After each short sequence, a question and rating scale will appear on the screen; ‘Thinking back to the first part of the experiment, how FAMILIAR is the timing pattern of the sequence you have just been presented?’. The possible responses are: 1 = very unfamiliar, 2 = unfamiliar, 3 = somewhat unfamiliar, 4 = somewhat familiar, 5 = unfamiliar, 6 = very familiar”.

13. “You make your response by pressing the corresponding numeric key (1 to 6) across the top of the keyboard (point to keys). You may take your time in making this response. After you have done so, another question and scale will be presented on the screen: ‘How certain are you in your rating of familiarity?’ The possible responses are: 1 = complete guess, 2 = very uncertain, 3 = somewhat uncertain, 4 = somewhat certain, 5 = very certain, 6 = completely certain. Again, you make your response by pressing the corresponding key (1 to 6) across the top of the keyboard (point to keys)”.

14. “After you have made your rating you press the spacebar to continue with the next sequence. There are a number of sequences. Two-thirds will have the same timing pattern as sequences in the first part of the experiment and the other one-third will have new timing patterns. This part of the experiment will take approximately 15 minutes.”
15. Give the participants the demographic questionnaire and explain the purposes of the study. Inform the participants to not to tell student colleagues who may potentially participate about the purpose of the study.

F.2. Experiment 3

1. “There are 2 parts to today’s study, and it should take about 50 minutes in total. We are interested in how quickly and accurately you identify syllables, PA, TA and KA. The findings will become a part of a published research project”.

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2. “For the first part of the experiment, you will be listening to a series of syllables over headphones. Your task is to identify which syllable you heard: PA, TA or KA (present in order consistent with the key attribution). You do this by pressing the corresponding keys on the keyboard here (point to number pad) as quickly and accurately as possible.

3. “In this experiment, the syllables are in a random order. However, they are presented in a sequence that has a repeating timing pattern or rhythm. Your task is also to learn this timing pattern or rhythm so that you can anticipate when the next syllable will be presented. With a timing pattern or rhythm, I am referring to an ordering of short or longer silences between individual syllables, or groups of syllables, for example, ‘ta pa pa pause ta ta versus ta pa pa pause pause ta ta’. These timing patterns will combine in certain ways so that there is a regular longer timing pattern that repeats within the
sequence”. (Check that the participant understands what is meant by timing pattern or rhythm.)

4. To help you answer quickly, please keep you right index, middle, and ring fingers on the keys at ALL times”.

5. “You do not have to wait until the sound finishes before you respond. Respond as soon as you can identify the syllable. The computer will record each of your responses and measure your speed and accuracy”.

6. “The aim is to respond to each syllable before you hear the next one. It is important that you respond after every syllable with just ONE key press. Do not correct yourself by pressing a second response. If you miss a syllable, just respond to the next one”.

7. “It is a challenging task. Please pay attention to the syllables and try to be as fast and as accurate as possible”.

8. “You will hear and respond to about 2 minutes of syllables at a time, and then you will get a break and can proceed to the next set when you are ready. We will now begin with some practice trials to be sure you understand the task. Afterwards, you will have the opportunity to ask any questions.”

Post-Tests

9. “Before we begin the second part of the experiment, I have some questions for you to answer.” (See Appendix I, Section 1.2)

10. Present participants with the “pen and paper” questionnaire: “Answer each question before turning over to the next question”.

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11. Remind participants that the sequences followed a temporal pattern or rhythm:
“The syllables were presented according to a fixed timing pattern or rhythm. At the beginning of the experiment you were instructed to learn the timing pattern or rhythm so that you can anticipate when the next syllable will be presented. In this next part of the experiment we are interested in your familiarity with the timing of the presentation of the syllables”.

12. “You will be presented with sequences of syllables, PA, TA and KA, only this time the sequences will be shorter than those in the first part of the experiment. You will perform the task just as you did in the first part of the experiment. Again, you identify each syllable as quickly and accurately as possible using the corresponding keys on the keyboard”.

13. “You do not have to wait until the sound finishes to respond. Respond as soon as you can identify the syllable. It is important that you respond after every syllable with just ONE key press and do not correct yourself by pressing a second response. If you miss a syllable, just respond to the next one”.

14. “After each short sequence, a question and rating scale will appear on the screen; ‘Thinking back to the first part of the experiment, how FAMILIAR is the timing pattern of the sequence you have just been presented?’. The possible responses are: 1 = very unfamiliar, 2 = unfamiliar, 3 = somewhat unfamiliar, 4 = somewhat familiar, 5 = unfamiliar, 6 = very familiar”.

15. “You make your response by pressing the corresponding numeric key (1 to 6) across the top of the keyboard (point to keys). You may take your time in making this response. After you have done so, another question and scale will be presented on the
screen: ‘How certain are you in your rating of familiarity?’ The possible responses are: 1 = complete guess, 2 = very uncertain, 3 = somewhat uncertain, 4 = somewhat certain, 5 = very certain, 6 = completely certain. Again, you make your response by pressing the corresponding key (1 to 6) across the top of the keyboard (point to keys)”.

16. “After you have made your rating you press the spacebar to continue with the next sequence. There are a number of sequences. Two-thirds will have the same timing pattern as sequences in the first part of the experiment and the other one-third will have new timing patterns. This part of the experiment will take approximately 15 minutes.”

Give the participants the demographic questionnaire and explain the purposes of the study. Inform the participants not to tell student colleagues who may potentially participate about the purpose of the study.

F.3. Experiments 4, 5 and 6

1. “There are 2 parts to today’s study, and it should take about 50 minutes in total. We are interested in how quickly and accurately you identify syllables, PA and TA and the findings will become a part of a published research project”.

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2. “For the first part of the experiment, you will be listening to a series of syllables over headphones. Your task is to identify which syllable you heard: PA or TA (or TA and PA depending on the key attribution). You do this by using your thumbs to press the corresponding keys on the numeric keypad (point to number pad) as quickly and
accurately as possible. To help you answer quickly, please keep your thumbs on the keys at ALL times”.

3. “You do not have to wait until the sound finishes before you respond. Respond as soon as you can identify the syllable. The computer will record each of your responses and measure your speed and accuracy”.

4. “The aim is to respond to each syllable before you hear the next one. It is important that you respond after every syllable with just ONE key press. Do not correct yourself by pressing a second response. If you miss a syllable, just respond to the next one”.

5. “It is a challenging task. Please pay attention to the syllables and try to be as fast and as accurate as possible”.

6. “You will hear and respond to about 1 and a half minutes of syllables at a time, and then you will get a break and can proceed to the next set when you are ready. We will now begin with some practice trials to be sure you understand the task. Afterwards, you will have the opportunity to ask any questions.”

Post-Tests

7. “Before we begin the second part of the experiment, I have some questions for you to answer.”

8. Present participants with the “pen and paper” questionnaire: “Answer each question before turning over to the next question”. (See Appendix I, Section I.1)

9. Inform participants that the sequences followed a temporal pattern or rhythm: “The syllables were presented according to a fixed timing pattern or rhythm. You may or may not have noticed that there were sometimes pauses in between some syllables, or that
perhaps the syllable sequences followed a beat or rhythm. In this part of the experiment we are actually interested in your responses to the timing of the presentation of the syllables”.

10. “You will be presented with sequences of syllables, PA and TA, only this time the sequences will be shorter than those in the first part of the experiment. You will perform the task just as you did in the first part of the experiment. Again, you identify each syllable as quickly and accurately as possible using the corresponding keys on the keypad”.

11. “You do not have to wait until the sound finishes to respond. Respond as soon as you can identify the syllable. It is important that you respond after every syllable with just ONE key press and do not correct yourself by pressing a second response. If you miss a syllable, just respond to the next one”.

12. “After each short sequence, a question and rating scale will appear on the screen; ‘Thinking back to the first part of the experiment, how FAMILIAR is the timing pattern of the sequence you have just been presented?’. The possible responses are: 1 = very unfamiliar, 2 = unfamiliar, 3 = somewhat unfamiliar, 4 = somewhat familiar, 5 = unfamiliar, 6 = very familiar”.

13. “You make your response by pressing the corresponding numeric key (1 to 6) across the top of the keyboard (point to keys). You may take your time in making this response. After you have done so, another question and scale will be presented on the screen: ‘How certain are you in your rating of familiarity?’. The possible responses are: 1 = complete guess, 2 = very uncertain, 3 = somewhat uncertain, 4 = somewhat certain, 5 =
very certain, 6 = completely certain. Again, you make your response by pressing the corresponding key (1 to 6) across the top of the keyboard (point to keys)”.

14. “After you have made your rating you press the spacebar to continue with the next sequence. There are a number of sequences. One half will have the same timing pattern as sequences in the first part of the experiment and the other half will have new timing patterns. This part of the experiment will take approximately 15 minutes.”

15. Give the participants the demographic questionnaire and explain the purposes of the study. Inform the participants not to tell student colleagues who may potentially participate about the purpose of the study.

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24 Experiment 5: “Two-thirds will have the same timing pattern as sequences in the first part of the experiment and the other on-third will have new timing patterns.”
Appendix G: Information Sheet

Information Sheet – Syllable Identification Experiment
The MARCS Institute, Bankstown

Dear Participant,

You are invited to participate in a study conducted by Josephine Terry of MARCS Institute. There are 2 parts to the study. In both parts you will be identifying syllables that you hear over headphones and making your responses using a numeric keypad. Throughout the study we are interested in how quickly and accurately you can identify the syllables. It should take about 50 minutes in total.

Information gathered will be de-identified and all aspects of the study, including results will be confidential. Only the researchers will have access to information on participants. 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.

When you have read this information, Josephine Terry 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 Josephine Terry (j.terry@uws.edu.au, (02) 9772 6660), HDR candidate, or Prof Catherine Stevens (kj.stevens@uws.edu.au, (02) 9772 6324) of the School of Social Sciences and Psychology, UWS Bankstown campus.

This study has been approved by the University of Western Sydney Human Research Ethics Committee. The Approval Number is H8352. 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 or Fax 02 4736 0013. Any issues you raise will be treated in confidence and investigated fully, and you will be informed of the outcome.

If you agree to participate in this study, you may be asked to sign the Participant Consent Form.

Josephine Terry
Principal Researcher
Appendix H: Consent Form

Participant Consent Form

This is a project specific consent form. It restricts the use of the data collected to the named project by the named investigators.

Research Project – Syllable Identification Experiment

I,........................................, consent to participate in the research project titled Syllable Identification Experiment.

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 recording of my responses and to the use of the data as outlined in the information sheet.

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 now or in the future.

Signed: ________________________________

Name: _________________________________

Date: _________________________________
Appendix I: Post-test Questionnaire

I.1. Experiments 1, 2, 4, 5, and 6

QUESTION 1.
Think back to the sequences presented in the task you have just completed. Did you notice any regularities in the sequences? If so, describe the regularities you noticed.

QUESTION 2.
Did you notice any regularity in the timing of the presentation of the syllables? If so, describe the regularity you noticed.

QUESTION 3.
Please comment on the difficulty of the task.

QUESTION 4.
Did you use any strategies to perform the task?

I.2. Experiment 3

QUESTION 1.
Think back to the sequences presented in the task you have just completed. Did you notice any regularities in the timing of the presentation of the syllables (a rhythm)? If so, describe the timing pattern or rhythm you noticed.
QUESTION 2.
Did any of the sequences (blocks) have a different timing pattern or rhythm from the others? If so, can you recall which one(s)? Can you describe the difference?

QUESTION 3.
To help you develop expectations of when syllables would be presented, you were informed at the beginning of the experiment that they were presented in a repeating timing pattern, or rhythm. Did you use this information and how did you do so?

QUESTION 4.
Please comment on the difficulty of the task.

QUESTION 5.
Did you use any other strategies to perform the task?
Appendix J: Demographic Questionnaire

1. Age:

2. Sex:

3. Handedness (right-, left-handed, ambidextrous)

4. First language:

5. Do you have normal hearing? If no, explain.

6. What types of music do you listen to most often?

7. What were the types of music you were exposed to as a child?

8. Do you or did you play any musical instruments or perform with your voice? (If no, skip the next two questions.)

9. For how many years have you received formal training on a musical instrument or voice?

10. List the instruments and the years you played.

   Instrument or voice: Instrument or voice:

   From age: From age:

   To age: To age:

   Instrument or voice: Instrument or voice:

   From age: From age:

   To age: To age:

11. Are you trained in music theory? If yes, describe your background.
12. Have you taken any other music courses? If yes, list courses.


[Not at all] [A lot]

14. Have you had any formal dance training? (If no, skip the next two questions.)

15. For how many years have you received formal training in dance?

16. List the dance styles and the years you trained.

   Dance style:__
   From age:__
   To age:__

   Dance style:__
   From age:__
   To age:__

17. Do you like dancing? Circle your response below.

[Not at all] [A lot]

18. Do you play console games? (e.g. Playstation, Nintendo Wii)

19. If yes, how many hours per week do you play?
Appendix K: Ethics Approval

Sent: Wednesday, July 14, 2010 4:51 PM

Notification of Approval

Email on behalf of the UWS Human Research Ethics Committee

Dear Catherine and Josephine

I'm writing to advise you that the Human Research Ethics Committee has agreed to approve the project.
Title: Implicit Learning of Rhythms with Even and Uneven Metrical Structures
H8352 Student: Josephine Terry (Supervisor: Catherine Stevens)

The Protocol Number for this project is H8352. Please ensure that this number is quoted in all relevant correspondence and on all information sheets, consent forms and other project documentation.

Please note the following:
1) The approval will expire on 31/12/2013. If you require an extension of approval beyond this period, please ensure that you notify the Human Ethics Officer humanethics@uws.edu.au prior to this date.

2) Please ensure that you notify the Human Ethics Officer of any future change to the research methodology, recruitment procedure, set of participants or research team.

3) If anything unexpected should occur while carrying out the research, please submit an Adverse Event Form to the Human Ethics Officer. This can be found at http://www.uws.edu.au/research/researchers/ethics/human_ethics/human_ethics_adverse_eventend_of_project_report

4) Once the project has been completed, a report on its ethical aspects must be submitted to the Human Ethics Officer. This can also be found at http://www.uws.edu.au/research/researchers/ethics/human_ethics/human_ethics_adverse_eventend_of_project_report
Finally, please contact the Human Ethics Officer, Kay Buckley on (02) 4736 0883 or at k.buckley@uws.edu.au if you require any further information.

The Committee wishes you well with your research.

Yours sincerely

Associate Professor Janette Perz  
Chair, UWS Human Research Ethics Committee

Kay Buckley  
Human Ethics Officer  
University of Western Sydney  
Locked Bag 1797, Penrith Sth DC NSW 1797  
Tel: 02 47 360 883 http://www.uws.edu.au/research/ors/ethics/human_ethics