

'… and I feel good!' The Relationship between Body-Movement, Pleasure and Groove in Music

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ABSTRACT

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In many musical cultures, people synchronise their bodies to the rhythmic patterns of the music, and such embodied engagements are one of the most overtly enjoyable forms of musical appreciation. However, the ways in which rhythmic structure, body-movement and pleasure are related remains unclear. The present thesis directs a broadly psychological, yet multi-methodological and interdisciplinary, approach towards this relationship, centring on the rhythmic structure of syncopation in groove-based funk music. Through perceptual experiments, computational modelling, rating surveys, neuroimaging and motion-capture recording, syncopation was found to relate, in primarily negatively linear and inverted U-shaped ways, to finger-tapping performance, perceptions of stability, subjective desire to move and feelings of pleasure, neural activity in motor and reward areas, and force, synchrony and periodicity in body-movements. These relationships also depended on individuals' musical training, dancing experience and groove familiarity. Ecological and embodied theories of perception and a phenomenology of groove provide a backdrop to the empirical findings, on the basis of which it is suggested that the different relationships between syncopation in groove and perceptual, subjective, neural and corporeal attributes interact in reciprocal ways. It is proposed that syncopation invites the body to physically enact the musical structure and directly participate in the rhythms of groove, due to the perceptual tension and 'open spaces' afforded by the perception of metric events in syncopation. In groove, body, mind and music extend into each other and this distributed musical process has affective significance. Since the physical pleasures of dancing to music are such a historically and culturally ubiquitous phenomenon, the empirical findings and theoretical proposals of this thesis make significant contributions towards a much-needed coupling of affective and embodied theories of music.

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I dedicate this thesis to my loving parents,

the solid rocks.

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CHAPTER ONE

Introduction

What is it about music that makes us want to move? And why does it feel so good? Few contexts make the pleasurable effect of music more apparent than that of a dance club. The rhythmically moving bodies grooving together to pulsating beats are perhaps the most overtly manifested expressions of hedonic engagement with music. However, little is known about what it is about music that motivates such behaviour and how body-movement and pleasure are related in music. The present research takes a psychological perspective on the relationship between groove, wanting to move and feelings of pleasure.

Examples of groove-based music include funk, soul, hip-hop, electronic dance music and jazz. What is common to these genres is their association with sensorimotor synchronisation and repeated rhythmic patterns, which are often manifested in complex ways. Through a multi-method cross-disciplinary approach, the perceptual, subjective, neural and embodied mechanisms underlying the relationship between body-movement, pleasure and groove are investigated, and in theoretical-phenomenological discussions, the nature of this relationship is explored. Via finger-tapping experiments, computational modelling, subjective rating, functional Magnetic Resonance Imaging (fMRI) and motion-capture measurements, the effects of one specific structural characteristic of rhythmic complexity in the groove-based genre of funk – syncopation – is studied. Its effects are shown to be related to tapping variability, perceptions of stability, feelings of wanting to move and pleasure, neural activity in pleasure and motor areas of the brain and force, synchrony and periodicity of dance movements. These relationships interact with musical training, groove familiarity and previous experience with dancing. Using embodied and

ecological theories of perception and a phenomenology of groove, these different relationships are integrated into a broader concept of groove experience, in which the notion of metre perception binds cognitive, affective and embodied dimensions together. In particular, it is proposed that *perception of metric events* during syncopation, a process by which a pulse can be perceived in the absence of sounding events, enables a distribution of music, mind and body in groove. Syncopation invites the body to overtly embody the pulse, physically enact the metric events through body-movement, and thus actively take part in the rhythmically complex relationships articulated by the groove. Such interactions between musical structure, mind and body are discussed primarily with regard to their psychological significance, but the theoretical proposals allow for extensions into more social and cultural domains. With the empirical findings reported in this thesis as the starting point, these interactions contribute to understanding what it is about music that makes us want to move, and why it feels good. Since few can resist the urge to tap their feet, bop their heads or get up and dance when they hear groove, the integration of embodied and affective theories is a timely addition to the understanding of musical experience.

The main chapters of this thesis report and discuss the findings of empirical studies and theoretical proposals in which various aspects of the relationship between body-movement, pleasure and syncopation in groove are addressed (a synopsis is given below). In doing so, the relevant literature and previous research will be reviewed in the context of each study. However, in the remainder of this chapter, the main concepts of the research are defined, the most important theories described more broadly and the main research aims stated. In this way, the different fields and research questions with which the thesis engages are presented as a backdrop to the subsequent empirical chapters, making explicit the interdisciplinary context of the project as a whole.

1.1 Defining Groove

Genres commonly referred to as *groove-based*, such as funk, soul, hip-hop, jazz, electronic dance music, reggae and dancehall, often share a cultural heritage. Many of these genres originated in African-American communities, and influences can be traced to African music. Aside from these cultural origins, musicologists concerned with groove have primarily analysed its rhythmic structure and the ways in which it affects experience (Butler, 2006; Danielsen, 2006, 2010b). The rhythmic complexity, degree of repetition and constancy of tempo in groove are what most noticeably distinguish it from other types of music, such as Western classical music.[1] Its rhythmic and repetitive character makes groove particularly suitable for continuous synchronising of body-movements in dance, and this embodied quality is central to the definition of groove provided by Kernfeld (2009) in the New Grove Dictionary of Jazz:

> In the realm of jazz, a [groove is a] persistently repeated pattern. More broadly, Feld (1988), studying groove from an ethnomusicological perspective, defines it cautiously as 'an unspecifiable but ordered sense of something that is sustained in a distinctive, regular and attractive way, working to draw the listener in'. Connections to dance are important, and the statement that a performance has, or achieves, a groove, usually means that it somehow compels the body to move.

In psychological research, the embodied effect is of primary interest, and groove is often simply defined as music that makes people want to move or a sensation described as a positive drive towards body-movement (Janata et al., 2012; Madison et al., 2011). In such studies, the term 'groove' is used to label both the musical structure and the psychological experience, but little effort is made to determine exactly *how* the musical structure elicits the psychological experience.

---

[1] There are, of course, classical pieces that can be said to include grooves. What often distinguishes grooves in classical and popular genres is that, in the former, grooves are included as sections featured in otherwise goal-directed forms (e.g. Stravinsky's 'Sacrificial Dance' from *The Rite of Spring* and Prokofiev's Cello Sonata in C Major, op. 119), while in the latter, the groove is the basis for structural development.

Zbikowksi (2004, p. 275) provides a simplified, but structurally focussed definition of groove: 'A groove is a large-scale multi-layered pattern that involves both pitch and rhythmic materials, and whose repetitions form the basis of either a portion or all of a particular tune.' However, although rightly pointing to groove's repetitive character, Zbikowski neglects to specify what characterises the multi-layered patterns. In order to be somewhat more specific and to include the psychological effects involved, the following preliminary definition is proposed:

> *Grooves are continuous multi-layered patterns of repeating units, commonly 2–4 bars in length, with varying degrees and expressions of rhythmic complexity, associated with a pleasurable desire for body-movement*.

However, as will be apparent throughout this thesis, the way in which the musical structure is related to the embodied and affective effects is not unidirectional. That is, rather than being a stimulus–response relationship, groove occurs reciprocally between music, mind and body.

The rhythmic complexity of groove is distinctive of the genre, and should thus be emphasised. However, the multiple layers do not necessarily all have to be sounded: rhythmically complex relationships can occur between a single instrumental stream and the underlying pulse in groove. For example, if the instrumental stream momentarily indicates a triple metre, while the underlying metric framework remains in a duple ratio, there is a moment of cross-rhythm between the layer of the instrument and the layer of the pulse. Syncopation is another example, in which the rhythmic events of an instrumental layer are metrically displaced, revealing its complex relationship with the underlying metre.

1.2 Groove as Structure

Groove's musical structure, and chiefly its forms of rhythmic complexity, have primarily been analysed by musicologists. Butler (2006) takes an analytical approach to rhythm and metre in electronic dance music (EDM) and demonstrates how structures such as syncopation and 'turning the beat around' create tension and ambiguity.[2] However, aside from claiming that tension and ambiguity are important characteristics of the aesthetics of EDM, Butler's analyses are not grounded in any general theory. Danielsen's object of study is funk (2006). Although funk usually includes at least one large-scale form of variation, it is not uncommon that a groove is repeated and unchanged for long periods of time, and Danielsen's analyses focus on the structures that are featured within the repeated basic unit of the groove.[3] Special emphasis is given to 'microtiming' and 'displacement', which are treated as ways of creating forward-movement and rhythmic interplay between textural layers. Microtiming refers to the occurrence of rhythmic events that do not occur exactly 'on' the pulse, but slightly 'late' or 'early' in relation to it (Iyer, 2002; Keil & Feld, 1994; Waadeland, 2001). Displacement is a structural strategy in which a rhythmic motif is first presented in relation to a specific metric framework, and later shifted to start at a new metrical location, causing different layers to interlock in novel ways and form new cross-rhythmic relationships. Danielsen's and Butler's analyses elucidate the effects of structural tension in a context of extensive repetition, a characteristic of groove-based music that extends beyond EDM and funk.

---

[2] When 'turning the beat around', a track is at first introduced by one or more textural layers that suggest a certain basic pulse, but gradually other layers with patterns that suggest a conflicting metre are added to the groove. The conflicting metrical frameworks cause tension and ambiguity. Furthermore, if the metre of the later layers is more stable (due, for example, to loudness or timbral quality), the listener will reinterpret the basic pulse accordingly and temporally shift the metric framework.

[3] 'The basic unit of the groove' is the rhythmic phrase that is repeated (normally of 2–4 bars in length). It is also referred to as the 'loop'.

1.3 Cultural Approaches to Groove

The cultural contexts in which people engage with groove-based music are primarily clubs, bars, parties, ritual ceremonies and other social events.[4] Dancing in these venues, people synchronise their body-movements not only to the pulse of the music, but also to the movements of other bodies. A number of scholars address the cultural frameworks within which people engage with groove-based music. For example, Forman and Neil (2004) give an account of hip-hop culture, Danielsen (2006) describes the cultural and political backdrop of funk, and Keil and Feld (1994) address the aesthetic experience of groove in a number of cultures, including African-American jazz communities and the Kaluli of New Guinea. However, the majority of cultural studies of groove-based music have taken EDM and the related club scene as their object of study (e.g. Gilbert & Pearson, 1999; Reynolds, 1999; Thornton, 1995), perhaps reflecting an assumption that these subcultures are larger, more globally distributed and tied to spatial arenas (i.e. the club) to a greater extent than, for example, funk or hip-hop.

Despite the explicit relationship between EDM and dancing, popular music scholars researching EDM have favoured discussions of gender, sexuality, class and drug culture (e.g. Reynolds, 1999; Thornton, 1995) as opposed to psychologically embodied and pleasurable effects. Gilbert and Pearson's study (1999) is an exception, discussing how musicology has largely neglected the study of contemporary popular dance music due to the long history of opposition to music as a source of sensory pleasure. The topics of gender, sexuality, technology and drugs are still considered, but they also discuss how these issues are manifested in relation to the bodily nature of musical experience.

[4] Another common context is during physical exercise. However, only certain forms of exercise explicitly involve synchronised movement, such as aerobics and zumba (both dance-based forms of exercise). Music is thought to motivate movement during exercise more broadly, but it has been difficult to demonstrate a direct relationship between musical rhythm and sensorimotor synchronisation in non-dance-based exercise (e.g. running) (Karageorghis & Terry, 1997).

Nonetheless, cultural approaches often fail to address how social and pleasurable dimensions of groove interact with the rhythmic structure and how aesthetic and interpersonal experiences of groove are underpinned by cognitive, neural and corporeal mechanisms.

1.4 Rhythm and Metre Perception

The musical properties upon which groove most significantly relies – rhythm and metre – are often considered together in music research, due to their mutual dependence in real musical contexts. Nonetheless, they can be theoretically distinguished. *Rhythm* is a pattern of discrete durations, and primarily depends on the underlying mechanism of grouping (Clarke, 1999; Fraisse, 1982). *Metre* is the temporal framework according to which rhythm can be perceived, and relies on the hierarchical embedding of time intervals, via recursive subdivision into usually simple ratios, such as 1:1 (duple metre) and 2:1 (triple metre). However, more complex, often called compound, ratios can also occur, such as 3:2 and 5:1. In a metric rhythm, the recursively subdivided time intervals provide the framework for a rhythm's *pulses*, which are isochronously spaced temporal events that form regular and predictable patterns. It is the relationship between these pulses that constitutes metre. The further down in the metric hierarchy, the shorter the space between the pulse events. The *main pulse* (or tactus) is the primary reference point in the metre, and is often the pulse to which listeners tap their feet and dancers synchronise their body-movements. *Beat* is sometimes (often colloquially) used to refer to the main pulse, but more commonly 'a beat' denotes a single rhythmic event within a metric rhythm. The inter-onset-intervals (IOIs) of the main pulse usually fall at around 500–700 milliseconds, corresponding to the commonly preferred spontaneous tapping tempo (Parncutt, 1994). Rhythm and metre were first suggested to depend on distinct mechanisms (e.g. Lerdahl & Jackendoff, 1983), the

former on the innate ability for grouping, and the latter on acquired hierarchical processing, but more recently, it has been suggested that they may stem from the same underlying process, namely the process of *dynamic attending* (Jones, 2009, described below).

The process by which metre is perceived in rhythm is called 'metre perception', 'beat perception' or 'beat induction'. These terms are often used interchangeably, but due to the somewhat diverging use of the term 'beat' described above, the term *metre perception* is the most concise and will thus be used throughout this thesis. However, at times, the 'beat'-referring terms will be cited, when they are used by other researchers whose literature is of relevance to the study. When metre is described as *induced,* it normally refers to instances in which a pulse is not consistently present in the rhythm, acoustically. In these cases, the sense of pulse is thought to be evoked via the predictability afforded by a regular metre. When some of the pulse events are absent (i.e. not acoustically sounded), the listener's expectations about their temporal placements provide the necessary framework to uphold the sense of regularity in the pulse and in the rhythm as a whole. Lerdahl and Jackendoff (1983) refer to such absent pulse events as *metric*, as opposed to *phenomenal*, the latter being based on the presence of physical sound.[5] However, the extent to which metric events are any less *perceived* than phenomenal events is questionable, since expectations towards the metric events are *psychologically* phenomenal. Thus, metre will be referred to as *perceived,* as opposed to induced, in the remainder of this thesis.

Nevertheless, there are instances of metre perception in which a distinction between phenomenal and metric events is useful, on a purely acoustic basis. This is

[5] Strictly speaking, Lerdahl and Jackendoff refer to phenomenal and metric *accents,* not events. However, since the term 'accent' is potentially confounded with degree and method of 'accentuation', the terms *phenomenal events* and *metric events* are used in the remainder of this thesis to denote sounded and silent events at metrically salient positions in a rhythm.

because, although metric events are expected to coincide with phenomenal events, there are moments in which this expectation is violated. Such moments are called *syncopation*. Broadly speaking, syncopation (further defined below) occurs when a phenomenal event does not occur when it is expected – in other words, when a metric event does not coincide with a phenomenal event. Thus, syncopation affords a rhythm in which a pulse event is acoustically silent. Nonetheless, the metric events can still be perceived in syncopation, due to the regularity of the pulse and the rhythm's metric framework as a whole. A central argument of the present thesis, which will be addressed from Chapter Five onwards, is that the perception of metric events in syncopation motivates body-movement and elicits pleasure in groove. However, rather than viewing metric events as induced, it is proposed that overt (or covert) body-movements express the pulse as both perceived and embodied.

In this regard, it is noteworthy that rhythm and metre perception is associated with activity in areas of the brain known to be involved in motor perception and action. A number of studies have found that secondary motor areas, such as the premotor cortex, supplementary motor area and cerebellum, are recruited during the perception of rhythm and metre (e.g. Bengtsson et al., 2009; Chapin et al., 2010; Chen et al., 2006, 2008; Grahn & Brett, 2007; Grahn & Rowe, 2009, 2012). Many of these studies also found activity in the basal ganglia, a subcortical area of the brain responsible for fine motor control, reinforcing the view that rhythm and metre are inherently related to sensorimotor processes.

1.5 Dynamic Attending and Entrainment

The theory that is perhaps the most sensitive to embodied aspects of rhythm is *Dynamic Attending Theory* (DAT). It was first proposed for temporal perception more generally (Barnes & Jones, 2000; Ellis & Jones, 2009; Jones & Boltz, 1989; Large & Jones, 1999),

and somewhat later appropriated for music and rhythm specifically, often using the broader term *entrainment* (Clayton et al., 2004; London, 2012; Phillips-Silver et al., 2010). The theory states that temporal events and musical rhythm are perceived in a much more dynamic and flexible way than suggested in previous theories, such as the information processing theory (e.g. Lerdahl & Jackendoff, 1983; Temperley, 2001) and the clock model (Povel & Essens, 1985). In information processing theories, rhythm perception is seen as a linear input–output process, in which temporal events are encoded as abstracted information, which is subsequently translated to cognitive representations or motor programs. By contrast, DAT shares important links with the ecological theory of perception (described in more detail below), which views perception as occurring reciprocally between the perceiver and the environment. Modelled on resonance theory, DAT proposes that temporal perception resembles the process by which two or more self-sustaining generators of rhythm (or pulse) achieve a degree of synchrony. In rhythm perception, these oscillations are attentional processes, which rely on spontaneous temporal expectations afforded by the music to frame the perception of the rhythm. These expectations are tuned to both the period (tempo) and the phase (onset) of the attending processes, properties which are shaped reciprocally between the perceiver and the rhythmic stimulus. Importantly, the self-sustaining attentional processes and spontaneous temporal expectations in entrainment are what enable the perception of metric events in the absence of phenomenal pulse events in syncopation.

Entrainment as a process was first addressed in physics, after the seventeenth-century mathematician and physicist Huygens discovered that two unsynchronised pendulum clocks placed on a common support would eventually synchronise their periodicities (Clayton et al., 2004). This phenomenon can also be identified in biological processes (e.g. the circadian rhythm). For a while, entrainment was seen as a theoretical

metaphor for rhythm and metre perception, but not as a real underlying mechanism. However, recent studies have shown that dynamic oscillations in the firing patterns of neural networks in the brain exhibit entrainment-like behaviour, suggesting that DAT is neurophysiologically anchored (Nozaradan et al., 2011).

Conceptually, entrainment is the process by which an independent oscillating periodicity adapts in phase and period to another oscillating process, to achieve a degree of synchrony. Crucially, this process of adaptation distinguishes entrainment from simple synchronisation. For entrainment to occur, one oscillating periodicity must be *driven* or *captured* by another, by the shifting of phase and/or period, while synchrony can occur by chance and requires no adaptation. Synchrony is often the end state following entrainment, but it need not be strict synchrony, as long as there is a consistent relationship between the coupled periodicities. An example is anti-synchrony, in which two oscillations have the same period, but the phase of one is exactly counter to the phase of the other. In such cases, where the period and phases are constant, the two oscillations are said to be *phase-locked.* Synchrony is a special kind of phase-locking, in which the constant phases are perfectly aligned in the two oscillations.

There are also different forms of entrainment, and an important distinction is drawn between uni- and bi-directional coupling. In the former, only one periodicity is being driven and entrained. This kind of entrainment happens to a listener's attention when tuning into the pulse of a musical rhythm, or a dancer's body-movements in sensorimotor synchronisation to music, because the shifting in phase and period only happens one way (in the listener or dancer). Bi-directional entrainment happens between two or more periodicities, and here the coupling is mutual. It can occur during communal clapping in a concert hall, when individual clappers start off with separate periods and phases, but through sensorimotor feedback become entrained to each other to produce one

synchronised pulse. Bi-directional coupling is the property of DAT that gives rise to the perception of metre. For example, when two mutually coupled oscillators are phase-looked and have a period-relationship of 2:1, a sense of duple metre occurs.

Some research also distinguishes between entrainment that occurs in the context of one, two and more than two individuals (Phillips-Silver et al., 2010). Self-entrainment occurs when an individual responds rhythmically to a self-generated rhythmic signal, for example when a musician synchronises her motor-expressive movements on the fiddle to the stomping of her foot. Social entrainment denotes instances in which the attending processes of an agent are entrained by those of another, such as when a soloist in an orchestra follows the rhythmic gestures of the conductor. When there are two agents who both entrain to each other, the entrainment is mutual, such as between a singer and his accompanist in a jazz duo. Finally, collective social entrainment occurs among larger groups of individuals, such as between all the members of a chamber ensemble. However, although these different forms of entrainment can be separated conceptually, there are instances in which more than one might be at play. For example, in the chamber ensemble, the second violinist might self-entrain to her own foot-tapping, while also coupling with the rhythms of the first violinist, as well as the rhythm and metre of the music played by the ensemble as a whole.

In the present research, DAT offers a theory of the mechanism underlying metre perception, body-movement and pleasure in groove, in the context of individual experience and uni-directional entrainment (i.e. between the listener/dancer and the music). However, although interpersonal entrainment is not studied empirically, the theory (along with broader ecological and embodied theories of cognition) allows for the consideration of social dimensions to groove and dance, even in the absence of bi-directional coupling between one individual and another. Due to the active nature of groove experience, as

grounded in body-movement, and the social associations of music in general and groove in particular, entrainment is always social, in some respect. Music and groove are created in social contexts, at least in a cultural sense, and are primarily enjoyed among groups of people. This social dimension is thus always latent in the music and the experience, making the distinctions between self-, mutual, social and collective entrainment only operational at a descriptive level.[6]

1.6 Syncopation and Expectation

The reliance on expectations in dynamic attending can explain how metric events are perceived despite momentary absences of phenomenal pulse events. The self-sustainability of the attending processes produces expectancies about the phase of a periodic pattern, and when a rhythmic stimulus violates this expectation, the result is a perceptually grounded experience, which can signal meaning. Expectancy violation theory (discussed below) is widely cited as accounting for emotional arousal induced by music, and there are a number of structures in groove that can be understood as stimulating expectation. For example, microtiming often characterises the rhythmic design of groove-based music and is most often defined in terms of microtemporal 'deviation', (e.g. Gabrielsson, 2003; Iyer, 2002).[7] Displacement is another structural strategy often featured in groove-based music whereby expectations are stimulated on the basis of the music's metric framework. However, *syncopation* is perhaps the most studied of expectancy violations in rhythm. Although it has been analysed in the context of specific genres, such as rock (Temperley & Sleator, 1999), funk (Danielsen, 2006) and EDM (Butler, 2006), the majority of studies interested

[6] This covert sociality of music is considered again below, in connection with embodied theories of cognition.

[7] However, some recent theoretical analyses of groove-based music treat microtiming less as deviations from strict grid-points and rather as a product of dynamic attending (Carlsen & Witek, 2010), or otherwise treat pulses as broader, less point-directed categories (Danielsen, 2010a). From this perspective, the tension generated by microtiming is not a result of deviations from grid-like frameworks, but from cross-layer rhythmic relationships.

in the psychological processes behind syncopation have used simple generic rhythmic patterns.[8] In 1984, Longuet-Higgins and Lee published a theory that has been highly influential in shaping the study of syncopation. Their model assigns weights to each event in a rhythmic pattern based on a model of metric salience derived from the hierarchical metric tree-structure of Lerdahl and Jackendoff's *Generative Theory of Tonal Music* (1983). The higher up in the metric hierarchy, the stronger the weight of the metric location and the greater the expectation that an event will occur at that point. Importantly, at different hierarchical levels, the metrically strong locations provide the framework for the pulses embedded in the rhythm, and the main pulse in particular. Rests, on the other hand, are expected to occur at metric locations with lesser weight. The authors state that syncopation works by virtue of violating these expectations; that is, when rests occur at metrically strong locations, and events occur at metrically weak locations. Acoustically, the result is a momentary physical absence of a pulse event, or a metric event without a phenomenal event, and a perturbation of the regularity of the rhythm.

Based on this theory, Longuet-Higgins and Lee (1984) developed an index by which the relative salience of syncopated patterns – or a pattern's syncopation degree – can be specified, based on the relationship between metric weights of events and rests in a rhythm. As will be reviewed in Chapter Three, many researchers have used Longuet-Higgins and Lee's index to measure the destabilising effect of syncopation on metre perception (e.g. Fitch & Rosenfeld, 2007; Ladinig, 2009). Others have used computational modelling, often relying on large corpora of musical material and calculations of their statistical properties, to define syncopation and its psychological effects (for a review, see Thul & Toussaint, 2008). However, these researchers usually study syncopation in isolated rhythmic patterns and monophonic contexts. This is problematic for the understanding of

[8] Snyder & Krumhansl's study (2001), in which syncopation was studied in the context of ragtime, is a notable exception.

syncopation in groove, since groove is a multi-layered phenomenon. For example, the basic unit of the groove in 'Sex Machine' by James Brown (1970) has syncopations in almost all textural layers (guitar, bass and drums, circled in Figure 1.1). Here, syncopation is manifested polyphonically: while one instrument omits a phenomenal pulse event, another always remains metrically as predicted with a phenomenal event at the metrically strong location. Furthermore, since the basic unit is repeated throughout most of the track, the syncopations provide rhythmic tension from expectancy violation *continuously*, and could thus be expected to become predictable.

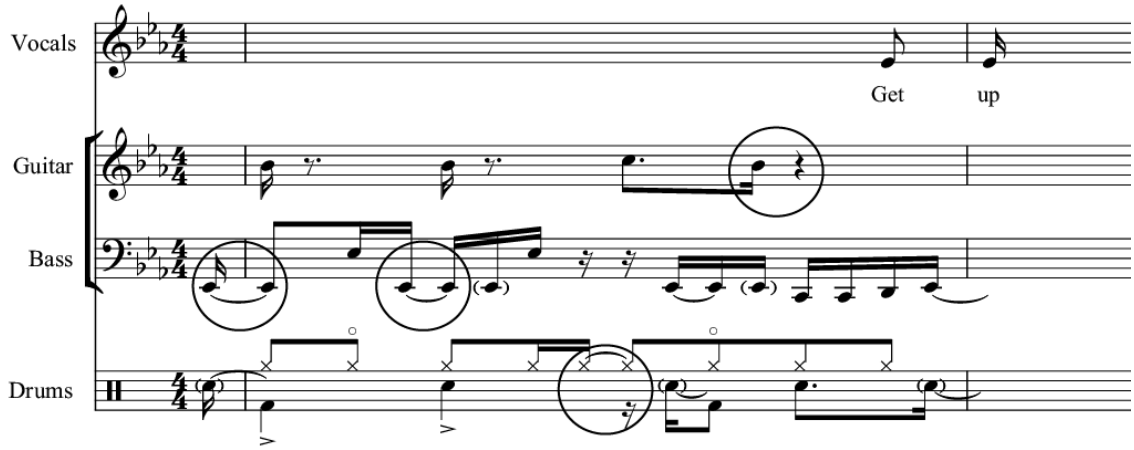


Fig. 1.1 Syncopations in the basic unit of the groove in 'Sex Machine' by James Brown (1970).

Existing computational indices and perceptual theories of syncopation cannot take account of such a contextualisation of syncopation. In fact, if all the textural layers of 'Sex Machine' were defined as one monophonic layer, the syncopations would cancel each other out. Similarly, the repetitiveness of syncopation fundamentally challenges the definition of syncopation as expectancy violation in the first place. Since metric expectations rely on repetition and regularity, it is reasonable to assume that syncopations in groove become expected, due to the high degree of repetition. This phenomenological

problem has been noted by Temperley (2010). He points out that the outcome of his probability model for syncopation depends greatly on the style of the corpus on which the model is based:

> Much twentieth-century popular music is highly syncopated; in such music, we would expect the probabilities of some syncopated patterns to be quite high. What makes a pattern seem syncopated, I would argue, is that it is low in probability in relation to the norms of common-practice rhythm (Temperley, 2010, p. 371).

Thus, Temperley solves the problem by excluding syncopation in highly syncopated music from the definition of 'common music'. However, such an exclusion effectively ignores a substantial portion of music across the world, primarily popular and non-Western genres. Furthermore, it is perfectly possible to account for the continuing effects of syncopation in music in which it is a widespread and repeated characteristic by making use of Bharucha and Todd's (1989) distinction between schematic and veridical expectations. The former refers to the kinds of predictions that Temperley and the majority of other rhythm researchers are concerned with, including those studying DAT. They are low level, unconscious and integrated into perceptual processes. Furthermore, schematic expectations are driven by culturally dependent statistical regularities in the environment. Veridical expectations, on the other hand, are consciously manifested and depend on a person's explicit engagement with the music. They are shaped by individual experience and depend on the immediate musical context, rather than the statistical regularities of music as a whole. Schematic and veridical expectations can be conflicting, such as when a piece of music contains events that are schematically atypical, yet veridically conform to the piece's common structure. Thus, it is possible that in groove, syncopations have a certain perceptual effect on expectations at a schematic level, while they function in other ways veridically. For example, while syncopation might be related to perceptions of stability in a

certain way at a schematic level, modulations may occur based on subjective appraisal due to consciously experienced effects, such as movement-induction and pleasure.

While the distinction between schematic and veridical expectations eases the way in which syncopation is defined in groove, it also raises questions about the 'disembodied' basis on which schematic expectations are often understood. If subjective expectations interact with schematic processing of syncopation, then the context in which the subjective experiences are grounded becomes the context in which schematic expectations are perceived. In groove, that context is the body. The desire to move and dance associated with groove makes the structural expectations overt, as opposed to covert, enabling the physical enactment of syncopation. In this way, the rhythm is always perceived and embodied, in the moment as well as in anticipation. The syncopated rhythm is never just a purely mental construct, but is always physically felt and danced. Because the veridical expectations provide the temporal framework within which the syncopations become expected, dancers can synchronise their movements to the main pulse and thus physically embody the metric events without the phenomenal events that the syncopations afford. The body moves from beat to beat, and the violated schematic expectations are realised with the movements of arms, torso, legs and head. Due to the veridical expectations, the tension caused by the violation of the schematic expectations can be physically explored through body-movement.

1.7 Expectation, Affect and Arousal in Music

As mentioned, structural expectations are also related to affective arousal in music. For example, music's ability to send shivers down the spine and make the heart race is believed to result from the stimulation and violation of expectations (e.g. Gomez & Danuser, 2007; Grewe et al., 2009; Grewe et al., 2007; Guhn et al., 2007; Krumhansl,

1997; Ritossa & Rickard, 2004). In psychology and biology, such responses are referred to as the 'fight, flight, freeze responses', as their primary function is to arouse the autonomic nervous system when faced with surprising and potentially threatening situations. The majority of researchers investigating music-induced autonomic arousal have studied 'chills', which are momentary pleasurable somatosensory responses, also referred to as 'shivers' or 'goose pimples' (see Grewe et al., 2009, for a review). The tendency for music to elicit 'chills' is consistent with Meyer's theory of expectation (1956), in which he proposed that emotional arousal is achieved through stimulation of perceptual expectations towards structural events, which he called 'tendencies' in music. By inhibiting, deviating from or delaying the fulfilment of structural tendencies, the expectations of the listener are frustrated and feelings of instability occur. More recently, the theory of expectation has been developed by Huron (2006), whose focus is on the *prediction* of structural events in music and the ways in which predictions are psychologically rewarded:

> Accurate predictions help an organism respond better to expected events than unexpected events. When a stimulus is expected, appropriate motor responses are initiated more rapidly and more accurately. In addition, a stimulus is more accurately perceived when it is predictable. Since accurate predictions are of real benefit to the organism, it would be reasonable for psychological *reward and punishment to arise in response solely to the accuracy of the expectation.* Following a storm, for example, I might predict that I will slip and fall on the sidewalk. In the event that I actually fall, the outcome will feel unpleasant, but the experience will be mixed with a certain satisfaction at having correctly anticipated this dismal outcome. This expectation-related emotion might be dubbed the *prediction response.* When the stimulus is expected, the emotional response is positively valenced; when the stimulus is unexpected, the emotional response is negatively valenced (Huron, 2006, pp. 12–13, italics in original).

In similar ways, being able to predict musical structure will elicit this positive prediction response. Huron suggests that deviations from predictions of musical structure elicit pleasure due to the pleasant contrast between the initial 'fight, flight, freeze' response,

which is a cue for avoidance and defence, and the immediately following cognitive appraisal of the situation as non-threatening.

The contrast between negative physiological responses and positive subjective appraisal alludes to the complexity of the relationship between musical structure and affective experience. For example, recent discussions consider the apparent paradox of sad music, questioning the motivation to listen to music that elicits an emotion that people normally avoid in everyday life (Huron, 2011). Furthermore, the source of emotion in musical structure is difficult to determine. Although the 'chill' effect is compatible with the expectation theory of musical emotion, replicable physiological arousal caused by specific musical structures has been hard to produce. Finally, although a number of studies show that certain kinds of music reliably elicit categorical emotions, such as happiness and sadness, the elicitation of other basic emotions, such as anger and fear, has been more difficult to demonstrate (Juslin & Västfjäll, 2008). Therefore, some researchers favour the circumplex model of emotion, in which feelings are mapped onto a two-dimensional space of arousal (low to high) and valence (negative to positive) (Russel, 1980).

The most influential two-dimensional model is Berlyne's theory of *Aesthetics and Psychobiology* (1971). He proposed that affective–aesthetic response to art is grounded in arousal (physiological responses) and activation (behaviour), which result from relationships between intrinsic sources of energy in visual and auditory structures. Rather than describing the associated discrete emotions, Berlyne modelled the evaluative pleasure, or *hedonic tone*, from the intersection of activation and liking. Accordingly, music's level of intensity, representing for example rhythmic complexity or loudness, can be modelled against valence. Berlyne insisted that people prefer intermediate levels of intensity in art. A number of studies have found such an *inverted U-shape* (otherwise known as the negative quadratic curve, or the Wundt curve) between structural complexity and liking in music

(North & Hargreaves, 1995; Orr & Ohlsson, 2005). The inverted U-shape (Figure 1.2) demonstrates that as activation intensifies with increasing complexity, the evaluative response moves towards the positive pole on the axis of liking, until the complexity becomes too intense and the pleasurable response reverses towards disliking. In fact, Berlyne opposes the view that music can represent and induce extra-musical concepts, such as emotions, and argues that its primary purpose is to express the realisation of and induce pleasure from autonomically related structures. Although more recent empirical studies of the induction of emotions from music dispute this claim (e.g. Juslin & Västfjäll, 2008; Zentner et al., 2008) and the autonomy of sources for emotion in music are challenged by ecological and embodied theories of cognition (e.g. Clarke, 2005; Johnson & Larson, 2003), Berlyne's theory and the inverted U-shaped relationship between complexity and liking remain influential in the study of music and affect.

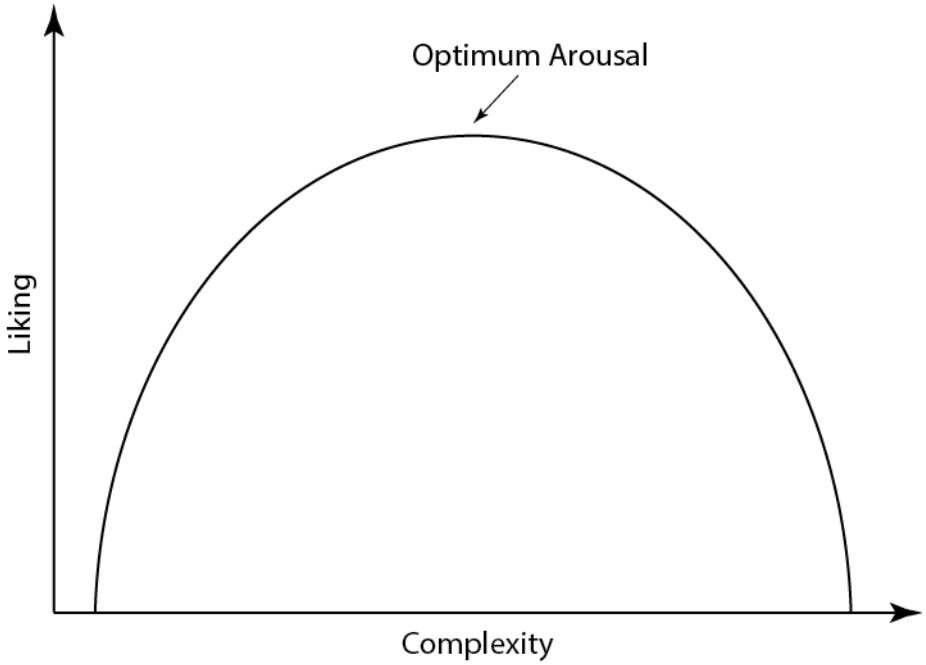


Fig. 1.2 Inverted U-shaped relationship between complexity and liking.

1.8 The Pleasure of Music, Dance and Groove

Defining affective experience in terms of levels of complexity and hedonic tone, or *pleasure*, as opposed to discrete emotions such as happiness versus sadness, may be more appropriate in musical contexts in which complexity is a primary structural characteristic. In this regard, the rhythmic complexities of groove, such as syncopation, may be more easily modelled within the two-dimensional space of intensity and liking. Furthermore, pleasure is often used to describe more broadly positive feelings, which are rooted in the bodily senses. Thus, the term lends itself to the description of the positive drive towards body-movement associated with groove-based music. Furthermore, the motivational aspect of pleasure can more accurately capture the *desire* to move that people experience with groove. However, despite widespread acceptance of its fundamentality to human functioning, pleasure has proved to be a complicated phenomenon to understand and study more broadly. This is reflected in the definition provided in the Oxford Dictionary of Philosophy:

> A surprisingly complex concept, although central to any account of human and animal motivation. Perhaps the simplest theory of pleasure treats it as being on the same dimension as pain: a bodily sensation, but of a positive kind, where pain is of a negative kind. This, however, fails to account for cases where we take pleasure in an activity or from receiving a piece of news, when nothing like a pleasurable taste or other sensation is apparent (…). Pleasure seems more to be a quality of consciousness, intimately connected to contentment or happiness, rather than another element within conscious experience (Blackburn, 2008).

The bodily aspect of pleasure is central to the definition, but its biological motivational function can be less clear in certain situations. Note also that pleasure is thought to be associated with happiness, but is also separate from this discrete emotion, due to pleasure's dynamic and embodied properties. The embodiment of pleasure can also have sexual

connotations, which has been of primary interest to certain philosophers and psychoanalysts (e.g. Freud, 1955; Lacan, 1992).[9]

Despite these phenomenological challenges, recent empirical advances in cognitive neuroscience have been able to draw a distinction between what are called 'fundamental' and 'higher-order' pleasures (Kringelbach & Berridge, 2009). The former are grounded in the senses and function at a low and largely automatic level. The evolutionarily advantageous effects of fundamental pleasures, such as food and sex, are underpinned by what is known as the *reward system* in the brain, which involves activation in regions including the basal ganglia, the anterior inferior insula, the anterior cingulate cortex and the orbitofrontal cortex (OFC), and are associated with the release of the neurochemicals dopamine, serotonin and endorphins. Behaviour that increases the chances of survival for an individual, its group and its species will be rewarded by the brain via neural activity resulting in feelings of pleasure (Kringelbach & Berridge, 2010). This is why activities that are the most important evolutionarily are also the most pleasurable, such as consuming food and having sex. 'Higher-order' pleasures are more contextual and dependent on conscious engagement. Such pleasures are associated with activities involving monetary, social, religious and artistic rewards. Despite the apparent lack of direct relevance for survival, such pleasures activate the same areas in the brain as those that are more fundamentally biological (see Kringelbach & Berridge, 2010).

A number of studies have found that musical 'chills' correlate with patterns of activity in areas of the brain associated with fundamental pleasures (e.g. Blood & Zatorre, 2001; Brown et al., 2004; Koelsch, 2010; Menon & Levitin, 2005; Salimpoor et al., 2011). Furthermore, there are a number of aspects of musical engagement which can be seen as

[9] In this regard, it is noteworthy that funk, a form of groove-based music, can also have sexual undertones, as reflected in a number of funk song titles (e.g. 'Sex Machine' and 'Body Heat' by James Brown) and in the discourse surrounding 'the black body' as 'other' in Western views of African-American music (e.g. hot jazz). Sexual connotations are also mentioned in the definition of groove in the New Grove Dictionary of Jazz (Kernfeld, 2009).

beneficial to the human race (see Cross, 2009, for a review). For example, music-like properties are said to characterise the communication between a caregiver and her/his baby, and it is suggested that without such interpersonal attunement at the early stages of life, humans are less likely to develop appropriate social skills (Dissinayake, 2001). Another example regards sexual selection: it has been proposed that music lends itself particularly well to the demonstration of physical fitness and creativity during courtship (Miller, 1997).

The aspects of music that are most often considered for their potential evolutionary functions are sensorimotor synchronisation and entrainment. In general, synchronising body-movements in interpersonal contexts has pro-social effects, such as promoting liking (Hove & Risen, 2009), helping and cooperation (Kirschner & Tomasello, 2010). It is thought that the shared sense of embodied time afforded by social sensorimotor entrainment promotes collectively represented intentions and goals, which satisfy the human desire to share emotions, experiences and activities (i.e. higher-order pleasures). It has also been suggested that synchronising body-movements and vocalisations, the sum of which is louder than the separate contributions of individuals, can signal the strength and size of a social group, enhancing the 'competitiveness' of the group as a whole (Bispham, 2006; Merker et al., 2009). Thus, the pleasure of synchronising movements to music, such as in dance, not only *occurs* in social contexts, but might also exist in the first place to *promote* social interaction. However, even if there once was an evolutionary origin of sensorimotor synchronisation, the pleasures that characterise the experience of dancing to music today are much more complex and rich than the sum of these biological processes. In particular, the cultural contexts in which people dance together, ranging from sound-system street parties in Kingston, Jamaica (Henriques, 2008) and the 'higher' places to which Sufis are transported during trance (Becker, 2004), to the warehouse raves escaped

to by socio-economically disillusioned British youths in the 1980s (Gilbert & Pearson, 1999), involve music and social behaviour whose criteria for what is pleasurable are profoundly dependent upon context. Nonetheless, despite being aesthetically differentiated across cultures, an argument advanced in this thesis is that all of these effects are in some way rooted in underlying psychobiological effects, such as social bonding in sensorimotor synchronisation, which form a crucial basis for more culturally specific phenomena.

Cognitive neuroscience has also been able to distinguish between different components of a pleasurable experience. With regard to both fundamental and higher-order pleasures, there are separate stages of 'wanting', 'liking' and 'learning', which are said to constitute the 'pleasure cycle' (Berridge & Kringelbach, 2011). Figure 1.3 (adapted, with permission, from Berridge & Kringelbach, 2011) presents the classic reward cycle, as well as suggestions for how such a cycle might reflect music-elicited pleasures in particular. Typically, rewards are processed dynamically, with initial expectation and 'wanting' for the reward, which is subsequently consumed and 'liked', sometimes leading to a 'peak' experience, such as during sexual orgasm, a drug-induced rush or winning a bet. Eventually, the consumption leads to satiety and 'learning', during which our knowledge of the processes involved in achieving the reward is adjusted and strengthened. At the neural level, the 'wanting' is encoded as prediction, the 'liking' and the 'peak' are the result of neural evaluation, and the 'learning' period is underpinned by prediction-error monitoring in the brain. Neurophysiologically, it has been shown that the anticipation of food reward ('wanting') recruits the dopamine system, while the consumption of food reward ('liking') involves other neurotransmitters, such as opioids (Berridge, 1996; Smith et al., 2010). Subsequently, the 'learning' period is underpinned by prediction-error monitoring in the OFC. During music-listening, the anticipation of large-scale structural changes corresponds to the 'wanting', the 'chill' occurs at the culmination of increasing

'liking', after which a period of tension release and 'learning' mediates the association of the music with the rewarding experience. This 'musical pleasure cycle' has been demonstrated at the neural level by Salimpoor et al. (2011), who showed that the *anticipation* of a music-induced chill correlated with increased activity and dopamine binding in the caudate, while the *experience* of the chill was associated with more activity in the Nucleus Accumbens (NAc).

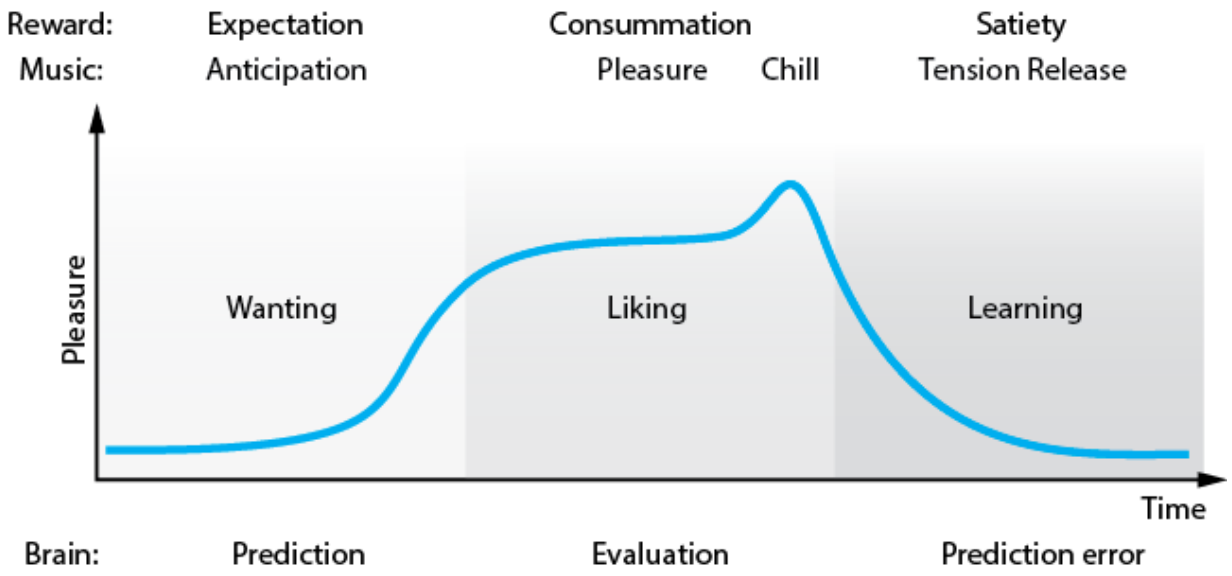


Fig. 1.3 Reward and musical pleasure cycles, dissociating dynamic components of 'wanting', 'liking', 'chill' and 'learning' during experiences of reward, according to psychological (top panel) and neural processes (bottom panel).

In groove, the 'wanting' part of pleasure might be seen as corresponding to the desire to move the body, while the 'liking' is perhaps the satisfaction experienced during dancing. However, it is unclear to what extent the groove pleasure cycle can be divided into such distinct processes, as the desire must persist in order for dancing to be enjoyed throughout the groove. As there is no defined 'peak' moment in the groove,[10] but rather a

[10] Pieces of groove-based music may of course include peaks, as has been studied previously (Witek, 2009), but these often occur across the repeated groove, and not within it.

web of constantly repeating cross-rhythmic relationships, it is likely that a groove pleasure cycle will look different compared to conventional pleasure cycles, and that the dissociations between 'wanting', 'liking' and 'learning' are more blurred. In fact, rather than conceiving of groove pleasure as having distinct and cyclical stages at all, it might be better conceptualised as a process in which 'wanting', 'liking' and 'learning' are distributed more equally across the process (Figure 1.4).[11] Such a groove process fosters a dispersing of music, body and mind during which rhythmic complexity, wanting to move and pleasure are interwoven, and the dancers' attending processes and body-movements become part of the groove itself.

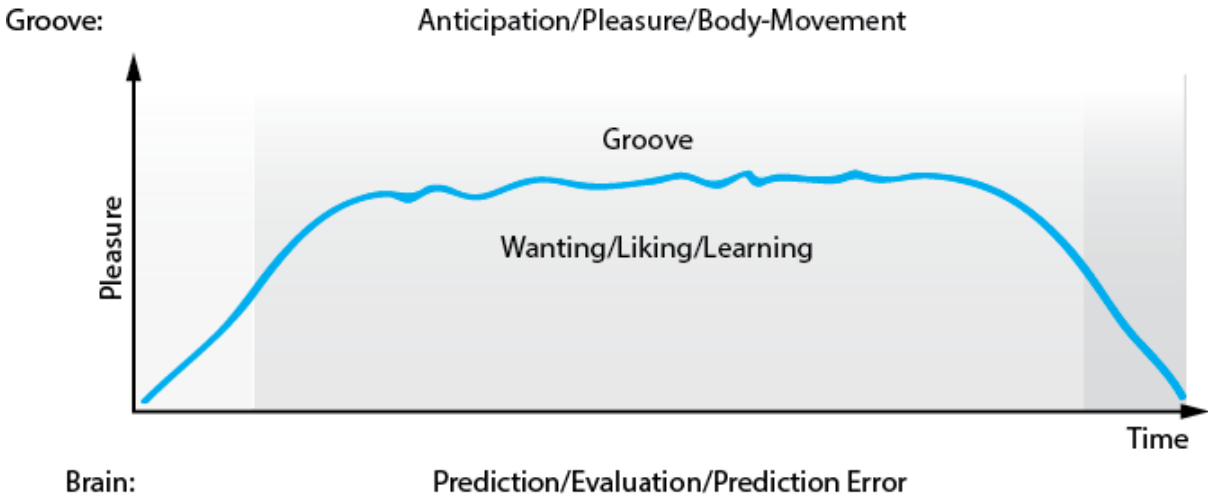


Fig. 1.4. Groove pleasure process, in which 'wanting', 'liking' and 'learning' phases are distributed across the psychological experience of anticipation, pleasure and body-movement (top panel) and at the neural level of prediction, evaluation and prediction error (bottom panel).

[11] Groove is, of course, cyclical, but it is the basic unit, structurally, which is cyclical, and not the different processes involved in pleasure.

1.9 Musical Background

In this distributed process, the dancer brings a number of skills, preferences and personal characteristics, which shape the engagement with the music. In any type of behaviour, relevant skills and knowledge that make someone an 'expert' cause differences in perception and cognition. In music research, privilege has been given to the explanatory significance of musical training, so that in studies concerned with the perceptual effects of syncopation, it is common to investigate the effect of musical expertise on sensorimotor accuracy in tapping performance. Generally, it is expected that the more trained a participant is, the more accurately a rhythmic task is completed.[12] Typically, researchers have recorded the number of years of formal instrumental/vocal tuition, the age at which tuition began, the intensity of training, and the number of live performances attended (Ollen, 2006). Another common method is to measure musical proficiency directly, via rhythm-, melody- and memory-tests (e.g. Radocy & Boyle, 1987; Wallentin et al., 2010). However, there are a number of 'new' musical skills, often associated with popular music genres, which are rarely included in traditional questionnaires about musical expertise. These include DJing and digital music production, which are often self-taught.[13] In many forms of groove-based music, such as hip-hop and EDM, these skills are more relevant than the ability to play an instrument. Furthermore, a shift has recently occurred in the understanding of musical competence. Rather than favouring performance and theoretical knowledge, such as instrumental proficiency and analytical skill, broader listening competence is more frequently assessed. Even those who have not undergone formal (or self-taught) musical training, and thus might not call themselves 'musicians', have accumulated musical knowledge simply by taking part in cultural activities, through active

[12] However, as shall be discussed in Chapter Three, systematic advantages of musical training on sensorimotor synchronisation accuracy has been difficult to reproduce.

[13] Music production, however, is increasingly taught at music colleges and academic institutions.

music listening and passive exposure. Thus, some of the most recent psychometric tests of musical expertise treat musicality as a multi-faceted ability that is shared among the wide majority of an enculturated population (e.g. Müllensiefen et al., 2012). In addition to the more traditional quantifications of formal training, and testing of rhythmic and melodic perceptual skills, the ability to categorise music according to genre, self-perceived emotional, embodied and social engagement with music and more general musical enthusiasm are now more frequently recorded. For the present research project, for example, measuring familiarity with groove-based music and frequency and enjoyment of dancing to music might be rather more informative than the number of years and the intensity of musical tuition. Such an ecological view of expertise not just understands musicality as highly refined perceptual, motoric and analytical skills acquired through playing an instrument and learning music theory, but equally considers sophisticated perceptual, motoric and analytic abilities gained through active listening, dancing and informal conversation in musical cultures and subcultures.

1.10 Ecological and Embodied Theories of Perception

Such a broadly active view of perception resonates with ecological and embodied theories of perception and cognition. The *ecological* approach to perception posits that sounds, musical as well as 'everyday', specify events and sources in the environment to which perceivers are attuned through exposure. This attunement comes about through 'perceptual learning', a process by which sensitivity to the environment develops gradually through progressive differentiation. In this way, perceivers become increasingly sensitive to the statistical properties of the world around them.[14] Thus, perception occurs within a mutual

[14] 'Statistical learning' is another way of describing similar mechanisms. Although not strictly ecological, it describes knowledge acquired through exposure, in which the frequency of events provides the foundation for pre-conscious learning (Huron, 2006).

relationship between the perceiver and the environment. Furthermore, objects and events in the environment are perceived on the basis of their *affordances.* First proposed by Gibson (1979), affordances are forms of 'functions' or 'meanings', but with a strongly 'active' component. This relationship between action and perception is central to the theory. In this sense, music is perceived in terms of what the perceiver can 'do' in relation to it, and not what it represents. Following on from Gibson's work, Clarke (2005) demonstrates how music affords, and how the concept of 'source' is not just specified by psychoacoustic properties, but is shaped by perceptual and cultural context, in a multimodal way. In fact, according to the ecological view, action tendencies are the most natural response to encountering perceptual information in the world, and action is the most effective way of learning. As Clarke points out, many forms of responding to music fit into this claim, dancing perhaps being the most obvious.[15] Furthermore, the reciprocity and attunement between perceiver and environment, and perception and action, questions the input–output approach to rhythm perception and sensorimotor synchronisation and echoes the mutuality and resonance between stimulus and attending processes posited in DAT. According to ecological theory, syncopation in groove affords the perception of metric events, the desire to move, feelings of pleasure and dance. All these affordances are the components of groove, manifested reciprocally between the 'external' music, the body and the mind. Groove's perceptual meaning emerges on the basis of the interaction between the perceiver and the music, both in the moment and based on previous experiences and enculturation. Furthermore, the absent pulse onsets in syncopated grooves are not induced, but fully *perceived*, due precisely to the actions (both overt and covert) they afford. And through

[15] Other examples given by Clarke are worship, co-ordinated working, persuasion, emotional catharsis, marching and foot-tapping.

body-movement, the pulse onsets are no longer absent, but fully present in the body of the listener/dancer.[16]

In *embodied* theories of cognition, this fluid and reciprocal relationship between the environment, the mind and the body is also central. Resisting traditional mind/body dualism, 'thinking' is seen as something in which the body is integrally engaged, rather than something that is the province of a disembodied mind – the results of which are then transmitted to an unthinking body. A cautious approach to such notions is expressed in Barsalou's theory of the Perceptual Symbol System (PSS) (Barsalou, 1999, 2008). His claim is that what underlies human intelligence is symbolic operation, which provides a system for interpreting experience. However, rather than being semantic, the concepts that form the basis for the symbol system are perceptual images grounded in experience.[17] His idea is that the experience of something, for example a dog (Barsalou, 2008), activates a number of modal systems (e.g. sight, smell, hearing, touch), which are 'captured' by the brain and integrated into higher-order multi-modal neural representations of the experience. Later on, when simply thinking about dogs, the same neurons, which were active during the experience, will be partially re-activated. In this way, cognition is the *simulation* of previous experience. In his theory of motor cognition, Jeannerod (2006) develops the idea of a simulation network for action representations, such as imagining actions, recognising tools, learning by observation and even understanding the behaviour of other people. Thus, when observing an action performed by another agent, that action is simulated by the motor system in the brain and provides information about the intention

[16] Clarke uses the ecological approach to analyse the trip-hop music of Tricky (Clarke, 2010). Here, the music is groove-based and embodied, but not dance music. Through notions of affordance and autonomy, this ambiguity is thought to afford a unique kind of perception and listening, which resists entrainment yet is powerfully corporeal. Thus, Clarke shows that even in the apparent absence of obvious action-tendencies, the ecological view can accommodate the many rich, complex and sometimes contradictory forms of musical experiences.

[17] Images in this sense are not confined to the visual domain, but should be thought of as cognitive objects, concepts or situations.

and *meaning* of the actions. In a related manner, Molnar-Szakacz and Overy (Molnar-Szakacz & Overy, 2006; Overy & Molnar-Szakacs, 2009) propose that simulation might explain the ways in which listeners experience music. Rather than perceiving sounds as purely acoustic signals, we perceive them as the expressive and affective actions and bodily gestures of music performers.

Although the simulation hypothesis is an important contribution to the general understanding of cognition as grounded in the body, it seems limited in fully accounting for embodied music cognition. For example, in dance, nothing is simulated but rather is fully and actively enacted in the moment. Zbikowski (2004) attempts to account for the ways in which groove elicits body movement by appropriating Barsalou's PSS theory and the notion of simulation. He claims that the concepts of regularity, cyclicity, differentiation, and feeling of strong embodiment guide our understanding of musical rhythm through cross-domain mapping. In other words, musical rhythm feels like rhythmic movement because musical rhythm is structurally similar to human movement. Nonetheless, this theoretical reasoning implies an understanding of movement as *indirectly* elicited by music through mapping and representation. This indirectness seems to be a natural consequence of understanding cognition as simulation. It implies that cognition is *almost, but not quite* like 'real' perception and action, and the problem with such a representational aspect of cognition has not gone unnoticed. For example, Damasio (1999) critiques the traditional understanding of representation in his embodied theory of consciousness:

> The problem with the term representation is not its ambiguity, since everyone can guess what it means, but the implication that, somehow, the mental image or the neural pattern *represent*, in mind and in brain, with some degree of fidelity, the object to which the representation refers, as if the structure of the object were replicated in the representation (Damasio, 1999, p. 320, italics in original).

Rather than simulations or replications, Damasio views cognition as 'mental images' embedded in the sensorimotor interaction of the body with the environment. In a closely related approach, Edelman (1992) describes in detail how the synchronised firing of neurons in the brain can translate to situated experience, as opposed to the abstracted maps or representations of conventional cognitive science. Edelman achieves this by combining neuroscientific evidence with phenomenological perspectives on the 'mind as matter'. Opposing the Cartesian duality between mind and body, the brain is described in terms of its interconnected neuronal maps whose connections are dynamically shaped by experience.

This bridging between theories of consciousness and neuroscience has its musical counterpart in a theory proposed by McGuiness and Overy (2011). They claim that, due to the shared sense of pulse afforded by mutual, social and collective entrainment, and the potential for emotional contagion between listeners, players and dancers, music is primarily experienced as a pre-reflective kind of co-subjectivity in which the agency and individuality of the perceived subjects are covertly manifested. Such pre-reflective co-subjectivity may develop into more consciously expressed inter-subjectivity, which then functions as a more direct communication of intentions, goals and semantic meanings (akin to language). Underpinned by the Mirror Neuron System in the brain, which is a network of brain cells that are thought to fire equally when an action is executed *and* observed, imagined or predicted (Gallese & Goldman, 1998), music is embodied via the innate and universal perception of culturally contextualised gestures. Taking this further, they suggest that musical experiences exist in preconscious states, before the self is distinguished from the other, as there is no conscious acknowledgement of another agent or intention. In this state, music mirrors agency and intentionality without necessarily representing another person. Thus the latently social dimension to music is central to the very basis upon which

it is experienced. Importantly, this is also how emotions are perceived and experienced in music. Because of the gestural component of emotion, music can 'mimic' those gestures normally expressed during human emotion. The authors propose that through emotional contagion, as mediated by neural activity in the anterior insula in the brain, emotions are induced in the listener. According to this view, the experience of groove combines the dancer's own pleasurable body-movements with the rhythmic and affective gestures suggested by the music itself; and the social dimension of groove lies not only in the direct engagement between dancers in a dance club, but also within the relationship between the individual dancers and the rhythmic pulse.

The embodied approach to cognition has been taken even further. For the philosopher Andy Clark, there is no boundary between mind, body and world. In his Extended Mind Theory (EMT) (Clark, 2008), cognition is a unified system in which the mind and the world are coupled, and material things that are used in aiding cognitive processing are not simply 'tools' but fully part of that cognitive process. Clark offers the imaginary example of Inga, who remembers how to get to the Museum of Modern Art in New York in the usual manner; and Otto, who has Alzheimer's disease, who consults his notebook for the same purpose. Although Inga's memory is 'internal' and Otto's notebook is 'external', according to EMT, there is no fundamental difference between the two, as long as the consultation of the notebook and the memory serve the same function. The fact that Otto's circumstances involve overt perception and action only reinforces the point that perception and action are fully integrated in cognition. Clark's theory thus takes the anti-dualist approach to mind and body to the extreme, by stating that in certain contexts, there is no real or fixed boundary between our internal minds and the external world. He proposes that language is central to extending the mind into the world, and crucially that it enables social coupling, and we might consider music as serving a similar function. In

music, mind, body and musical structure are distributed, and through performance, musicians extend into other musicians and listeners, and listeners extend into musicians and other listeners, via the music. In groove, the attending processes and dancing bodies extend into the syncopated rhythms, and the body *is* the groove, both structurally and cognitively. This helps to overcome the uncomfortable gulf between 'groove' as used to describe the music, and to describe the psychological process. At least in the context of groove, this more literal, rather than simulated, embodied view of cognition better describes the experience. It can also account for groove experience in social contexts, such as in a dance club, where the process is also distributed across socially interacting people. Here, the syncopated groove provides a social site in which people's minds and bodies extend interpersonally and (sub)culturally.

1.11 Phenomenology of Groove

Bodily pleasures are central to Danielsen's writings on the experience of the funk groove (Danielsen, 2006). However, as with many other forms of Black music, she claims the corporeal and sensual attraction of groove among white Western fans and scholars is in danger of reducing funk and other African-American genres to non-reflective, 'barbaric' music. The racial charge of groove, she says, is a result of the long tradition in the West of living out the 'internal other', or the prohibited pleasures of the body, by fetishising the cultural 'external other'. In particular, African-American rhythm has remained a means of catharsis in the West, through its 'raw, unmediated nature' (Danielsen, 2006, p. 214).

Aware of these pitfalls, Danielsen analyses 'the groove mode of listening' and its temporal and embodied dimensions. Adopting hermeneutic and phenomenological notions of time, listeners are described as being immersed in an 'eternal present', in which expectations of future structural development and retentions of passing musical events are

non-linear, and in equilibrium. Because the music is repetitive, the listener's attention is directed inwardly, to what is happening in the moment. However, grooves are never static, and in ways that echo psychological notions of dynamic attending and entrainment, the groove mode of listening involves 'moving together with the groove':

> (…) [A] groove does not stand still. Even though it is unchanging, consistent and of a potentially infinite duration, even though the principles of making it are almost given in advance (…), and even though the groove is not proceeding towards a definite goal, it is – to the last degree – in motion. The groove is in fact changing all the time – it moves, but the movement is repeated time and time again (Danielsen, 2001, p. 164).

Thus, motion is central to music, mind and body in groove. However, the bridging of the mind–body gap does not result in an overemphasis on the body and a neglect of the mind:

> The meaning of funk is still to be found in the interaction of music and body, in how the music hits the body. However, it may no longer be that easy to reduce the funk to its supposedly barbaric nature. The state of being in funk may rather be interpreted as an experience not of being out of place, out of time, but *in place, in time*. When connected to the groove, it is not its barbaric nature but rather its deliberate form that causes the particular sensational state of the body that is the right feeling (Danielsen, 2006, p. 214 , italics in original).

Danielsen traces the non-linear way of listening to groove back to its African origins. Building on ethnographic and analytical descriptions of African music by Chernoff (1979) and Nketia (1975), the experience of groove is described as a conversational and participatory one in which the rhythm and the listener relate to each other reciprocally. The main pulse of the rhythm is considered particularly instrumental in fostering this mutual relationship. It forms the basis for how the groove is played, danced and listened to. However, the pulse does not need to be acoustically, or phenomenally, manifested to achieve this goal:

> As Chernoff says about African Music, "The rhythm that might be considered the main beat of the music is not emphasized. We can say that the musicians play 'around' the beat, or that they play on the off-beat, but actually it is precisely the ability to identify the beat that enables someone to appreciate the music. We begin to 'understand' African music by being able to maintain in our minds or our bodies, an additional rhythm to the ones we hear" (Chernoff, 1979, p. 58, cited in Danielsen, 2006, p. 55).

'Playing on the off-beat' is another way of describing syncopation, and this notion of the importance of the 'internal beat' seems to allude to what is described in the present thesis as the perception of metric events or absent pulse onsets during syncopation. In fact, Danielsen, again quoting Chernoff, notices the significance of 'open spaces' in groove:

> In groove music in particular, the space between the notes seems very important. It is as if the silence creates a tension that locks the groove: the gaps between the sounds create the groove as much as the sounds themselves do. The gaps almost represent a field of power, making the gestures stick to their positions (…). Similarly, Chernoff suggests that it might be fruitful to study music as a pattern of open spaces: *"The music is perhaps best considered as an arrangement of gaps where one may add a rhythm, rather than as a dense pattern of sound"*. At the same time, in principle it seems odd to consider the negative to be more important than the positive. The reciprocal relationship between figure and non-figure renders a preference for one or the other meaningless; their relation is better viewed as fundamentally complementary (Danielsen, 2006, p. 54 italics in original).

Here, the open spaces Danielsen is referring to are likely the rests at metrically salient positions in syncopated rhythm, and there is no more obvious and enjoyable a way to 'add' to a rhythm than with body-movement in dance. Thus, syncopation in groove is a structure that not only emphasises the main pulse, rather than deviates from it, but also offers the reciprocity between listener and music through dance.

1.12 Research Questions and Thesis Outline

Despite the rich body of ideas developed in the literature discussed so far, the perceptual, subjective, neural and corporeal mechanisms which underlie the relationship between

body-movement, pleasure and groove remain unexplored. To what extent does syncopation contribute to the desire to move that is so central to the experience of groove? Since rhythmic complexity and expectancy violation are known to elicit pleasure in music, and pleasure's biological function is to motivate behaviour, what is the relationship between syncopation and pleasure, and to what extent does pleasure motivate body-movement in groove? To what extent can the perception of metric events be said to promote embodied and affective experiences with groove? Finally, as ecological and embodied theories suggest that engagement with music relies on the reciprocal relationships between musical structures, the listener and the environment, what is the effect of musical background on the relationship between syncopation, body-movement and pleasure in groove?

The empirical studies reported in this thesis address different aspects of these broader questions, isolating particular links between syncopation, metre perception, body-movement and pleasure. The methodology of these studies and a more detailed consideration of the theoretical approach are discussed in Chapter Two. As well as addressing the strengths and limitations of each empirical and theoretical method, and the motivations behind the methodological choices and overall project design, the role of psychological experiments and theoretical-phenomenological perspectives in understanding music experience is considered.

Chapter Three reports a study in which the perceptual effect of syncopation is addressed. As existing models of syncopation cannot take account of polyphonic music, and because groove is defined by its polyrhythmic properties, the effect of polyphonic context and instrumentation in syncopated rhythmic patterns of a drum-kit was studied by measuring finger-tapping variability and degrees of perceived stability.

Based on the syncopation study, an index of polyphonic syncopation is proposed in Chapter Four, according to which a multipart drum-kit rhythm can be assigned a degree of

syncopation. Using the results, as well as a model of metric salience, instrumental and metric weights can be ascribed to and combined in syncopations across a drum-break. A number of drum-breaks are considered according to the index, and the 'location' of instability in polyphonic syncopations is discussed.

Chapter Five reports a study in which the index of polyphonic syncopation was used to measure varying degrees of syncopation in funk drum-breaks and the resulting subjective ratings of wanting to move and feelings of pleasure, using an online survey. The drum-breaks were also coded according to a measure of beat salience, and a measure of entropy, and the influence of participants' musical training, groove familiarity and dance experience was examined.

To address the neural relationship between movement-desire and pleasure in syncopated grooves and the role of metre perception, a subset of the drum-beaks was rated while participants' blood-oxygenated level-dependent (BOLD) responses were recorded using fMRI. Chapter Six reports the neural correlates of syncopated drum-breaks, and proposes that networks between motor, perceptual and attentional systems in the brain underpin the embodied and affective experience of groove in ways which interact with individual musical background.

In Chapter Seven, the results from a motion-capture study are reported in which the force, synchrony and periodicity of movements of the lower back and right hand during spontaneous dance to syncopated drum-breaks were recorded. The embodied relationships between musical background, movement force, synchronisation accuracy and metricality of movement are measured and discussed.

Finally, Chapter Eight summarises and interprets the empirical findings of the previous chapters and contextualises the results according to theories of entrainment, musical pleasure and expectation, sensorimotor synchronisation, musical background,

ecological perception, embodied cognition and the phenomenology of groove. A theory of the embodied pleasure of groove is proposed, in which syncopation, the perception of metric events and cognitive distribution occupy central positions. Finally, a methodological discussion sets out the implications of combining scientific and humanistic methods in music research. With the results as a backdrop, this chapter provides a theory of the pleasure of rhythm, syncopation and sensorimotor synchronisation in music, and in doing so contributes to an understanding of musical behaviour more broadly, a behaviour that remains uniquely human and culturally ubiquitous.

CHAPTER TWO

Research Methodology

There are a number of ways in which one might study body-movement, pleasure, groove and the relationship between them. Situated in the field of music psychology, the methods of this research were chosen with the aim of understanding the cognitive mechanisms underlying the experience of groove, with a particular focus on embodied and affective processes, and the relationship between such processes in a phenomenological context. The empirical methods used – perceptual, computational, subjective, neural and embodied – were chosen for their complementarity in a *multi-methodological* sense. Furthermore, embodied, ecological and phenomenological approaches were adopted in order to frame the empirical findings in an *interdisciplinary* way, providing a richer and broader understanding of the relationship between body-movement and pleasure in the experience of groove. In this chapter, each of the empirical methods and theoretical frameworks will be described, the motivations behind using them reported, and their capacity to address the relationship between body-movement, pleasure and groove considered. The order of appearance of the studies in the thesis reflects the order in which they were conducted in the project, the chronology being a consequence of the recursive nature of the main research questions and the resulting gaps revealed in the field. Specifically, asking what characterises the relationship between body-movement, pleasure and groove led to the decision to explore the neural correlates of the reward and motor networks in the brain and measure body-movements in dance (third and fourth studies in Chapters Six and Seven). However, before such direct measurements could be undertaken, a more subjectively manifested understanding of the relationship was needed. Thus, it was decided to carry out

a rating survey, which would explore how movement induction and pleasure are related to groove at a conscious level (second study in Chapter Five). However, in order to study this subjective dimension systematically, the concept of groove was narrowed down to a particular attribute of rhythmic complexity: syncopation. By choosing syncopation, the need for a clear index that could model its effect became apparent (Chapter Four). When no appropriate index of syncopation could be found, a perceptual experiment was designed in order to develop a more suitable measure (first study, Chapter Three). The discussion of these methods will thus appear in chronological order in order to reflect this development, albeit in a 'bottom-up' rather than recursive fashion, starting with the perceptual experiment. The chapter ends with a discussion of the theoretical approach and how it can complement empirical research.

2.1 Syncopation: A Perceptual Experiment

As a starting point for this research, a method was needed to measure rhythmic complexity, and specifically syncopation. Syncopation and other forms of rhythmic complexity are structural attributes, which, due to their fundamentally temporal and metric properties, have been predisposed to computational modelling (Longuet-Higgins & Lee, 1984; Thul & Toussaint, 2008). Computational indices provide tools that are easy to use and control in psychological experimental settings, but care must be taken in deciding which index to use, if the quantified outcome is to reflect the perceptual nature of the phenomenon as closely as possible. As the focus of the present research is groove, and groove rarely consists of only one instrument, a measure that can address more than one instrument in syncopation is needed. However, existing measures of syncopation are only able to assess syncopation in monophonic contexts (Longuet-Higgins & Lee, 1984; see Thul & Toussaint, 2008 for a review). Thus, an experiment was designed in which the

effect of syncopation in polyphonic contexts could be addressed. As the majority of empirical studies into the effect of syncopation use tapping paradigms and/or measures of perceived stability, uncertainty or complexity, it was decided to adopt a method consistent with this approach, by combining measurements of tapping performance and perceived stability as a function of polyphonic syncopation. In this way, the results would be comparable with previous research, while offering new insights.

Tapping variability in response to syncopated rhythm is believed to reflect the degree to which the syncopation has an effect on the tapper's ability to synchronise sensorimotor processes with the rhythm. This in turn is thought to reflect the tapper's perceived stability of the syncopated rhythm. The stability of a rhythm relates to its metrical context, i.e. the hierarchical framework according to which the events and rests in the rhythm can be heard. Finger-tapping experiments have been the primary method used to investigate the perception and production of rhythm and metre in music, and sensorimotor synchronisation more generally. In 2005, Bruno Repp reviewed the current empirical and theoretical conclusions drawn from the tapping literature. As still holds today, two related, but qualitatively different theories are primarily taken as ways to explain human sensorimotor synchronisation: information processing theory (IPT) and dynamic attending theory (DAT). The former considers responses as discrete time series and aims to describe internal mechanisms based on external behaviour (e.g. Ladinig et al., 2009; Palmer & Krumhansl, 1990). The latter studies movements as continuous trajectories, often represented in circular phase space, and deals with the cognitive mechanisms as dynamically grounded in a relationship between the internal and the external, using mathematical models of temporal expectation (e.g. Large et al., 2002). At the time of Repp's review, IPT was more commonly used than DAT, due to the complexity in modelling the latter. Compared to IPT approaches, which assume linear relationships

between input (sound sequence) and output (tapping performance), the DAT model is more complex and flexible, and assumes that the relationship between input and output is non-linear (i.e. what comes out of the model is not proportional to what goes in). In recent years, the use of DAT in sensorimotor synchronisation research has increased, in tandem with the increasing support of more ecological and embodied understandings of music perception and production. However, the theory is often applied theoretically and phenomenologically, as opposed to mathematically, to explain musical behaviour (e.g. Overy & Molnar-Szakacs, 2009; Phillips-Silver et al., 2010). Furthermore, although DAT is currently attracting significant attention, the ways in which researchers analyse their empirical data are often more linear, and similar to IPT approaches, than the non-linear DAT. However, as Repp noted (2005), the two theories relate closely to one another. In fact, one can view IPT as a simplified version of DAT, which simply shows the input and output of the model but leaves the process unexplored. Thus, it is possible to propose DAT as the primary mechanism, while using IPT-related techniques in data analysis, as long as this methodological simplification is made clear. This is, in fact, how the perceptual study in Chapter Three should be seen. In a broad sense of the relationship between body-movement, pleasure and syncopation, DAT is a more appropriate theory, due to its sensitivity towards the embodiment, dynamics and reciprocity thought to characterise the experience of groove – as discussed in Chapter One. However, in the analysis of the results of the tapping experiment, methods more akin to IPT were used, such as timing-error measurements and categorical comparisons.

The second measure used in the study in Chapter Three – subjective perceptual ratings – has also been used in previous syncopation research (Fitch & Rosenfeld, 2007; Keller & Schubert, 2011; Ladinig, 2009). Compared to tapping, it is a less implicit measure of the effect of syncopation, relying on conscious reflection, often by rating the

perceived degree of ‘stability’, ‘complexity’ or ‘irregularity’. In this way, it is closer to what subjects actually experience when they listen to syncopated patterns. However, ratings are rarely in a one-to-one relationship with what researchers are interested in: in the context of syncopation, it is often metre, and metric salience in particular, that is of primary interest. As these notions rely on technical language, more general and secondary labels are often used. Thus, perceptions of ‘stability’, ‘complexity’ and ‘irregularity’ are believed to reflect the salience of syncopation in its metric context: for example, the more salient the syncopation, the less stable will the pattern be perceived to be.

Rating studies are prone to top-down contextual variability and are thus more difficult to control for confounding variables. For example, ‘stability’ as a consciously experienced phenomenon in response to a syncopated rhythm makes sense in a musical-analytical framework, but might be less intuitive to a participant with little or no musical training. Thus, it is important to explain to participants what is meant by the measure, in order to minimise uncertainty during individual ratings, and between-subject variability. There are a number of other potential limitations and confounds related to rating data, as will be considered below, in connection with the discussion of the online survey. However, in combination with the more implicit measure of tapping performance, ratings of stability provide a good indication of the effect of syncopation, at a perceptual level.

2.2 Syncopation: A Computational Index

Based on the results from the perceptual syncopation study, a computational index of polyphonic syncopation degree was developed. As mentioned above, computational indices provide controlled ways in which to measure and manipulate a variable, and indices that are based on perceptual-behavioural data, such as in the present research, are arguably more ecologically valid than those derived purely theoretically (e.g. Longuet-

Higgins & Lee, 1984). The aim here was to develop an index in terms of which a rhythm could be given a unique value reflecting its perceptual properties. The index proposed is believed to reflect the degrees of perceptual instability caused by variations in metric salience as a result of the polyphonic contextualisation of syncopation in rhythm. It is difficult to create indices that are sensitive to every possible configuration of the variable in question, and in the present research, only polyphonic syncopation in the context of certain instrumentation and at certain metric levels was modelled in the index. Nonetheless, the index provides a useful tool that can show how systematic variation of a single variable – syncopation – can elucidate some of the levels in the relationship between more complex phenomena, such as body-movement, pleasure and groove. The extent to which the index explains empirical variability can be estimated by testing its goodness of fit with a data sample, as shown in Chapter Five.

2.3 Subjective Experiences: A Web-Based Rating Survey

In the next step, the index of polyphonic syncopation, in conjunction with measures of beat salience and entropy, was used to code a collection of grooves (Chapter Five). The effects of variations in these descriptors on subjective ratings of wanting to move and feelings of pleasure were recorded via a web-based survey. Psychological experiments administered on the internet are becoming increasingly common (Birnbaum, 2004), and have been used in music and rhythm research (Ladinig, 2009). There are a number of advantages to web-based as opposed to laboratory-based experiments. First, data can be collected more easily from a larger and geographically diverse pool of participants. Second, the absence of an experimenter can prevent experimenter biasing, demand characteristics and social desirability. For example, the participant may feel less inclined to ‘perform’ and impress during the experiment, since no experimenter is present. Third, the context is more

ecologically valid, as many people commonly listen to music at their computers. However, there are also potential problems, which should not be ignored. Most importantly, having no experimenter present jeopardises the control of the experiment: it can be difficult to prevent participants from making mistakes, misinterpreting the instructions, or simply 'conspiring' to skew the data. However, while these risks are always theoretically possible, there are ways of minimising them. For example, designing an experiment that is enjoyable and presents no reason for conspiracy or bias may prevent misbehaviour. Music studies have a good chance of being experienced as enjoyable, due to the enjoyment people report with listening to music in their day-to-day lives. Furthermore, as the rating questions in the present study addressed the participants' individual subjective experiences, without relation to cultural or social issues, answers were less likely to be skewed by uncontrollable motives. Such problems might also be avoided by setting clear instructions and making sure the length of the experiment is manageable (maximum 20–25 minutes, including completion of demographics questionnaire). A final issue with web-based experiments regards their technical control. Particularly when involving sound, the quality of the stimulus depends on each participant's computer set-up. However, including instructions regarding volume levels and a question asking for the type of speakers used adds to the control of these potentially confounding variables. Taking such precautions, differences in technical set-up can be taken account of in the analysis.

Importantly, it has been shown that psychological experiments conducted in a laboratory can be replicated in web-based surveys, partly explained by the gain in statistical power from the increased sample size (McGraw et al., 2000). In this regard, a web-based survey is a good way of getting a first indication of a psychological phenomenon, which can later be studied more rigorously in a controlled laboratory setting. The present research project aimed to achieve this, with an initial web-based survey, the

rating questions and stimuli of which were later used in a lab-based setting (during neuroimaging, reported in Chapter Six).

Experiments involving self-reported ratings, regardless of whether they are conducted in the participants' homes or in a lab, rely on conscious reflection. In this way, answers represent the subjective experiences of participants in ways that reflect their conscious experiences to a greater extent than neural, physiological or sensorimotor recordings. However, such methods also present disadvantages. As discussed above, problems relating to demand characteristics, experimenter biasing and social desirability are more likely during self-report experiments than when using implicit measures, such as physiological measurements or tapping performance. Although these are attenuated when using web-based surveys, as in the present project, they still pose potential risk to the control of the experiment. For example, on might imagine that a jazz musician might, despite not being observed by any experimenter, feel inclined to rate particularly complex rhythms as more movement- and pleasure-inducing than what she really feels, due to the stereotypical aesthetic criteria of complexity in jazz music. Other potential confounds relate to culture- or individual-specific ways of using the rating scale. For example, it has been found that certain cultures' ratings are more affected by acquiescence and are more likely to use the extremes of the scale than others (van Herk, et al., 2004). In the online survey used here, people participated from all over the world, and thus it is possible that the rating scale was not used in the same way across cultural boarders. However, since ratings were subsequently replicated in the fMRI study, with only Danish participants, it can be stated with some confidence that the pattern found in ratings reflects listeners' experiences in both culture-specific and -general ways.

Another challenge with the self-report method is its reliance on language. Choices must be made about which verbal label to use to refer to the psychological attribute in

question. However, these verbal labels might not sufficiently reflect the complexity of the attribute, and thus simplify, or at worst skew, rather than enrich our understanding of it. Thus, care must be taken when deciding on how to phrase a rating question. In the study reported in Chapter Five, the rating questions used – regarding the degree of wanting to move and experience of pleasure – are common in similar studies investigating similar attributes. In fact, the degree to which a groove makes people want to move has been shown to be the most salient factor in people's spontaneous descriptions of subjective experiences with groove (Janata et al., 2012; Madison et al., 2011). Questions addressing pleasure are somewhat less converging and, particularly in music research, notions of emotion, pleasantness, liking and pleasure are often confounded or used interchangeably (Koelsch, 2010; Vuust & Kringelbach, 2010). In the web-based survey of the present project, it was felt that a question addressing participants' feelings of pleasure would best reflect the attribute of primary interest and provide participants with a label that would make sense in the context of a study about rhythm and body-movement. The latter assumption is based on the general knowledge that rhythmic dance is generally seen as a positively valenced affective activity, rather than a type of behaviour that elicits discrete emotions, such as happiness or sadness. Furthermore, the embodiment central to the definition of pleasure, as discussed in Chapter One, makes the term particularly suitable.

Despite the limitations of self-report, it has been said to be the most important measure of musically induced feelings, and was for some time the most used method in music and emotion research (Scherer & Zentner, 2001). However, since the advent and increasing availability of sophisticated technologies that can measure physiological and neural responses to music in less contextually and linguistically mediated ways, such as physiological recording and neuroimaging, its use has somewhat diminished. Nonetheless, it remains the only method that can give a direct account of subjective experience and thus

provides an important tool in investigating psychological phenomena, such as the relationship between body-movement, pleasure and groove.

2.4 Rhythm, Metre and Pleasure: A Neuroimaging Study

The use of neuroimaging techniques, such as fMRI, has massively increased in psychological research in recent years, both generally and in the field of the music psychology. It is a powerful tool that can increase our knowledge about the neural underpinnings of human behaviour and the ways in which neural structures are connected during experience. As reviewed in Chapter Six, neuroimaging has been used to demonstrate a number of important features of rhythm and pleasure in music. It has revealed how motor and reward areas in the brain connect with other areas to form networks, which collectively underlie rich and complex, embodied and affective phenomena in music. In the context of the present research, the potential to show evidence for such networks has important implications for the understanding of the research question: as the primary topic of interest is the relationship between body-movement, pleasure and groove, demonstrating the extent to which different parts of the brain involved in different cognitive mechanisms are collectively recruited can help reveal how this relationship is manifested.

However, there are some important methodological issues related to neuroimaging, and fMRI specifically, that should be noted. Firstly, fMRI is not a direct measure of neural activity: rather, it records the blood-oxygenated level-dependent (BOLD) response, which is estimated via the measurement of a magnetic signal caused by the hydrogen molecules in the blood that flows through the brain. The inference depends on the knowledge that the strength of the magnetic signal is proportional to the ratio of oxygenated and deoxygenated blood haemoglobin at a given location in the cortex. Because deoxygenated haemoglobin

is more magnetic than oxygenated haemoglobin, an increased signal indicates that there is more deoxygenated blood than oxygenated blood, which in turn is taken to indicate that the neurons at the location have been taking up the oxygen for metabolic purposes – i.e. to fuel activity. In this way, the fMRI signal reflects neural activity 'second hand'.

An important problem with taking blood flow as a measure of neural activity is its temporal resolution. While neurons normally fire at a rate of between 1 and 400 times per second, blood flows more slowly through the brain's blood vessels, typically with a lag of 1–2 seconds. This can make it difficult to determine the exact neural architecture of cognitive phenomena in which timing is important. As music is fundamentally temporal, and rhythm in particular relies almost exclusively on the temporal dimension, one might think that fMRI would be a poor method for the study of music and rhythm. However, some musical and rhythmic experiences, while always being temporal, are less time-point directed than others. For example, while it might be difficult to pin down the neural response to a musical structure which occurs at one specific point in time, such as those often reported to elicit 'chill' responses (Salimpoor et al., 2011), other characteristics of musical experiences might be said to be more distributed – as is believed to be the case with the experience of groove. Although the groove structure targeted in the fMRI study is syncopation, which might be said to be point-directed due to its occurrence at specific metric locations, the effect of interest is believed to characterise the experience of the groove as a whole, rather than individual moments of syncopation. In fact, what is being modelled throughout this research is the overall degree of syncopation distributed throughout a groove. And due to the repetitiveness of groove in general, and of the groove stimuli used in this study specifically, recordings of the haemodynamic response are here thought to better reflect the experience of groove than recordings of more temporally defined responses, which are possible with other methods such as electroencephalography

(EEG) and magnetoencephalography (MEG). The distributed character of groove also accounts for the more phenomenological-theoretical interpretations of the relationship between body-movement, pleasure and syncopation in groove. In this way, the findings of the fMRI study have direct implications for the embodied and ecological framework within which groove is considered.

A related limitation regards the noise produced by the MRI scanner. The rapid changes of currents in the gradient coils inside the scanner causes vibrations on the coils, which sound like fast and loud isochronously spaced bangs throughout the duration of scanning. Without good quality headphones, there is a significant risk of auditory interference with the stimuli being tested. For studies interested in music and pleasure, this danger is particularly serious, as positive affective responses to music have been found to depend on volume and sound quality (Kellaris & Rice, 1993). One solution involves the use of sparse sampling, which, due to the temporal lag of the BOLD response, enables signal recording in periods of time *after* the presentation of the stimulus. Specifically, the stimulus is presented with the scanner inactive, and when the stimulus ends, recording starts, capturing the delayed haemodynamic response to the stimulus. However, sparse sampling designs require stimuli of relatively short duration, in order for the corresponding BOLD data to be captured within the ensuing time lag. As groove is a distributed musical experience that depends on a repetition of 2–4 bar sequences (see definition in Chapter One), sparse sampling is not an option. However, it is possible that continuous sampling during listening to groove could mitigate the effects of major scanner noise, due to the complexity and continuity of the repeated groove. In the fMRI study reported in Chapter Six, there were no breaks during a given stimulus, and it is expected that the rhythmic complexity in the grooves attracted attention towards the stimulus and away from the regular bangs of the background noise.

Finally, the most important limitation of fMRI in the context of the present research regards its restrictions on body-movement. For successful recording to occur, the participant has to lie completely still while inside the scanner, as movements disrupt the signal and create artefacts in the acquired data. There are methods to reduce such effects, primarily though a technique called 'motion-correction'. However, this technique can only remedy some long-durational continuous drifting of head position, while larger and more abrupt movements cannot be corrected for, due to the constraints of the poor temporal resolution. For a study interested in a musical experience during which body-movement is an essential factor, this limitation is unavoidable and insurmountable. However, until these motion limitations are overcome by advances in technology, fMRI recording during full body-movement is not possible. The closest approximation is to measure body-movement outside the scanner, and relate the findings to neural correlates. A study with this aim is described in the following section.

2.5 Groove and Dance: A Motion-Capture Study

Motion-capture technologies, which record the velocity and/or acceleration of body-movements in time and space, were originally developed as a tool in the animation and video game industry, to map and create fast and natural movements on the screen. They were later appropriated by biomechanics and sports trainers to diagnose problems and improve performance. The use of motion-capture in psychological research is relatively new (Moeslund & Granum, 2001), and has only recently been used in music research. Researchers interested in music performance gestures, interpersonal musical-gestural communication, and musically guided dance movements were some of the first to adopt the technique using video recording (Camurri et al., 2000; Camurri et al., 2004; Clayton, 2007). Replacing dance and movement notation (Camurri et al., 1986), digital video-based

tracking systems enabled more accurate capturing of body-gestures. However, it was not until more sophisticated sensor-based motion-capture systems, such as Qualisys (Qualisys, Inc.) and Optitrack (NaturalPoint Inc.), were introduced to the field that the use of motion-capture became one of the most commonly used methods in studying body-movements in music. Compared to finger-tapping paradigms, it is a more ecologically valid approach to studying sensorimotor synchronisation, allowing the measurement of both spatial and temporal aspects of whole body-movements. Recordings typically take place in laboratory settings, with either individual participants or groups. The most sophisticated technologies enable the recording of high-resolution position, velocity and acceleration data in three dimensions, with as many as 50 sensor-markers on joints on each participant's body.

However, researchers have also appropriated less sophisticated and more accessible technologies to record body-movement to music, notably Nintendo's wireless motion-sensor video game Wii (e.g. De Bruyn et al., 2009; Phillips-Silver et al., 2011). Essentially an accelerometer, the remote (or Wiimote) stores acceleration data in time and three-dimensional space, which can be recorded via computer software. With a capacity to record eight Wiimotes simultaneously, the method also lends itself to social experiments. Compared to more sophisticated technologies, fewer markers can be used, no velocity data are stored, and the size and weight of the Wiimotes are more restrictive. Nonetheless, Wii is particularly useful in studies interested in simpler properties of movements, such as force, synchrony and periodicity. More detailed analyses of kinetically mapped gestures (Naveda et al., 2011; Toiviainen et al., 2010) require the more complex technologies already mentioned. Since the present study is primarily concerned with temporal and force-related measures, rather than the specific style of movements in response to groove, Wii provides an appropriate method of motion-capture.

Compared to self-reports of the desire to move to music, motion-capture measurements are more direct, but at the same time implicit since they are not dependent on language. Measuring body-movement is different from measuring the desire to move, the former relating to biomechanics, and the latter to subjective motivational behaviour and feeling. It is theoretically possible to move and exhibit expressive properties through movement despite feeling no spontaneous desire to move. Equally, a person might feel motivated to move, but for contextual reasons (e.g. social pressure, cultural etiquette, feelings of awkwardness or incompetence) be unwilling or unable to produce overt movements – perhaps particularly in the presence of an experimenter. In the present project, both self-reports of the desire to move and motion-capture were applied to study the relationship between body-movement, pleasure and groove. Thus, the subjective and directly corporeal yet implicit measurements of groove-related body-movements were recorded. Furthermore, although the context in which participants moved was a laboratory, they were asked to move spontaneously to the music, and the experimenter left the room before the experiment started. In this way, social pressure, demand characteristics and experimenter bias were minimised. While there is no doubt that dancing in a relatively sterile room on your own in the middle of the day is different from the late-night, dark, large and public spaces of clubs in which people normally dance to groove-based music, it seems reasonable to expect that people will also experience some desire (or at least capacity) to move to music alone in a laboratory setting.

2.6 Embodiment and Affect: A Phenomenological Approach

In order to frame the empirical findings from the experimental methods within a broader notion of what characterises the experience of groove as an integrated phenomenon, theories of embodied and ecological cognition and a phenomenological approach to groove

provided a conceptual backdrop throughout the research. As described in Chapter One, these theories propose that cognition and behaviour are situated in the body and its relationship with its surroundings, in a reciprocal way. As the empirical methods largely address the concepts of body-movement, pleasure and groove separately (albeit often within the same experiment), these theories enable a consideration of their interaction. In fact, since the primary interest of the research is *a relationship* (between body-movement, pleasure and groove), such integration is essential. In the final chapter, following a summary of the empirical results, such a theoretical approach attempts to re-situate the phenomenon of groove in its richer and more complex real-world context, and to propose phenomenological explanations for how body-movement, pleasure and syncopation interact in the experience of groove.

The phenomenological approach addresses the nature of experience, particularly its temporal and embodied dimensions. A whole branch of philosophy has been dedicated to the study of phenomenology, at first concerned with the essence of experience (e.g. Hegel, 1807), and later with the body as the site for all conscious and unconscious thought (e.g. Merlaeu-Ponty, 1945). Phenomenology has been appropriated in human sciences, including cognitive linguistics (Lakoff, 1987) and neuroscience (Damasio, 1999; Edelman, 1992). The present research does not engage with this rich and complex tradition of philosophical phenomenology, but rather with the more psychological question of the nature of the subjective experience of groove, and with the relationship between body-movement, pleasure and groove as a phenomenon. In particular, the concept of perception of metric events, and how it can be seen as the mechanism that integrates body-movement and pleasure in syncopated groove, is explored phenomenologically in the final chapter, with reference to embodied and ecological theories of cognition. As with any theoretical approach, the phenomenological discussion remains speculative, but helps to bring the

empirically grounded properties of groove experience closer to what is actually involved in listening and dancing to groove, and describes its movement- and pleasure-inducing properties in ways that resonate with how we move to groove outside the laboratory.

2.7 Summary

The present research project is interdisciplinary, in its use of perceptual, computational, subjective, neural, embodied and theoretical approaches to the study of groove. In this way, it aims to investigate some of the cognitive mechanisms underlying the relationship between body-movement, pleasure and groove, while framing its findings in a phenomenological context that allows for a broader understanding of how movement- and pleasure-induction are integrated into groove experience. The choice and order of the empirical studies resulted from the nature of the research questions, which required a recursive investigation into the different layers of mechanisms underlying the relationship between body-movement, pleasure and groove. Individually, the experiments are relatively narrowly focused on specific issues and characteristics, but are complementary in their subject matter and approach. Taken together, and understood alongside a phenomenological description of body-movement and pleasure in groove, this provides the necessary framework within which the implications of the empirical findings may be interpreted more broadly. As a contribution to the field of music psychology, these methodological considerations contextualise the research objectives and situate the psychology of groove in our understanding of music more generally.

CHAPTER THREE

The Effects of Polyphonic Context and Instrumentation on Syncopation

3.1 INTRODUCTION

In groove-based music, the rhythmic patterns of the different instruments are often syncopated against each other to create rhythmic tension and to invite body-movement and dance. However, a problem with existing formal and perceptual theories of syncopation is that they cannot adequately model such kinds of syncopation as they only address monophonic music and ignore the effects of instrumentation. This study therefore investigates the effects of polyphonic context and instrumentation on the salience of syncopations. Musicians and non-musicians were asked to tap along to rhythmic patterns of a drum-kit and rate their stability; in these patterns, syncopations occurred among different numbers of streams, with different instrumentation and at different metric locations. The results revealed that the stability of syncopated rhythms depends on the number of streams, instrumentation and metric locations, in variously interacting ways, and that syncopation affects non-musicians differently from musicians. It is proposed that listeners' experiences of syncopations are shaped by the polyphonic and instrumental configurations of the rhythmic pattern, its metric structure, and individual musical training, by virtue of a combination of the rhythms' acoustic properties and ecological associations, and as a result of statistical learning and exposure.

3.1.1 Metre Perception and Syncopation

Despite the recent explosion of research into the cognitive mechanisms underpinning music perception, there still remains some theoretical and psychological disagreement about rhythm perception. Particular challenges lie in the definitions of metre, rhythmic complexity and syncopation. Although these are separate concepts, they are strongly related. Music psychology researchers have attempted to define metre since the 1970s using a number of different theoretical and empirical approaches (e.g. Clarke, 1999; Jones, 2009; Large & Snyder, 2009; Lerdahl & Jackendoff, 1983; Martin, 1972; Parncutt, 1994; Povel & Essens, 1985). In formal terms, metre is generally referred to as the alternation of strong and weak accents, which provide a temporal, or metric, framework for a rhythmic pattern. This is formally expressed in the time signature of a piece of music. However, there is more disagreement about the perceptual definition of metre. At the most basic level, metre perception is understood as a subjective sense of pulse. However, the hierarchical differentiation of pulses and the exact structure of this hierarchy still remain unclear. These uncertainties are reflected in the perceptual definition of metre provided by Jones in the *Oxford Handbook of Music Psychology*:

> Intuitively, metre perception refers to a listener's sensitivity to musical timing regularities, evident when 'keeping time' by tapping in synchrony with musical tones. Sometimes tones are clearly accented and contribute to *metric hierarchies* (…) (Jones, 2009, p. 81, italics in original).

The strengths of this definition lie in its recognition of the role of the body in metre perception, and the implementation of hierarchy as an option and not a prerequisite. This not only accommodates different theoretical views of the structure of metric hierarchies, but also leaves room for more non-hierarchical understandings of metre that might

characterise musics of non-Western cultures.[1] Nonetheless, the relative looseness of Jones's definition reveals an ongoing uncertainty about how metre is believed to be perceived. Importantly, perceptual metre does not necessarily converge with formal metre.

Lerdahl and Jackendoff propose a highly hierarchical view of metre in their *Generative Theory of Tonal Music* (1983). Based on the implementation of a set of cognitive rules, they claim that rhythm perception is underpinned by a framework of metric salience organised in a tree-like structure, where every beat is recursively subdivided into equally spaced beats at the next level. Although the theoretical framework with which the authors operate is often criticised for giving too much attention to top-down processes of music cognition and not enough focus on the role of the body, a number of researchers have also adopted metric tree models in studying rhythm and metre (e.g. Longuet-Higgins & Lee, 1984; Temperley, 2007, 2009, 2010). Another influential model, which directs considerably more attention to the body, is dynamic attending theory (DAT). As already discussed in Chapter One, it was originally proposed by Jones and colleagues (e.g Barnes & Jones, 2000; Jones, 2004, 2009; Large & Jones, 1999), who claim that rhythm induces metric frameworks by way of entrainment: a listener's attention is captured and driven by the periodicities in the rhythmic pattern, and the experience of metric salience corresponds to the relative strength of attention directed towards each rhythmic event. Compared to Lerdahl and Jackendoff's model, the hierarchical nature of metre in DAT is considerably more flexible and adaptive, and is not imposed in a top-down manner. Rather, hierarchical relationships between pulses (i.e. metre) emerge from the

[1] For example, there is an ongoing discussion in African music scholarship about the role of different pulses in polyrhythmic music. For some time, the complexity of African rhythm was seen as stemming from the relative independence of cross-rhythmic layers, e.g. that simultaneous rhythms suggesting different metric frameworks, such as the well-known 'three against four' pattern, were equally important in the rhythm and that African listeners were able to hear several metres at the same time. This view was challenged by Agawu (2003), who claims that in a given polyrhythm, one of the pulses is always heard as the main pulse and all other pulses are heard in relation to it, and that the non-hierarchical understanding of African rhythm stems from the Western view of Africa as the egalitarian 'other'.

mutual relationships between different oscillating periodicities in music and attention. Computational models are a third common way of understanding metre (e.g. Desain & Honing, 1999; Dixon, 2001; Margulis & Beatty, 2008; Temperley & Sleator, 1999; Volk, 2008). One particularly influential theory is proposed by Temperley in his adaptation of a Bayesian probability model (Temperley, 2004, 2007, 2009, 2010). Through a generative process (similar to that proposed by Lerdahl & Jackendoff, 1983), metre is inferred from the probabilities of different patterns of regularity generated by a given rhythmic input. Vuust et al. (2009) also make use of a Bayesian framework in their adaptation of Friston's (2002) neurocognitive model of predictive coding for metre perception. This model proposes a hierarchical organisation of brain processes, in which predictions are formed by lower-level brain areas, based on expectations concerning inputs from higher-level areas. If the expectations are significantly violated, the hierarchical model is adjusted to comply. In this way, the error between input and prediction is recursively minimised. Supported by findings using magnetoencephalography (MEG) of the perception and production of polyrhythms, Vuust et al. claim that metre perception occurs through a process by which the brain minimises the error between the rhythm (the input) and the emerging metre (the prediction).

Polyrhythms and other forms of rhythmic complexity are often used in empirical investigations into rhythm and metre perception (e.g. Palmer & Krumhansl, 1990; Povel & Essens, 1985; Pressing, 1999; Shmulevich & Povel, 2000; Toussaint, 2002). The idea is that the ways in which complex rhythmic structures are processed can reveal the mechanisms underpinning rhythm and metre perception more generally. For example, some researchers have systematically varied the degree of rhythmic complexity as a factor in musical pattern recognition (e.g. Gomez et al., 2005), while others have been interested in how well rhythmic properties model human judgements of complexity (Shmulevich &

Povel, 2000). Syncopation is the form of rhythmic complexity that has been studied the most, and in a correlational comparison of 32 different measures of rhythmic complexity, Thul and Toussaint (2008) found that measures of syncopation, compared to entropy, for example, performed the best in explaining the behavioural data from four separate studies.

Apart from certain rhetorical nuances reflecting differing theoretical perspectives, most researchers and theorists generally define syncopations as rhythmic events that violate listeners' rhythmic expectations. A particularly influential definition was proposed by Longuet-Higgins and Lee (1984). Importantly, it conceptualises expectational salience as weights:

> If R is a rest or a tied note, and N is the (…) sounded note before R, and the weight of N is no greater than the weight of R, then the pair (N, R) is said to constitute a syncopation (Longuet-Higgins & Lee, 1984, p. 430).

Their definition depends crucially on a hierarchical model of metre: within a measure with a given time signature, each metric location is given a specific weight, a value of *metric salience* by hierarchically and recursively subdividing the measure into equally spaced parts (Figure 3.1). At the highest level, the semibreve (grid point 1) is the most salient and thus has the strongest weight, followed by the minim (grid point 9), crotchets (grid points 5 and 13), quavers (grid points 3, 7, 11, 15) and semiquavers (grid points 2, 4, 6, 8, 10, 12, 14 and 16) respectively. The events of a given rhythmic pattern, both sounding events and silent rests, can then be assigned specific weights based on the metric location with which they coincide.

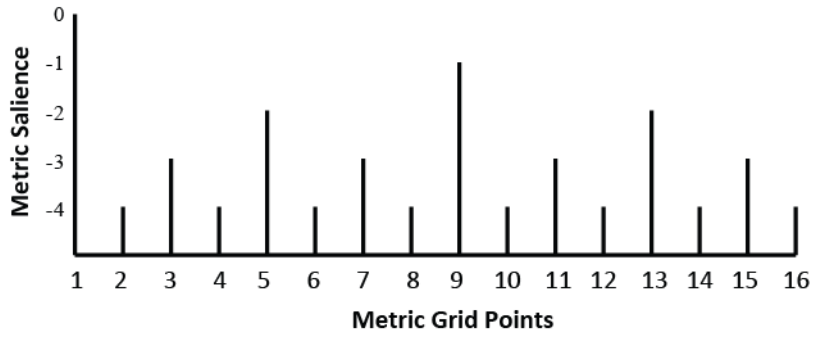


Fig. 3.1 Longuet-Higgins and Lee's model of metric salience (1984).

The weights range between 0 for the semibreve and -4 for the semiquavers.[2] Importantly, the stronger the weight of the metric location, the more strongly sounded events are expected to occur on them. In other words, events are expected to occur at the downbeat four times more powerfully than on the semiquaver that follows it, for example. Rests, on the other hand, are expected to occur on metric locations with lesser weight. Thus listeners are much more likely to expect a rest on the second semiquaver of a bar than on the downbeat. Syncopation works by violating these expectations, as notes occur at locations with lesser weight and rests occur at locations with greater weight. The authors propose an index for calculating the strength of a syncopation, based on the definition above and the relative weights of the rhythmic events involved:

> *If N<R, then S = N-R, where N is the metric weight of a syncopated note, R is the metric weight of the following rest and S is the degree of syncopation* (Longuet-Higgins & Lee, 1984, p. 430).

In this way, the degree of syncopation equals the difference in metric weight between a note on a metrically weak beat and a rest on a metrically strong beat, and the greater the difference in weight, the greater the effect of the syncopation.

[2] The weights are given as negative values for computational reasons.

Since it was proposed, a number of researchers have tried to test this model. These studies can generally be divided into two areas focusing on different, but related aspects of syncopation: 1) How can Longuet-Higgins and Lee's index of syncopation be used experimentally to determine the precise hierarchical relationships between levels of metric salience?; and 2) How does syncopation affect metre perception and sensorimotor synchronisation?

Ladinig, Honing and colleagues have primarily been interested in the former (Ladinig, 2009; Ladinig et al., 2009; Smith & Honing, 2006; Winkler et al., 2009). In one study (Ladinig & Honing, 2009), they tested the perceptual effects of syncopations on listeners' metric expectations and found that the degree of unexpectedness or perceived stability depended on the metric location at which the syncopation occurred. Furthermore, they found that, contrary to previous research (Palmer & Krumhansl, 1990), listeners with no musical training exhibited some hierarchical processing of metre, although not to the same extent as musically trained listeners. Researchers interested in the second issue (how syncopation affects metre perception and sensorimotor synchronisation) have used syncopations as a way of increasing complexity in rhythmic patterns and have investigated the extent to which such complexity affects the experience of a stable pulse and the ability to synchronise body-movements (e.g. Large, 2000; Mayville et al., 2001; Snyder & Krumhansl, 2001; Thaut & Kenyon, 2003). Fitch and Rosenfeld (2007) used Longuet-Higgins and Lee's index and showed that participants' number and magnitude of tapping errors correlated linearly with the degree of syncopation. Furthermore, as the degree of syncopation increased, participants were more likely to 'reinterpret' the rhythmic patterns as unsyncopated by resetting the phase of their internally generated pulse. In other words, the more syncopated a rhythmic pattern, the more likely listeners are to gravitate towards a perceptual arrangement that reduces/minimises syncopation.

Although these theories and empirical studies have provided practically applicable methods for studying metre and syncopation, they share an important limitation: the assumption of monophony. Most models can only take one instrumental layer into account when calculating metre and syncopation salience. This limitation is particularly problematic considering the polyphonic character of musical genres with which syncopations are largely associated, such as pop, rock and groove-based music. In this music, syncopated patterns are often accompanied by at least one other instrument emphasising the pulse and metric framework in some way. Currently, only one model attempts to theorise the cognition of metre in polyphonic music: using probabilistic methods, Temperley (2009) provides a model for polyphonic music analysis that takes metre, harmony and streaming simultaneously into account. Importantly, the generation of metric frameworks in listeners depends on 'metrical anchoring', which in turn is affected by the distribution of notes within melodic streams in a given musical pattern. Specifically, an onset at a metrically weak location is more likely to be succeeded (or anchored) by a metrically strong onset in the same stream than in a different stream, or by a rest. Temperley's data are based on large corpora of Western classical and folk music, and the assumption is that if certain structures are more common in the actual music, then listeners' cognitive capacities probably adhere to these structures, via statistical learning. However, Temperley makes no claims about the ways in which the instrumentation of streams in polyphonic music might affect metre perception. For example, does it make a difference if the syncopated stream is played by a cello and the anchoring stream by a violin, or vice versa? Furthermore, the assumption about the probability of syncopations becomes problematic when considering music in which syncopations are very common, such as groove-based music. By Temperley's reasoning, syncopations in groove should be highly expected because they are a dominant structural feature of the music. This seems

reasonable as a statement about expectations of a more veridical kind, but leaves open the question about what perceptual effect syncopations have in groove. In order to address this question, a model is needed that can be applied to polyphonic music in which syncopations occur across different instrumental layers. The study reported below was designed to investigate the effects of polyphonic context and instrumentation on syncopation, by recording participants' sensorimotor synchronisation with, and stability-ratings of, rhythmic drum-kit patterns, in which the perception of syncopations occurred in either one, two or three instrumental streams, and either in the bass-drum, snare-drum or hihat. As metric salience and musical training have been shown to affect syncopation in previous research, these aspects were also addressed in the study. Importantly, the study relies on the assumption that listeners' perceptions of stability and the quality of their sensorimotor synchronisation to syncopated rhythms reflect the degree of syncopation salience in the rhythms. The aim of the study was to enable an adjustment of the index of syncopation proposed by Longuet-Higgins and Lee (1984), in order to accommodate polyphonic context and instrumentation reflecting perceptual, rather than purely theoretical properties, and thus provide an index that could more suitably be used in the study of the psychological effects of groove-based music.[3]

3.1.2 Hypotheses

For the study, the following hypotheses were tested. First, the effect of polyphonic context was addressed – specifically, whether the number of streams in a syncopated rhythm affects the perception of stability. When a syncopation occurs in a monophonic pattern, there is no other instrument coinciding with the pulse. In other words, the metric event revealed by the syncopation is silent, resulting in acoustically disrupted regularity.

[3] This index is proposed and described in Chapter Four.

However, when a syncopation occurs in one instrumental stream among other unsyncopated streams in polyphonic patterns, the other instrumental streams may coincide with the pulse, and the metric event is acoustically sounded by the other instruments. The regularity of the syncopated stream is disrupted, but the metric framework as a whole is still acoustically intact in the other instrumental streams. It was hypothesised that there would be a linear relationship between the number of streams coinciding with the pulse in rhythmic patterns with syncopations and tapping accuracy and perceived stability of the patterns. In other words, when the syncopation occurred among two or three streams, and one or two other instruments co-occurred with the pulse, it was expected that tapping accuracy and perceived stability would be greater than when syncopations occurred in one stream, and there was no other instrument on the pulse. Furthermore, it was hypothesised that there would be a similar linear increase in tapping accuracy and perceived stability between the two- and three-stream conditions: a syncopated pattern in which two other instruments co-occurred on the pulse would be perceived as more stable than a syncopated pattern in which only one other instrument co-occurred on the pulse. This hypothesis is based on the principle that increasing numbers of instruments on the pulse would further reduce the salience of the syncopation.

Second, it was hypothesised that syncopations would be experienced as the least salient when played by the hihat, compared to the bass- and snare-drum, and that bass-drum syncopations would be experienced as the most salient, compared to both snare and hihat. This hypothesis reflects a positive linear relationship between timbral brightness and perceived stability: patterns with a syncopated bass are the least stable, because the bass is the darkest of the sounds, and patterns with syncopations on the hihat are the most stable, because the hihat is the brightest. These differences are perhaps the most significant in defining the instruments acoustically, and are explained by the relative dominance of

harmonic frequencies present in the sounds. An explanation for the greater salience of syncopations using darker sounds is based on cross-modal and ecological (or iconic) association. According to this explanation, darker sounds are cross-modally associated with larger and heavier animals or objects that gravitate towards the ground, while brighter sounds are associated with smaller and lighter animals or objects that spend more time off the ground (Maurer & Mondloch, 2004). By extension, larger and heavier animals or objects move in slower, more predictable and stable manners due to the constraints of their size and weight, while smaller and lighter animals or objects move faster and more unpredictably. In other words, it is claimed that darker sounds are expected to be more 'grounded', predictable and stable than brighter sounds, and thus rhythms with syncopations in the bass-drum are perceived as the most unstable (since they disrupt the 'grounded' component of the rhythm), followed by rhythms with syncopations in the snare-drum and the hihat, respectively. These cross-modal associations rely on principles of statistical learning, which influence the extent to which events and objects are associated according to the frequency of such associations in the perceiver's environment.

It was also expected that musicians would show greater tapping accuracy and perceive syncopations as more stable than non-musicians. This hypothesis was based on indications from previous research, such as Palmer and Krumhansl (1990), and the likelihood that musicians are more familiar with syncopations than non-musicians, due to their musical training. This hypothesis can also be seen as based on principles of statistical learning, in that musicians perceive syncopated patterns as less unstable because they are exposed to them more frequently, and thus experience them as less unexpected. However, no directional hypotheses were made for the interaction of musical training and metric salience in relation to syncopated rhythms, as previous research has shown inconsistent results (Ladinig et al., 2009; Palmer & Krumhansl, 1990). In fact, no directional

hypotheses were made for the effect of metric salience overall, the study being limited to a simple investigation of whether syncopated patterns were affected by their metric location.

3.2 METHOD

3.2.1 Participants

29 right-handed English-speaking participants (12 females, 17 males) aged between 21 and 34 (Mean = 24.75, SD = 3.32) took part in the study on a voluntary unpaid basis. According to a demographics questionnaire (Appendix One) that was completed after the study, participants were categorised as musicians (N = 14) if they had more than eight years of training (instrumental and/or theoretical), in addition to obligatory school music lessons, and had started playing an instrument before the age of 8 (following the example of Ladinig, 2009, and Ollen, 2006). A strict threshold for categorisation as non-musician was chosen: no musical training, apart from obligatory music lessons in school (N = 15).[4]

3.2.2 Stimuli

Participants heard 48 rhythmic patterns constructed using the music production software GarageBand 5.1 (Apple, Inc.) in 4/4 time and at a tempo of 120 bpm. Each pattern was preceded by one bar with a voice counting to four on the main crotchet pulse, and then one bar with a metronome (using the sound of a woodblock) on the main crochet pulse. Each rhythmic pattern was then presented four times in a continuously repeating fashion. Rhythmic events occurred only on the crotchets of the bar, apart from at the syncopated event, where one instrumental event occurred on the preceding semiquaver. In any given pattern, a syncopated event could occur on the semiquaver before one of the four crotchets,

[4] At this stage, participants' broader musical background was not investigated (e.g. familiarity with groove or frequency and enjoyment of dancing to music), as the study was interested in the effect of polyphonic syncopation more generally, and not just in relation to groove.

as played by one of the three instruments of the drum-kit – snare-drum, bass-drum or hihat – and in the context of one, two or three instrumental streams. Each possible combination of instruments was included for the different stream conditions.

Figures 3.2, 3.3 and 3.4 are visual representations of the different polyphonic and instrumental configurations in which syncopations occurred on the second crotchet: black bars represent main crotchet onsets, while the gridlines are the metric framework, with each box representing a semiquaver. The ringed grey bars indicate the syncopations. Including the introductory count-in, the bar of metronome and the repeated pattern, each stimulus lasted 20 seconds.

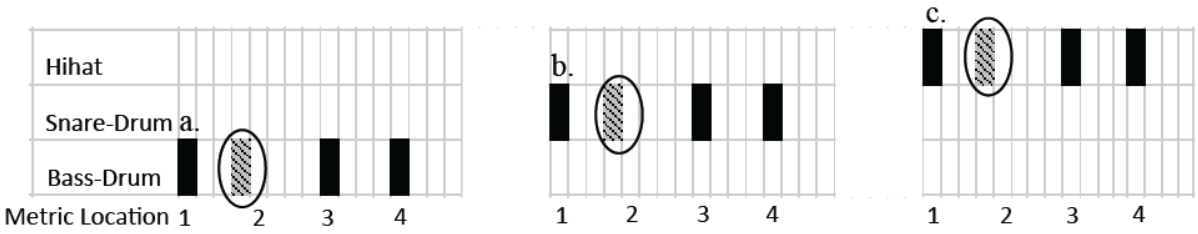


Fig. 3.2 Instrumental configurations of syncopations in one-stream patterns. Black bars = onsets on the crotchet pulse. Grey bars = syncopated onsets **a.** Syncopated bass-drum. **b.** Syncopated snare-drum. **c.** Syncopated hihat.

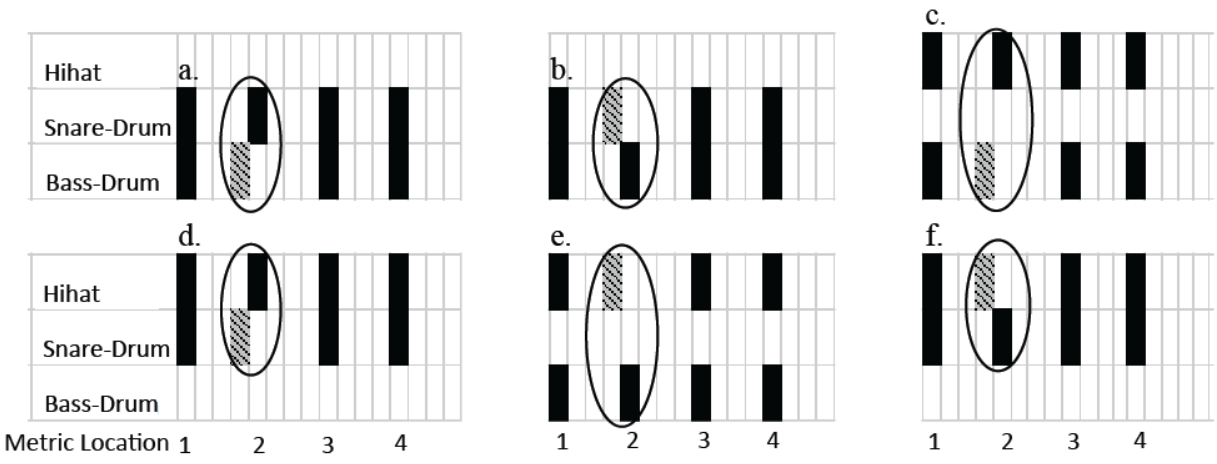


Fig. 3.3 Instrumental configurations of syncopations in two-stream patterns. Black bars = onsets on the crotchet pulse. Grey bars = syncopated onsets. **a.** Syncopated bass-drum with snare-drum on the pulse. **b.** Syncopated snare-drum with bass-drum on the pulse. **c.** Syncopated bass-drum with hihat on the pulse. **d.** Syncopated snare-drum with hihat on the pulse. **e.** Syncopated hihat with bass-drum on the pulse. **f.** Syncopated hihat with snare-drum on the pulse.

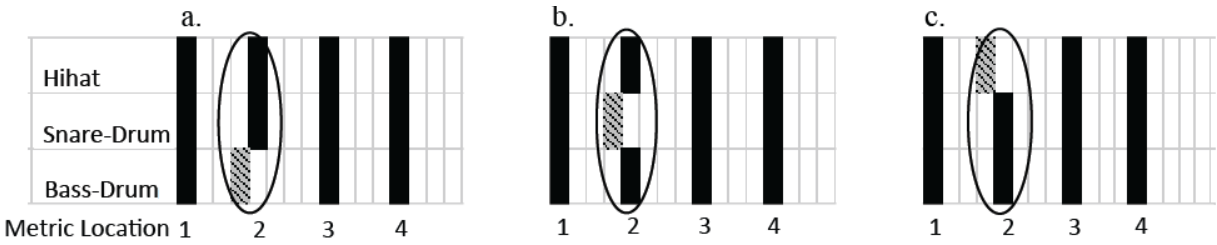


Fig. 3.4 Instrumental configurations of syncopations in three-stream patterns. Black bars = onsets on the crotchet pulse. Grey bars = syncopated onsets. **a.** Syncopated bass-drum with snare-drum and hihat on the pulse. **b.** Syncopated snare-drum with bass-drum and hihat on the pulse. **c.** Syncopated hihat with bass-drum and snare-drum on the pulse.

3.2.3 Procedure

Following instructions (Appendix Two) and training, participants performed the task on a computer, by tapping along with the metronome and through the subsequent rhythmic patterns after the voice had counted them in, with their right index finger on the computer keyboard. Importantly, they were instructed always to tap to the *pulse* of the rhythm, and not to the syncopations, and to tap to the downbeat on the G key, with the rest of the beats on the J key, in order to ensure that they performed according to the correct metric framework (i.e. that they placed the downbeat in the correct metric location). Between patterns, which were fully randomised, a continuous visual analogue rating scale appeared on the screen, with which participants had 12 seconds to rate the perceived *stability* of the rhythmic patterns by using keys on the keyboard. Rating and tapping performance were recorded using the software program Presentation (Neurobehavioral Systems, Inc.). The stimuli were presented to the participants over good quality headphones and at an enjoyable but comfortable volume, which was held constant across participants. The whole experiment lasted no more than 45 minutes, including the receiving of instructions, training and the completion of the questionnaire.

3.3 RESULTS

Overall, the results showed that syncopated drum-kit patterns affected tapping and perceived stability according to the number of streams, instrumentation and metric location in ways that interacted with the specific polyphonic, instrumental and metric context, and with the musical training of the listener. In what follows, the specifics of these effects and interactions will be described separately for the tapping and rating data. All statistical analyses were performed using Predictive Analytic Software (PASW) 17.0 (IBM, Inc.).

3.3.1 Tapping Performance

3.3.1.1 Analysis

Tapping data were first analysed in order to exclude any trials in which participants had not tapped according to the correct metric framework, or had made other tapping mistakes. Because general linear models require equal number of cases for each condition, the trials during which tapping mistakes were made were replaced with values using the Maximum Likelihood Estimation Method (Field, 2009, p. 166). Statistical analyses were performed in order to investigate whether there was an effect of number of streams, instrumentation or metric location on the magnitude of errors in tapping to syncopated patterns for musicians and non-musicians. Error was defined as the absolute time between each tap and its pulse target, measured in milliseconds. The temporal sampling rate in Presentation is 0.1 ms, and the maximum uncertainty with which responses were recorded was 0.2 ms. In order to perform an ANOVA on these data, responses were categorised according to the following conditions: number of streams (one stream, two streams *a*, two streams *b*, three streams), instrumentation (bass-drum, snare-drum, hihat) and metric location (beat one, beat two, beat three, beat four). The data were categorised into *two* two-stream conditions (*a* and *b*) since the number of instrumental configurations possible for each stream condition (one,

two and three) was irregular. For example, with three different instruments (bass-drum, snare-drum and hihat), there are six different instrument combinations in a two-stream condition: two for each instrument as syncopated, with either of the other two instruments on the pulse. In the three-stream condition, however, there are only three combinations: one for each instrument as syncopated against both of the other two simultaneously on the pulse. Thus, in order not to collapse the stream and instrument variables (which would have yielded a very large number of levels, 12), or to exclude any variables, the six two-stream combinations were divided across two two-stream conditions. Two-stream condition *a* included the following variables: syncopated bass-drum with the hihat on the pulse; syncopated snare-drum with the bass-drum on the pulse; and syncopated hihat with the snare on the pulse. Two stream condition *b* included: syncopated bass-drum with the snare-drum on the pulse; syncopated snare-drum with the hihat on the pulse; and syncopated hihat with the bass-drum on the pulse. The variables were categorised across the two conditions in this way in order to have each instrument at least once at a syncopated position and once at a pulse position within each condition. With the other conditions, instrumentation and metric position, as well as the between-subjects variable of musical training, the ANOVA had a 4 x 3 x 4 x 2 design.

3.3.1.2 Results

The results for tapping error revealed a significant main effect of metric location ($F(3, 81) = 4.12$, $p = .009$), a close significant main effect for number of streams ($F(3, 81) = 2.52$, $p = .064$), but no effect of instrumentation ($F(2, 54) = .85$, $p = .394$), nor was there any interaction. Bonferroni-corrected post-hoc comparisons showed that participants' tapping errors were close to significantly greater during syncopations occurring on beat one (Mean = 52.12, SE = 6.30) compared to beat two (Mean = 46.82, SE = 5.25) ($p = .054$). No other

significant differences were found for metric location. There were also close to significantly greater tapping errors during one-stream syncopated patterns (Mean = 53.50, SE = 5.80) compared to three-stream syncopated patterns (Mean = 47.00, SE = 5.30) (p = .071), as shown in Figure 3.5. No other significant differences were found for number of streams. Overall, musicians' tapping errors (Mean = 29.92, SE = 8.22) were smaller than non-musicians' (Mean = 68.61, SE = 7.94) ($F(1, 27) = 11.45$, $p = .002$), supporting previous research into the effect of musical training on tapping accuracy (Figure 3.5).

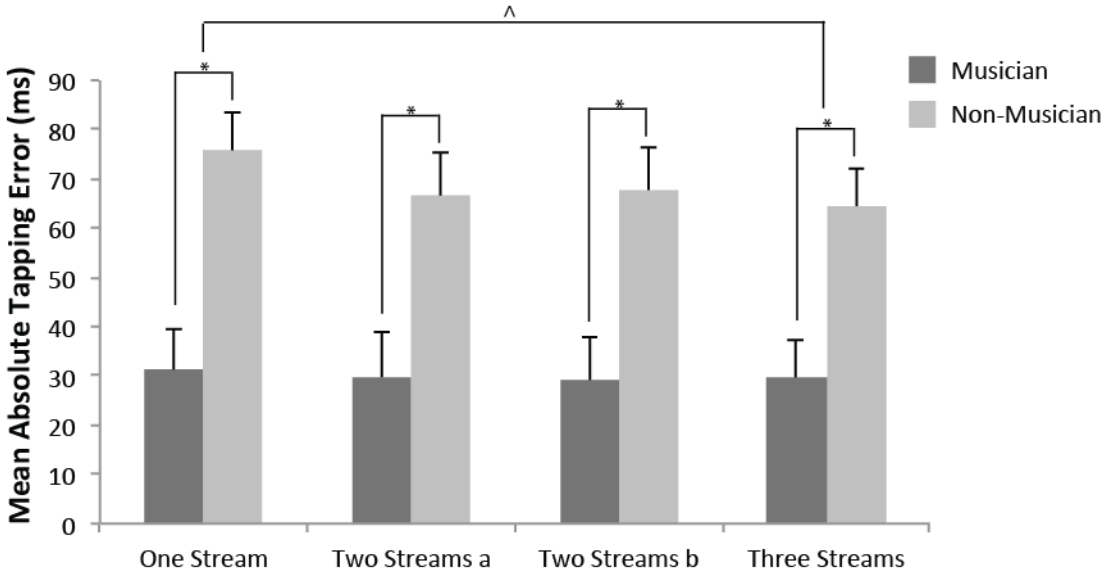


Fig. 3.5 Tapping error for musicians and non-musicians during patterns with syncopations among one, two and three instrumental streams. Error bars = standard error. *$p < .001$.
^ Approaching significance.

3.3.2 Ratings of Stability

3.3.2.1 Analysis

Rather than replacing rating values with artificially constructed values using the Maximum Likelihood Estimation Method in cases where participants had made tapping mistakes, it was decided to use the original rating data, as mistakes were likely to be a direct consequence of participants' perceived stability of the patterns and thus an important

contributor to ratings. Ratings were scaled from -4 to 4 and analysed using the same ANOVA design as in the tapping analysis.

3.3.2.2 Results

All within-subjects main effects were significant: stream ($F(3, 81) = 33.33$, $p < .001$), instrumentation ($F(2, 54) = 4.46$, $p = .016$) and metric location ($F(3, 81) = 3.56$, $p = .018$). A significant main effect was found for musical training ($F(1, 27) = 27.62$, $p < .001$), showing that musicians rated syncopated patterns as more stable (Mean = 1.75, SE = .31) than non-musicians (Mean = .71, SE = .30). There were also some significant interactions: musical training^{x}metric location ($F(3, 81) = 3.27$, $p = .025$), stream^{x}instrumentation ($F(4, 108) = 2.94$, $p = .009$) and a close to significant interaction for stream^{x}metric location ($F(6, 162) = 1.91$, $p = .051$).

Bonferroni-corrected post-hoc tests showed that syncopated patterns in the one-stream condition (Mean = .26, SE = .29) were rated as less stable than in all other stream conditions; two-stream condition *a* (Mean = 1.54, SE = .20), two-stream condition *b* (Mean = 1.45, SE = .23) and three-stream condition (Mean = 1.68, SE = .21) (all p's > .001, Figure 3.6). There were no significant differences between the other stream-conditions. Syncopations in the hihat (Mean = 1.33, SE = .21) were rated as more stable than syncopations in the bass-drum (Mean = 1.1, SE = .22) ($p = .022$), but no differently to syncopations in the snare-drum (Mean = 1.25, SE = .22) ($p = .957$, Figure 3.7). There was no difference between the bass- and snare-drum ($p = .076$). Finally, the post-hoc tests showed that syncopations occurring on beat 4 (Mean = 1.51, SE= .22) were rated as more stable than when occurring on beat 3 (Mean = 1.02, SE = .22) ($p = .004$, Figure 3.8). There were no other differences between syncopations at different metric locations.

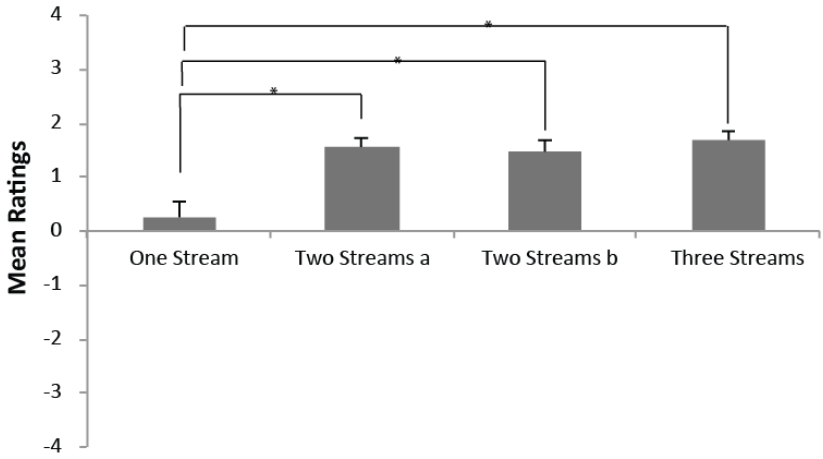


Fig. 3.6 Effect of number of streams on ratings of stability. Error bars = standard error.
* $p < .001$.

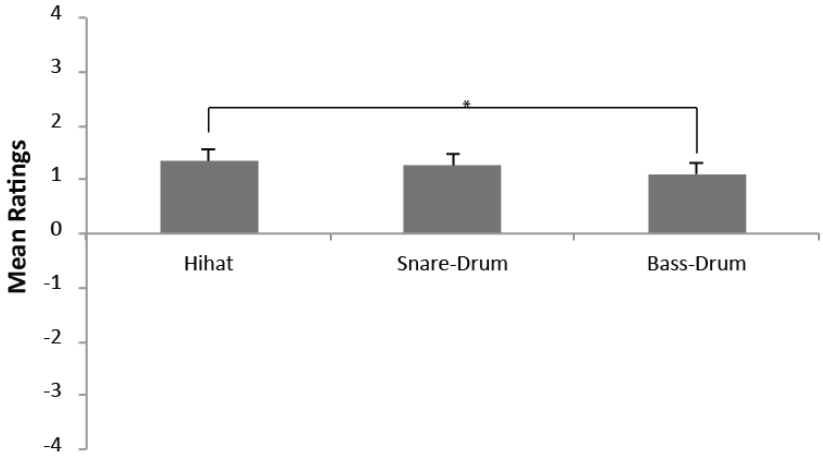


Fig. 3.7 Effect of instrumentation on ratings of stability. Instruments refer to the instruments being syncopated in the patterns of comparison. Error bars = standard error.
* $p < .001$.

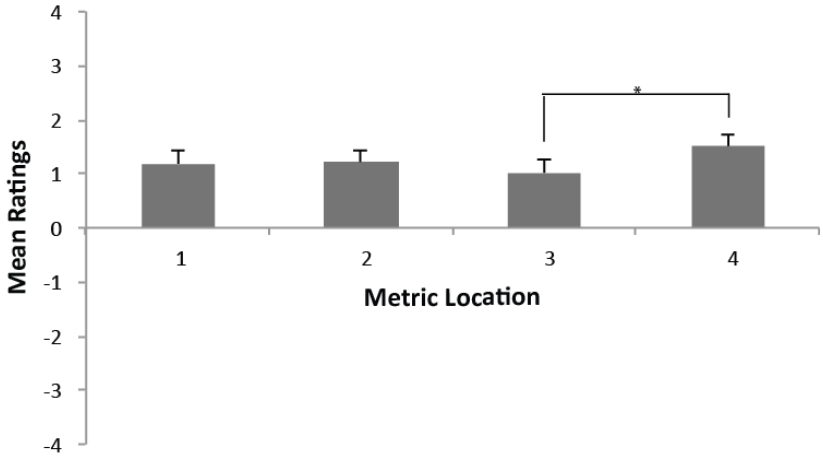


Fig. 3.8 Effect of metric location on ratings of stability. Error bars = standard error.
* $p < .001$.

Next, the nature of the interactions was investigated. To avoid comparing too many means, and thus reducing the statistical threshold extensively, the conditions of particular relevance to the hypotheses of the study were singled out for further comparisons.

Since the main effects had shown that, overall, one-stream conditions were rated as less stable than two- and three-stream conditions, and hihat syncopations were rated as more stable than bass-drum syncopations, the interaction between number of streams and instrumentation was further pursued by looking at the two- and three-stream conditions and snare- and bass-drum syncopations only. It was found that (Table 3.1), specifically, patterns with syncopations in the snare-drum were rated as significantly less stable when they occurred in two-stream condition *b*, (i.e. involving the hihat on the pulse) compared to the three-stream condition, but this difference was not found for the bass-drum. Furthermore, three-stream patterns with syncopations in the bass-drum were rated as less stable than three-stream patterns with syncopations in the snare-drum, but this difference was not found for the two-stream patterns. In other words, only when syncopations occurred in the snare-drum with the hihat on the pulse did a change from two to three streams (by adding the bass to the pulse) have an increasing effect on perceived stability, and there was only a decrease in perceived stability for syncopations occurring in the bass compared to the snare when the pattern consisted of three streams (Figure 3.9).

		Paired Contrasts	*t*	*p*
1	Bass	Two streams *a* vs. two streams *b*	1.77	.087
2		Two streams *a* vs. three streams	1.48	.150
3		Two streams *b* vs. three streams	-.03	.973
4	Snare	Two streams *a* vs. two streams *b*	1.55	.131
5		Two streams *a* vs. three streams	-1.56	.131
6		Two streams *b* vs. three streams	-4.10	<.001*
7	Two streams *a*	Snare-drum vs bass-drum	10	.923
8	Two streams *b*	Snare-drum vs bass-drum	.22	.830
9	Three streams	Snare-drum vs bass-drum	-3.37	.002*

Table 3.1 Paired contrasts for interaction effects of stream and instrumentation on ratings of stability. Df = 28, *Alpha adjusted, $p < .005$ (two-tailed).

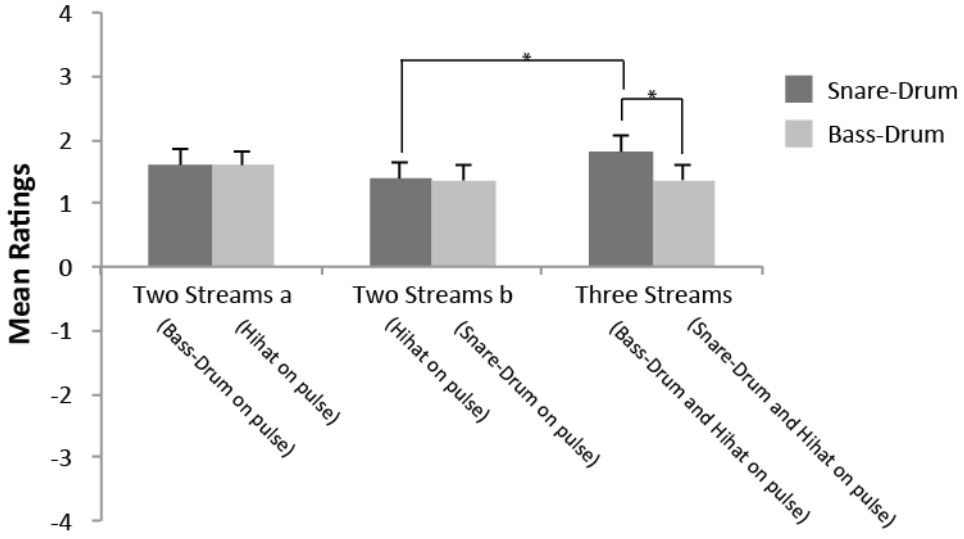


Fig. 3.9 Interaction effects of stream (two- and three-stream conditions) and instrumentation (snare- and bass-drum) on ratings of stability. Error bars = standard error. *Alpha adjusted, $p < .005$.

Since an overall difference in musical training had shown that musicians rated the patterns as more stable than non-musicians overall, the interaction between musical training and metric location was investigated by comparing means within each group separately only. For musicians, it was found that syncopations occurring on beat 1 were close to significantly less stable than when occurring on beat 2, and significantly less stable than when occurring on beat 4 (Table 3.2 and Figure 3.10). No other comparisons were significant. For non-musicians, it was only found that syncopations on beat three were significantly more stable than syncopations on beat four.

	Paired Contrasts		*Mean*	*SE*	*t*	*p*
1	Musician	Beat 1 vs. 2	-.47	.16	-3.00	.010^
2		Bear 1 vs. 3	-.29	.16	-1.81	.093
3		Beat 1 vs. 4	-.62	.15	-4.30	.001*
4		Beat 2 vs. 3	.18	.13	1.41	.181
5		Beat 2 vs. 4	-.16	.16	-1.00	.335
6		Beat 3 vs. 4	-.33	.22	-1.54	.147
7	Non-Musician	Beat 1 vs. 2	.36	.31	1.15	.267
8		Bear 1 vs. 3	.66	.30	2.22	.043
9		Beat 1 vs. 4	-.09	.31	-.30	.772
10		Beat 2 vs. 3	.30	.18	1.70	.110
11		Beat 2 vs. 4	-.45	.18	-2.58	.022
12		Beat 3 vs. 4	-.76	.20	-3.82	.002*

Table 3.2 Paired contrasts for the interaction effects of metric location and musical training on ratings of stability. Musicians N(df) = 14(13); Non-Musicians N(df) = 15(14). *Alpha adjusted, $p < .008$. ^Approaching significance.

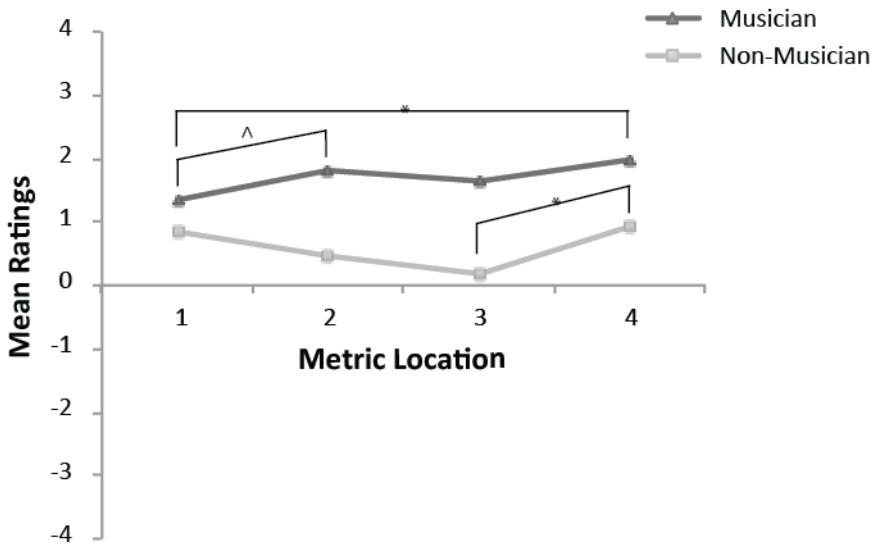


Fig. 3.10 Interaction effects of musical training and metric location. Error bars = standard error. *Alpha adjusted, $p < .004$

For the interaction between number of streams and metric location, syncopations at the different metric locations were compared within each stream condition. It was found (Table 3.3, Figure 3.11) that the effect of metric location only affected the one-stream condition and two-stream condition *b*. In the one stream condition, syncopations on beat 4 were rated as significantly more stable than syncopations on beat 1 and 3. In two-stream condition *b*, syncopations on beat 4 were rated as more stable than on beat 2, and almost significantly more stable than on beat 3.

	Paired Contrasts		*Mean*	*SE*	*t*	*p*
1	One Stream	Beat 1 vs. 2	-.38	.24	-1.61	.118
2		Bear 1 vs. 3	-.02	.28	-.09	.929
3		Beat 1 vs. 4	-.76	.26	-2.87	.008*
4		Beat 2 vs. 3	.36	.18	1.98	.058
5		Beat 2 vs. 4	-.38	.21	-1.81	.081
6		Beat 3 vs. 4	-.74	.22	-3.30	.003*
7	Two Streams *a*	Beat 1 vs. 2	-.05	.29	-.16	.871
8		Bear 1 vs. 3	.29	.29	1.01	.319
9		Beat 1 vs. 4	-.19	.25	-.77	.450
10		Beat 2 vs. 3	.34	.17	1.98	.058
11		Beat 2 vs. 4	-.15	.21	-.69	.494
12		Beat 3 vs. 4	-.48	.20	-2.39	.024
13	Two Streams *b*	Beat 1 vs. 2	.26	.24	1.10	.282
14		Bear 1 vs. 3	.22	.26	.85	.400
15		Beat 1 vs. 4	-.40	.22	-1.78	.086
16		Beat 2 vs. 3	-.04	.21	-.20	.843
17		Beat 2 vs. 4	-.66	.17	-3.76	.001*
18		Beat 3 vs. 4	-.61	.22	-2.79	.009^
19	Three Streams	Beat 1 vs. 2	.16	.24	.67	.510
20		Bear 1 vs. 3	.26	.23	1.15	.258
21		Beat 1 vs. 4	.12	.26	.47	.645
22		Beat 2 vs. 3	.10	.16	.65	.520
23		Beat 2 vs. 4	-.04	.15	-.25	.802
24		Beat 3 vs. 4	-.14	.20	-.71	.485

Table 3.3 Paired contrasts for the interaction effects of streams and metric location on ratings of stability. *Alpha adjusted, $p < .008$. ^Approaching significance.

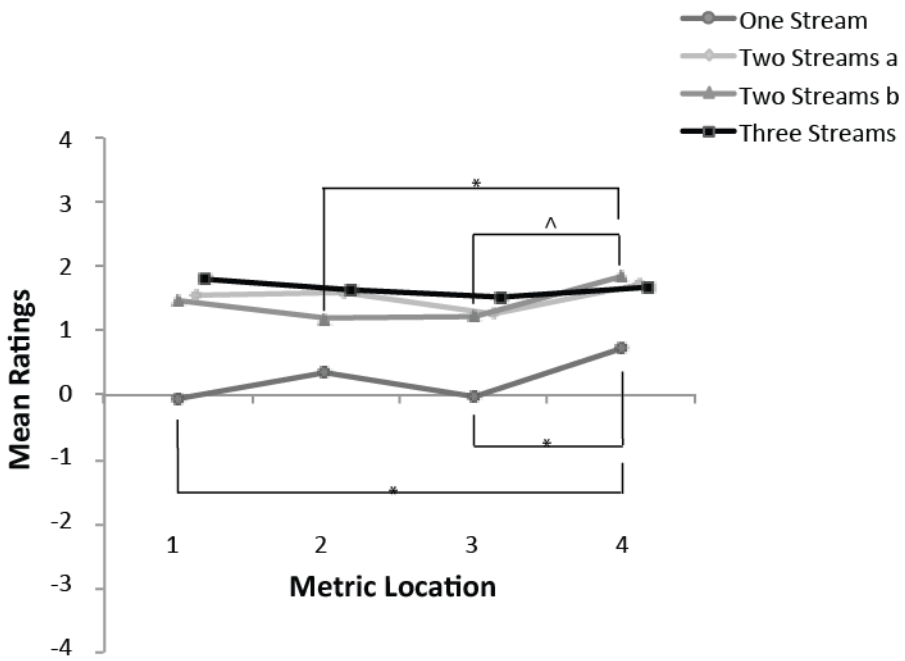


Fig. 3.11 Interaction effects of stream and metric location. Error bars = standard error. *Alpha adjusted, $p < .008$. ^Approaching significance.

3.4 DISCUSSION

The results show that the perceived stability of syncopated drum-kit patterns, according to both the tapping and rating data, was affected by the number of streams, instrumentation and metric location of the syncopation in ways that interacted with the polyphonic, instrumental and metric contexts, and with the musical training of the listener. Overall, musicians' tapping during syncopated patterns was more closely synchronised to the pulse and they also rated syncopated patterns as more stable than non-musicians. For both groups, syncopations occurring in one-stream patterns elicited close-to-significantly larger tapping errors compared to three-stream patterns, and these patterns were also rated as the least stable. Syncopations on beat 1 were the least stable, and syncopations on beat 4 were the most stable, as shown in both the tapping and rating data, although according to the ratings these patterns depended on the number of streams and musical training of the listeners. Furthermore, when syncopations occurred in the hihat, the patterns were rated as more stable than when syncopations occurred in the bass-drum or the snare-drum.

The interaction effects and subsequent contrasts for the rating data revealed that the relationship between ratings of perceived stability and number of streams of the rhythmic pattern depended on the type of instrument being syncopated. Thus, although there was no overall difference in ratings between patterns in which there were two instrumental streams (one syncopated and another on the pulse) and patterns in which there were three (one syncopated and two others on the pulse), there was a difference when the instrumentation of the syncopated stream was taken into account. This difference was observed when comparing syncopations in the bass- and the snare-drum: when it occurred in the snare-drum with only the hihat on the pulse, the syncopation was more salient than when both the hihat and the bass-drum were on the pulse. However, there was no difference between two- and three-stream conditions when the syncopation occurred in the bass-drum. Thus,

the first hypothesis was only partly confirmed: increasing the number of instrumental streams in patterns with syncopations, by gradually adding instruments to the underlying pulse, increases the perception of stability in a linear fashion, but only when adding the bass-drum as a third instrument to a syncopated snare-drum with the hihat on the pulse. For the bass-drum, this linear increase was only observed between one- and multiple-stream conditions, i.e. when comparing syncopations with no other instrument on the pulse with syncopations with one or two more instruments on the pulse. It made no significant difference when increasing from two to three streams for the bass-drum.[5]

Interestingly, this interaction between number of streams and instrumentation only regarded the two-stream condition in which the snare was accompanied by the hihat on the pulse (two-stream condition *b*) and not when it was accompanied by the bass-drum on the pulse (two-stream condition *a*). There was neither any effect for the two-stream condition in which the bass-drum was accompanied by the snare-drum. In other words, in the instrumentation-configurations that involved a combination of the snare-drum and bass-drum only, no differences in perceived stability were found.

Similarly, the second hypothesis was also only partly supported by the data: patterns with syncopations in the hihat were, overall, perceived as the most stable of the three instruments; but patterns with syncopations in the bass-drum were perceived as less stable compared to patterns with syncopations in the snare-drum only when there was an underlying pulse played by both remaining instruments, as in the three-stream conditions. When the pulse was played in one- or to two-stream conditions, the perceived stability was not affected by whether the syncopation was played by the bass- or the snare-drum.

At least three explanations for these findings seem immediately likely. First, there could be an acoustical reason why syncopated patterns in three-stream conditions are only

[5] However, it should be noted, that an earlier study, using a similar design, did find significant differences between the two- and three-stream conditions for both bass-drum and snare drum (Witek et al., 2010).

experienced as more stable than in two-stream conditions when the syncopation is played by the snare-drum, and why patterns with syncopations in the bass-drum are only experienced as less stable compared to patterns with syncopations in the snare-drum when the patterns have three streams. In other words, there could be something inherent in the acoustic properties of the bass-drum compared to the snare-drum that causes these effects. For example, it is possible that the darker timbre of the bass-drum is more salient (thus affecting perceived stability) only when it is heard in relation to the snare and the hihat *together* on the pulse. Figure 3.12 presents a spectrogram of the bass-, snare-drum and hihat sounds used in the study. The bass-drum has the lowest frequencies, followed by the snare-drum and hihat respectively. Another acoustic difference between the drum sounds lies in their ADSR (Attack – Decay – Sustain – Release) envelopes – the time it takes for a sound to reach its peak amplitude (rise time). In the present study, the rise times were the following for the instruments used: bass-drum = 24.40 ms, snare-drum = 1.81 ms and hihat = 1.21 ms. Thus it takes the longest for the bass-drum to reach its peak amplitude, and the shortest for the hihat to do so. Furthermore, the sounds have different durations. The bass-drum sound used in this study lasted for 212.24 ms, the snare-drum 73.33 ms and the hihat 67.35 ms.

In a related study, Hove et al. (2007) found that tapping accuracy to chords with microtemporal asynchronies between pitch onsets was affected by the changing perceptual centre caused by the asynchronies: the larger the asynchrony, the closer the perceptual centre became to the tapping target. With relevance to the present findings, they found that this effect increased when a low-pitched tone came after a high-pitched tone in the chord, indicating that sounds with lower pitch have a stronger perceptual salience than sounds with higher pitch.

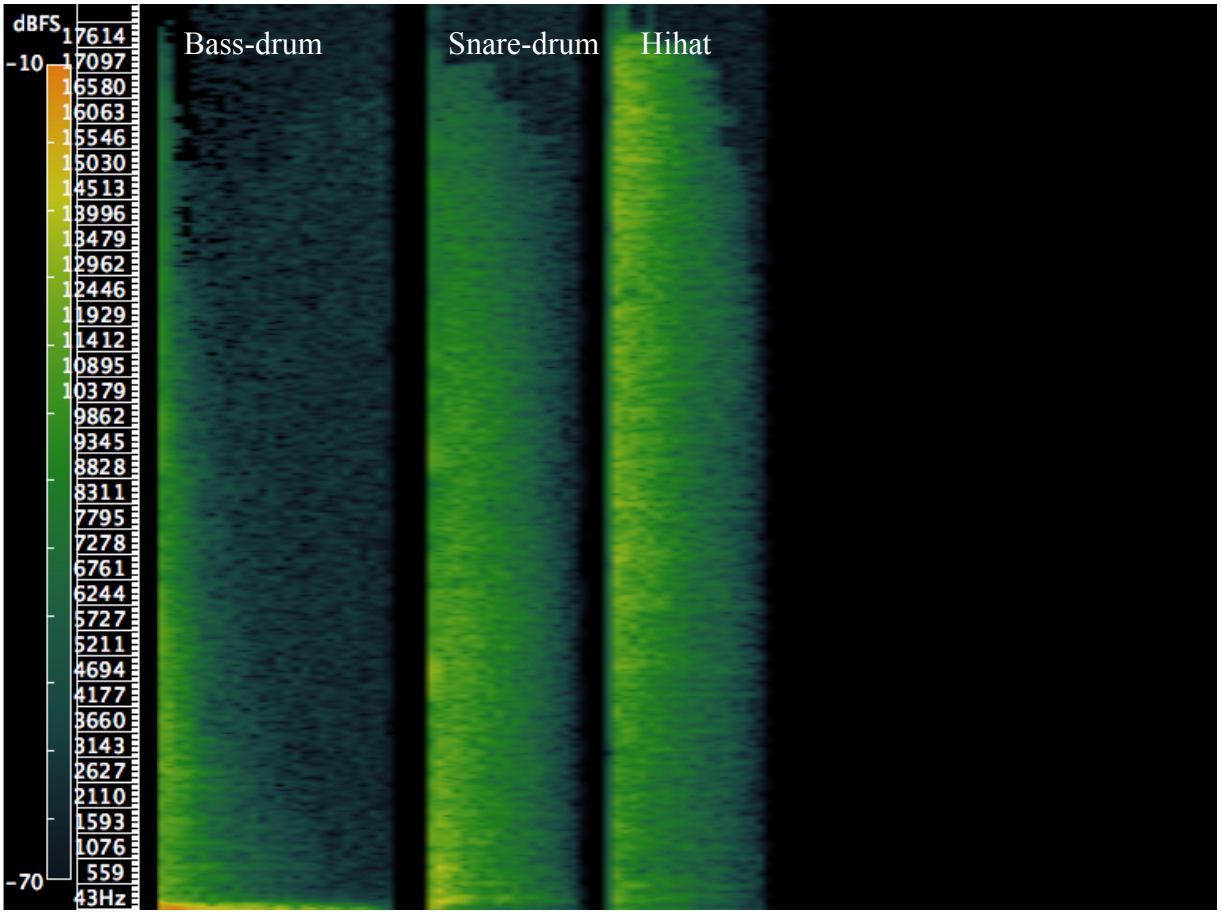


Fig. 3.12 Spectrogram (frequency on y axis, time on x axis and amplitude in colours) of the bass-drum, snare-drum and hihat sounds used in the study.

One possible explanation is *masking*: low tones mask high tones more than the reverse due to the 'upward spread of masking' (Moore, 1997), and low tones therefore have more salience when in close proximity to high tones. The syncopated events in the two- and three-stream conditions in the present study involved two or three different sounds in close proximity (one drum-sound occurred one semiquaver (125 ms) before the other drum-sounds), and thus it is possible that when the bass-drum occurred before the snare-drum and the hihat, it masked the snare and the hihat to a greater extent by virtue of its low frequencies, compared to when the snare-drum occurred before the bass-drum and the hihat. Furthermore, perhaps due to its high spectral frequencies, patterns with syncopations occurring in the hihat were systematically perceived as the most stable in the present study.

However, the bass- and snare-drums' masking abilities were no different when they were both only followed by the hihat, or when they followed each other only, without the hihat. Thus, the masking effect disappeared when the snare- and bass-drums were both followed by a brighter-sounding instrument, or when they were followed by a darker or brighter sound *only,* without a much brighter sound as well.

Similarly, the difference in durations might contribute to a masking effect: the longer duration of the bass-drum sound will mask the snare to a greater extent than the shorter duration of the snare-drum masks the bass. However, as with the possible timbre effect, any masking relating to duration can here only explain the effect on three-stream conditions. In other words, the instrumental context of the sounds seems to affect the degree of masking. It could be that the difference in timbre and duration for the bass- and snare-drum sounds is not great enough to produce the masking effect in relation to each other *only*, and that the instruments need to be heard in relation to a much brighter and shorter sound *as well*, i.e. the hihat, in order for the effect to occur.

Related to the interaction between number of streams and instrumentation, an exploratory study of tapping preferences to polyrhythms conducted by Handel and Lawson (1983) demonstrated that onset duration and pitch differentiation, among other aspects, affect the choices made by participants regarding which stream to tap along to. The authors conclude that the role of a single rhythmic layer is a function of the acoustic and musical context of the entire polyrhythm and not merely of its own temporal characteristics. This could be the reason why participants in the present study experienced syncopated patterns in different polyphonic configurations as eliciting different degrees of stability.

A second explanation of the findings is based on ecological association: the hypothesis is that darker sounds are perceived as more stable due to their association with heavier, and thus more stable and 'grounded' objects, and a dark sound is therefore

perceived as particularly unstable when it is syncopated. However, the results of the present study suggest that such an association can only explain the difference in perceived stability when darker sounds are in proximity with both a brighter sound and a much brighter sound: the destabilising effect of patterns with a syncopated bass-drum is no greater than for patterns with a syncopated snare-drum when there is no other instrument present, when they both have a only one brighter sound on the pulse (the hihat), and when the bass-drum is syncopated against the snare-drum only, without the much brighter sound of the hihat. In other words, ecological associations between sound and stability seems to be affected by instrumental context.

Finally, the results can be understood in terms of exposure and statistical learning – the idea that statistically more frequent events are more stable and thus less salient by virtue of their higher probabilities. In the three-stream conditions, a syncopated bass-drum may be more salient because it is less common than a syncopated snare-drum in real drum-kit patterns: in the majority of Western popular music, the bass-drum is usually played on the pulse, while syncopations are more commonly played by the snare-drum. Figure 3.13, for example, depicts a syncopated back-beat pattern, which in various forms permeates a large majority of popular music. Although there are patterns in which the instrumental configuration of the syncopation is reversed, this configuration is the most common. Thus, in accordance with the statistical-learning hypothesis, we experience patterns with syncopations in the bass-drum as more unstable in three-stream conditions because they occur less frequently in our musical environment than patterns with syncopations in the snare-drum in three-stream conditions. However, instrumentation made no impact on the difference between syncopations in two-stream conditions. It could be that, in patterns with only the hihat, snare- or bass-drum on the pulse, at the moment of syncopation, there is no significant difference in the statistical likelihood of syncopations occurring in the bass-

compared to the snare-drum. But the statistical-learning hypothesis cannot explain why patterns with hihat syncopations were perceived as the least destabilising, regardless of the number of streams, since this instrument is played on the quaver pulse in a large majority of popular music, and is only occasionally syncopated.[6]

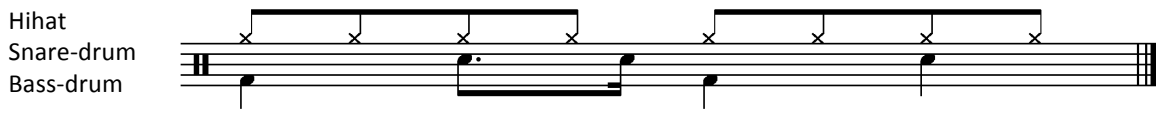


Fig. 3.13 Syncopated back-beat drum-pattern

The statistical-learning hypothesis was also considered by Hove et al. (2007), who propose that sounds with lower pitch are perceived as more salient because, due to exposure to certain kinds of music, lower-sounding tones are more expected to occur on the beat (e.g. walking bass in jazz, tuba in oompah music and bass-drum in electronic dance music). However, it could be that the bass-drum has been given this role in music in a non-arbitrary way because of its acoustic properties and ecological associations, e.g. its darker timbre, longer attack time and duration and association with more 'grounded' objects. Although there is little research dealing with the relationship between timbre and gravity specifically, studies investigating other kinds of cross-modal associations, such as between pitch and position in space, indicate strong learned associations (Eitan & Granot, 2006). However, based on the present results, it should be considered whether the association only relates to perceptual contexts in which the darker sounds are heard in relation to both brighter sounds and much brighter sounds: a darker sound on its own might not be experienced as having any more salience than a brighter sound, nor when in proximity with only a somewhat brighter sound. The present results situate rhythm

[6] As mentioned previously, there are jazz patterns in which the hihat is syncopated, such as variations of the hihat shuffle. However, compared to the pop back-beat patterns, such instrumental configurations of syncopated drum-kit patterns are less common.

perception in a more ecologically framed theory, in which perceptual tendencies are shaped both by perceivers' cognitive constraints and by the structures of the environment, in a reciprocal fashion (Clarke, 2005; Gibson, 1979). The salience of syncopations in rhythmic patterns specifies a degree of instability that depends on polyphonic and instrumental configuration, and in groove this instability affords ways in which listeners can engage with the music, for example through body-movement and dance.

The results of this study showed that patterns with syncopations on beat 1 produced more tapping errors than on beat 4, and that syncopations on beat 4 were perceived as more stable than patterns with syncopations on beat 3, albeit only in the one stream condition and two-stream condition *b*, and only for non-musicians. Musicians also rated syncopations on beat 1 as significantly less stable than on beat 4, and close-to-significantly less stable than on beat 2. These findings are consistent with a hierarchical model of metre, albeit without uniquely confirming to any specific model. Furthermore, the finding that degree of perceived instability caused by syncopations depended on the musical training of the listener generally confirms the hypothesis that listeners hear rhythm according to metric frameworks whose hierarchical structures differ according to musical training. However, since no further significant differences were found for patterns with syncopations occurring at different metric locations, for neither musicians nor non-musicians, a more detailed assessment of differing metric salience for these two groups cannot be proposed based on the present findings.

The study also indicated that the effect of metric location interacted with the number of streams. Specifically, the salience of syncopations in the one-stream condition and two-stream condition *b* was more affected by metric location compared to the salience of syncopations in the three-stream condition and two-stream condition *a*. It could be that the effect of instrumentation, rather than number of streams, was more influential in

patterns of three streams: as described above, the difference in perceived stability caused by the patterns with bass-drum syncopations compared to patterns with snare-drum syncopations only affected patterns with three streams. Although further research is needed to determine the exact relationship between syncopation, metric location and musical training, it is possible that metre perception is not as strictly hierarchical as some researchers and scholars believe (e.g Lerdahl & Jackendoff, 1983; Longuet-Higgins & Lee, 1984) and that, as Jones indicated in her definition of metre, rhythms are only '*sometimes* clearly accented and contribute to [metric hierarchies] (…)' (Jones, 2009, p. 81, italics added). In other words, metric hierarchies might only characterise metre perception in certain musical contexts and instrumental configurations. For example, in groove-based music, funk musicians often refer to the structural-developmental importance of 'the One' (Danielsen, 2006, 2011) and the metric dominance of the downbeat has been supported in empirical studies using rock drum-kit patterns (Ladinig et al., 2009). However, according to the present findings, it seems that instrumentation might have a more significant effect on perceived stability than metric salience in certain contexts.

Although interaction effects are clear from the ratings recorded in the study, it must be noted that there were none in the tapping data. It could be that listeners' sensorimotor synchronisation abilities in relation to syncopated patterns are less sensitive to such interactions, and that this more indirect measure of syncopation salience can only reveal more general mechanisms, such as the overall effect of musical training, monophonic syncopations, and the metric salience of the downbeat. More sophisticated measures of indirectly perceived stability might better determine the extent of the interaction effect. For example, event-related potentials and the mismatch negativity response measurable with EEG and MEG have successfully been related to temporal expectancy violations in rhythm in previous research (e.g. Mayville et al., 2001; Vuust, 2005; Winkler et al., 2009), and

such methods could be used in future investigations into the effects of polyphonic context and instrumentation on syncopation.

Alternatively, the discrepancy between the finger-tapping and rating data could be due to the much discussed limitations of rating data in general. As addressed in Chapter Two, measurements of subjective experiences are prone to contextually dependent confounds, and can thus be more variable than more implicit measures, such as finger-tapping. This could explain why complex interactions were found in the ratings compared to the tapping. However, since ratings remain the only way of accessing subjectively experienced phenomena, they provide a unique and necessary method of studying perception. Another study combining electrophysiological measures, as suggested above, and subjective ratings for the purpose of replicating the present findings, might provide clearer indications of the effects of polyphonic context on the perception of syncopation.

Other limitations of the study are its sole focus only on polyphonic instrumental configurations of drum-kit patterns, and its investigation of semiquaver-syncopations at crotchet locations only. It would be of particular interest to run the present study with different instrumental sounds in order to determine whether sounds are more salient due to their different masking abilities, ecological associations or statistical frequency in the repertoire. For example, using instruments among which the most frequently syncopated in the given repertoire have a darker sound (e.g. the bass-synth in dubstep), might shed more light on this question.

Despite these limitations, the knowledge acquired about the effects of instrumentation on the salience of syncopations in rhythmic patterns provides a more sophisticated and ecologically valid understanding of syncopation and rhythm. In the next chapter, an index of polyphonic syncopation is proposed, in which the results from the

present study are implemented, and which thus enables the modelling of syncopation in polyphonic drum-kit patterns.

CHAPTER FOUR

An Index of Polyphonic Syncopation

4.1 INTRODUCTION

As a result of the study reported in Chapter Three, the degree of syncopation in drum-kit rhythms with more than one instrumental layer can now be modelled. The drum-breaks of many funk tracks consist of different rhythmic patterns in different instruments of the drum-kit, related to each other in cross- and/or counter-rhythmic ways. Considering the rhythmic pattern in Figure 4.1, which is the famous 'amen break' from the funk track 'Amen, Brother' by the Winstons (1969), the degree of syncopation can be calculated in relation to the different instrumental combinations, as opposed to treating each instrumental layer separately (as would be necessary with the model of Longuet-Higgins & Lee, 1984).

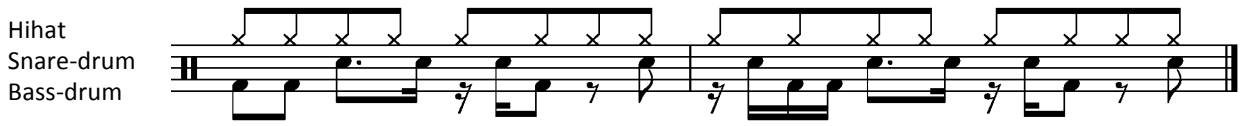


Fig. 4.1 The 'amen break' from 'Amen, Brother' by the Winstons (1969).

Intuitively, what makes this drum-break so compelling is not only that there are syncopations, but also that the drummer is alternating between the bass-drum and the snare-drum from metrically weak to metrically strong beats. Based on the findings of the study reported in Chapter Three, a new formal definition of syncopation is proposed here, which takes both monophonic and polyphonic contexts into account, and is sensitive to such rhythmic relationships between different instruments. The first part of the definition corresponds to the definition of monophonic syncopation proposed by Longuet-Higgins

and Lee (1984), while the second part stems from the results of the present study and deals with polyphonic context and instrumentation:

> *If N is a note that precedes a rest, R, and R has a metric weight greater than or equal to N, then the pair (N, R) is said to constitute a monophonic syncopation. If N is a note on a certain instrument that precedes a note on a different instrument, N_{di}, and N_{di} has a metric weight greater than or equal to N, then the pair (N, N_{di}) is said to constitute a polyphonic syncopation.*

Based on this definition, an index of polyphonic syncopation is proposed, according to which the degree of syncopation can be calculated for rhythmic drum-kit patterns.

4.1.1 A New Index of Polyphonic Syncopation

A polyphonic index of syncopation provides a way of calculating the overall degree of syncopation, based on both metric and instrumental weights. A number of points need to be made with regard to the index. First, although the increase in perceived stability from syncopations in two- to three-stream patterns was only found for patterns in which the syncopations occurred in the snare-drum, the index is based on the assumption that this positive linear relationship also exists for patterns in which syncopations occur in the bass-drum. This decision was made based on the findings of an earlier study investigating the same hypotheses using a somewhat different design (Witek et al., 2010). This study yielded exactly the same results as the study reported in Chapter Three with regard to the increased effect of perceived stability in three-stream patterns with snare-drum syncopations, compared to three-stream patterns with bass-drum syncopations. However, the increased perceived stability caused by three-stream conditions compared to two-stream conditions was found for both the bass- and the snare-drum syncopations, as opposed to only in the snare-drum, as was found in the study reported in Chapter Three. It was decided that the index should take the findings of the earlier study into account since,

overall, despite the lack of statistical significance for the bass-drum, mean ratings of stability in response to three-stream patterns were greater than in two-stream patterns for both instruments in both studies. This was also the case for the tapping-error means in two-stream compared to three-stream conditions (i.e. greater error values for two-stream conditions).

Second, although monophonic syncopations do occur in drum-kit rhythms, and the hihat can be syncopated against the other instruments, or can itself contain a monophonic syncopation, the overwhelming norm in funk (and many other genres) is for the hihat to play on every quaver. Thus, for simplicity and ecological validity, the current version of the index of polyphonic syncopation only considers drum-kit patterns in which the hihat is always on the quaver pulse.

Finally, the results from the study reported in Chapter Three were inconclusive in relation to metric salience. Since it appears that no single model of metric salience adequately reflects listeners' perceptual processes, the index of polyphonic syncopation presented here is designed so that it can adopt any metric model, either theoretical or empirical, that seems appropriate. Furthermore, the index presented here deals with 4/4 time signatures only, since the music of interest to the present research, i.e. groove, is almost exclusively in 4/4. The index can easily be adapted to other metric signatures, such as 3/4 (although assumptions are then made that syncopations are not affected by time signature). The flexibility regarding metric models also enables the index to be sensitive to listeners' backgrounds, both in terms of their musical training and exposure. For example, when comparing the effect of a funk drum-break to a rock drum-break, one could use metric weights in the index that differed according to the listeners' experience with the two genres, both in playing and listening.

For the purposes of this chapter, the metric model in Figure 4.2 is used. In this model, the downbeat at the semibreve-level has the strongest weight (0), as in Longuet-Higgins and Lee's model (1984). In the empirical study reported in Chapter Three, there were indications that the downbeat was the most salient metric location, a finding that is supported by previous research (Ladinig et al., 2009; Winkler et al., 2009). However, the subdivisions following the second level differ from Longuet-Higgins and Lee's model: rather than subdividing the bar into a minim level, and then a crotchet level, these two levels are conflated so as to reflect the lack of consistent empirical evidence regarding the differentiation of these metric levels (Ladinig & Honing, 2009; and results from study reported in Chapter Three). However, in light of stronger empirical evidence from other studies in relation to the subdivision of metric salience between the crotchet, quaver and semiquaver levels (Ladinig & Honing, 2009; Palmer & Krumhansl, 1990), metric weights are assigned from the crotchet level and downwards in the hierarchy, by recursively subdividing from one level to the next. The model is thus conservative and less culturally specific, since it makes no claim regarding the difference in metric salience at the middle levels of the hierarchy.

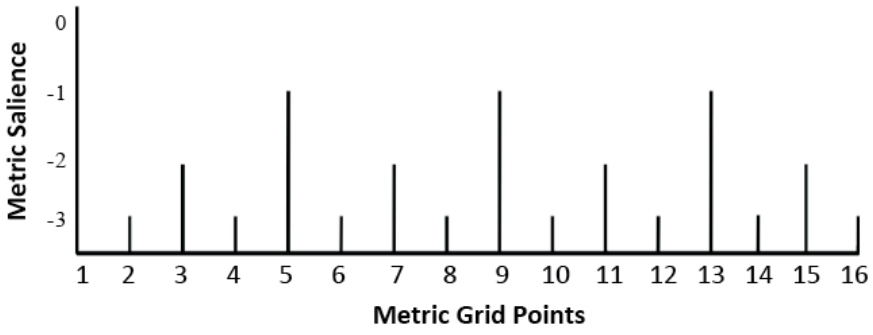


Fig. 4.2 Model of metric salience.

INDEX OF POLYPHONIC SYNCOPATION

Step 1: Assign metric weights to each metric location
Step 2: Locate instances of polyphonic syncopations.
Step 3: Assign instrumental weights: Three-stream syncopated bass-drum = 2, three-stream syncopated snare-drum = 1, two-stream syncopation = 5.
Step 4: Calculate degree of syncopation:

$$S = N - N_{di} + I$$

… where S is the degree of syncopation, N is the metric weight of the first note, N_{di} is the metric weight of the following note of different instrumentation and I is the instrumental weight of the syncopation.

Box 4.1. Index of polyphonic syncopation

The index is presented in Box 4.1. As an example of how the index works, consider the rhythmic pattern in Figure 4.3, which is the drum-break in 'Lifetime Monologue' by Lou Rawls (1968). In step 1, metric weights are assigned to each note at every metric location in the pattern, according to the model of metric salience in Figure 4.2. The weights range between -3 and 0, and the downbeats of each bar are always given the highest value (0). The lowest value, -3, is given to every semiquaver location. The remaining metric locations are assigned metric weights according to the model in the same fashion. In step 2, all instances of polyphonic syncopation are located, according to the definition above: where a note N on a certain instrument precedes a note N_{di} on a different instrument and N_{di} has a metric weight greater than or equal to N. In Figure 4.3, these instances are underlined.

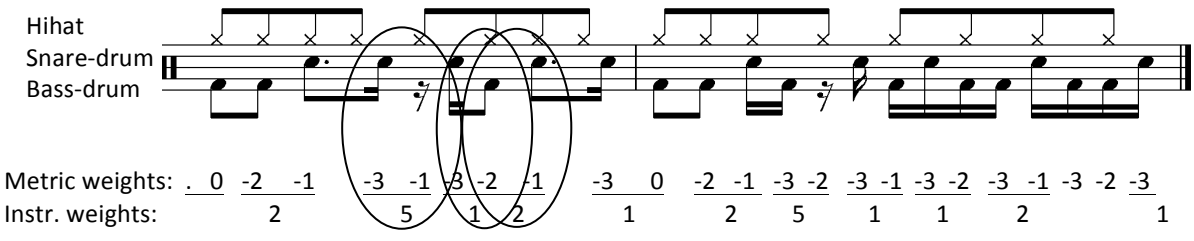


Fig. 4.3 Drum-break of 'Lifetime Monologue' by Lou Rawls (1968). Degree of syncopation = 41.

Next, the instrumental weights are assigned in step 3. The instrumental weight values are assigned to *pairs* of notes in the syncopation, as opposed to single events, as the instrumental weight depends on the relationship between the instruments in the pair. Since the results reported in Chapter Three showed that in three-stream conditions, a syncopated bass-drum with the snare-drum and hihat on the pulse was more destabilising than a syncopated snare-drum with a the bass-drum and hihat on the pulse, three-stream bass-drum syncopations are given an instrumental weight of 2 (i.e. bass-drum at metric location N followed by snare-drum and hihat at metric location N_{di}, where N is metrically weaker than or equal to N_{di}), while three-stream snare-drum syncopations are given an instrumental weight of 1 (i.e. snare-drum at metric location N followed by bass-drum and hihat at metric location N_{di}, where N is metrically weaker than or equal to N_{di}). For syncopations with only the hihat on the pulse, the instrumental weight is always 5, since syncopations in two-stream patterns were found to have a similar degree of stability regardless of the instrument (bass-drum or snare-drum) playing the syncopation. The value of 5 was chosen for the instrumental weight of this type of syncopation as it is the minimum value required to ensure that syncopations in two-stream contexts would always be calculated as having a greater degree of syncopation compared to syncopations in three-stream contexts, regardless of metric location.

In the fourth and final step, the degree of syncopation is calculated for each event of syncopation by adding the values of the instrumental weights to the values of difference in metric weights. For the first ringed syncopation in Figure 4.3, which is a two-stream syncopation, this means subtracting the metric weight of the snare-drum from the metric weight of the hihat and adding the instrumental weight of two-stream syncopations: $-1 - (-3) + 5$. Thus, the degree of syncopation here is 7. For the second ringed syncopation, which is a three-stream syncopated snare-drum with the bass-drum and the hihat on the

pulse, the metric weight of the snare-drum is subtracted from that of the bass-drum, before adding the instrumental weight of a three-stream syncopated snare-drum with the pulse in the bass-drum and hihat: -2 − (-3) + 1 = 2. The third ringed syncopation, which is a three-stream syncopated bass-drum with a pulse in the snare and hihat, has a value of -1 − (-2) + 2 = 3. The remaining instances of syncopation have values of 3, 4, 3, 6, 3, 2, 4 and 4 respectively (the last instance being between the last note of the pattern and the first downbeat of its repetition). The sum of all the instances of syncopations represents the degree of syncopation for the rhythmic pattern as a whole. For 'Lifetime Monologue', this amounts to 41.

By way of comparison, Figures 4.4 and 4.5 present two other rhythmic patterns, the former from the drum-break of 'Impeach the President' by The Honeydrippers (1973) and the latter from 'Actual Proof' by Herbie Hancock (1974). When compared to 'Lifetime Monologue', 'Impeach the President' has considerably fewer instances of syncopation, and none that are in two-stream configurations. This is reflected in an overall syncopation degree of 5 for this pattern. 'Actual Proof', however, has considerably more syncopations, many of which occur in two-stream conditions, even on the downbeat, which is the most salient metric location. According to the polyphonic index of syncopation, the pattern has a relatively high value of syncopation: 68.

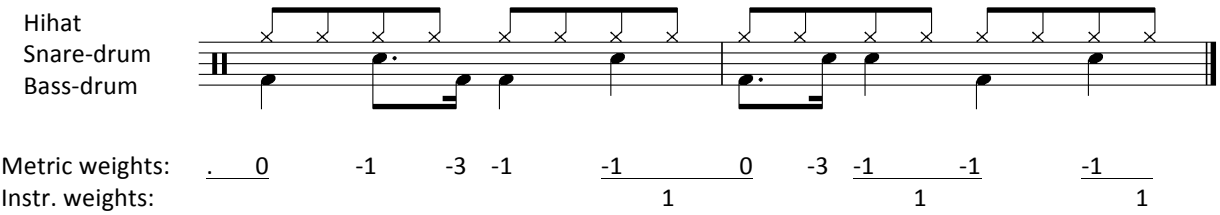


Fig. 4.4 Drum-break of 'Impeach the President' by The Honeydrippers (1973). Degree of syncopation = 5.

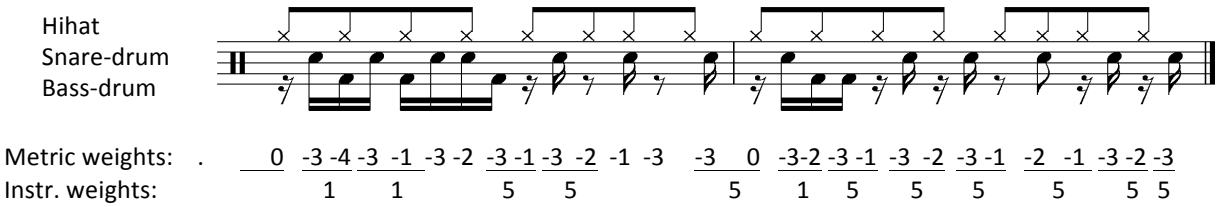


Fig. 4.5 Drum-break of 'Actual Proof' by Herbie Hancock (1974). Degree of syncopation = 68.

4.2 DISCUSSION

The index proposed enables the computation of polyphonic syncopation degree in drum-kit patterns using adaptable metric models, and thus provides a more ecologically valid model of syncopation, which is particularly suitable for empirical studies concerned with groove. Interestingly, the index also highlights an aspect of the way in which syncopation is theoretically defined. According to the definition proposed, a syncopation constitutes a *pair* of notes or a note and a rest, because it relies on the difference in metric and instrumental weights *between* them. However, in formal music theory, in which syncopation is usually only considered in monophonic contexts, the rhythmic disruption or instability that is associated with syncopation is assigned to the *first* of the pair, by referring to this note as 'syncopated'. The note is seen as 'displaced' from its metric location and shifted forward in time (for an example of this view, see Temperley, 1999). However, in perceptual terms, it is not until the arrival of the succeeding event that syncopation is properly experienced. In other words, only when the second event on the metrically stronger beat is a rest, or a note with a different instrumentation, is instability and unexpectedness experienced. At the moment of the first event, it is still possible that the second event will be a note of the same instrumentation and consequently not a syncopation. Thus, although the syncopation depends on both events in the pair, the experience of instability occurs predominantly at the moment of the second event.

Another way of thinking about syncopation is in terms of *anchoring*, a term coined by Temperley (2009, 2010). This view takes as its point of departure the premise that notes are expected to occur on metrically strong beats and rests are expected to occur on metrically weak beats. However, if these roles are reversed, different degrees of unexpectedness are experienced depending on the events at the surrounding metric locations. Thus, as opposed to attributing the unexpectedness to one of two notes in a pair, the anchoring view sees instability as being *caused* by the note on the weak beat, but *experienced* at different metric locations during the syncopation depending on whether and how the weak beat is anchored:

> Consider a weak eighth-note beat with stronger beats on either side (…). A note on such a beat is extremely unlikely if there is no note on either side (we call this an 'unanchored' note); it is only slightly more likely if there is a note only on the previous beat ('pre- anchored'), much more likely if there is a note on the following beat ('post-anchored'), and again very likely if there are notes on both beats ('both-anchored') (Temperley, 2009, p. 8)

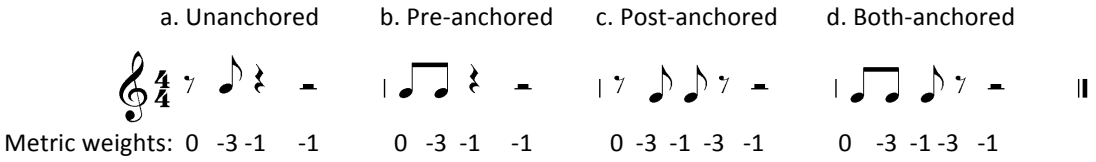


Fig. 4.6 Types of anchoring of notes on metrically weak beats.

Figure 4.6 depicts examples of different types of anchored weak beats. Understood in terms of Longuet-Higgins and Lee's (1984) definition, only the unanchored note constitutes a true syncopation, as it is the only case in which a metrically weak beat is followed by a metrically strong rest. According to the definition of polyphonic syncopation proposed above, the post-anchored and both-anchored notes are also syncopations, as long as the last event in question is played by a different instrument from the event immediately

preceding it. However, a pre-anchored weak note would not be regarded as a syncopation according to either definition, because here the first of the two events in the pair is the metrically stronger one: i.e. the strong beat precedes the weak beat. It is likely that pre-anchored weak beats also elicit a certain degree of perceived instability compared, for example, to a note on a metrically strong beat followed by a rest on a metrically weak beat.[1] Furthermore, it might be that a pre-anchored weak beat would elicit a greater degree of perceived instability if the weak beat were on a different instrument from the strong beat. None of these configurations of pre-anchored weak notes were investigated in the empirical study reported in Chapter Three, and so these hypotheses cannot be implemented in the index of polyphonic syncopation. Furthermore, the index of polyphonic syncopation considers only pairs of metric locations, and the concept of anchoring considers groups consisting of a maximum of three metric locations (as in the both-anchored weak notes): it might be that the stability of a note on a metrically weak beat depends on even more of the surrounding notes in a rhythmic pattern, or that a group of notes with a certain weight distribution is experienced as having a certain degree of stability depending on the distribution of weight in other groups of notes preceding or succeeding it. In other words, the context according to which syncopations are experienced could extend beyond the immediately adjacent notes, and empirical investigations into such effects might provide a richer and more sophisticated understanding of rhythm and metre perception that could be used to further develop the index of polyphonic syncopation. It might also reveal the exact distribution of attention and perceived instability caused by notes on weak beats, depending on the way they are anchored.

Nonetheless, using the index developed here, the degree of polyphonic syncopation for rhythmic drum-kit patterns can be estimated, contributing to a more sophisticated and

[1] In fact, this is what Temperley claims in his probabilistic model, based on the frequency of occurrence of such rhythmic events in the music repertoire.

ecologically valid theory of syncopation – a category of rhythmic structure that, despite its frequent occurrence in music in general, popular music in particular, and groove-based music most characteristically, is still poorly understood in music psychology and music theory.

CHAPTER FIVE

Syncopation, Body-Movement and Pleasure in Groove: An Online Rating Survey

5.1 INTRODUCTION

Chapters Three and Four have shown that syncopation is closely related to listeners' judgements of the stability of rhythmic sequences, and that an objective measure of the degree of syncopation in polyphonic drum sequences can be developed. The aim of this chapter is now to relate this structural component of rhythmic organisation – syncopation – to the feelings of pleasure, and the desire to move, that listeners may experience with groove. Research has shown (references given below) that structural complexity is an important contributor to pleasurable experiences with music, and an inverted U-shaped relationship has been demonstrated between complexity and positive affect. In groove, positive affect is related to synchronised body-movement, which relies on the mechanism of metre perception. However, the metre in groove is characteristically articulated in different ways, usually through different forms of rhythmic complexity, of which syncopation is the most common. Syncopation has been shown to elicit pleasurable responses in music more broadly, but the function of syncopation in eliciting pleasure and body-movement in groove is unknown. This chapter reports an online rating survey which investigated the relationship between ratings of movement- and pleasure- induction and syncopation, using the index of polyphonic syncopation presented in the previous chapter, as well as alternative measures of beat salience and entropy. Participants heard 50 funk drum-breaks with varying degrees of polyphonic syncopation, and rated the extent to which the drum-breaks made them want to move and how much pleasure they

experienced. An inverted U-shaped relationship was found between degree of syncopation and movement and pleasure ratings, indicating that grooves with medium degrees of syncopation elicit the most desire to move and the most pleasure. The ratings were also related to the degree of beat salience in an inverse U-shaped fashion. By contrast, entropy was found to be a poor predictor of movement-induction and pleasure in response to groove, though with some indication of an underlying linear relationship. There were no effects of musical training or familiarity with groove, but it was found that listeners who enjoy dancing to music want to move more and experience more pleasure with the drum-breaks than those who do not enjoy dancing. It was also shown that the polyphonic index of syncopation, as presented in Chapter Four, provided a better fit with ratings than a monophonic index. Finally, it is proposed that a medium degree of syncopation elicits the most desire to move and the most pleasure because it affords the optimal balance between the perception of metric and phenomenal rhythmic events, inviting the listener to embody the metre through synchronised body-movement.

5.1.1 Musical Complexity and Affect

Along with emotional responses (e.g. Gabrielsson, 2010; Juslin & Laukka, 2004; Ritossa & Rickard, 2004) and familiarity (e.g. Bradley, 1971; North & Hargreaves, 1997, 1998; Peretz et al., 1998; Schubert, 2007; Szpunar et al., 2004), structural complexity has been shown to be an important factor in the understanding of why people enjoy listening to music (e.g. North & Hargreaves, 1995, 1997, 1998). Most famously, Berlyne (1971) proposed that an inverted U-shaped curve reflects the relationship between aesthetic appreciation and structural complexity in art. According to this relationship, degree of complexity correlates positively with liking, arousal and pleasure up to an optimal point, after which a further increase in complexity correlates negatively with these measures.

Drawing on Yerkes and Dodson's work (1908), Berlyne postulated that positive experiences with art are greatest at intermediate degrees of complexity because psychological and physiological arousal levels are optimised at such levels; too little or too much arousal is avoided in art. The theory was first empirically demonstrated for music by Heyduk (1975), using objective measures of complexity in classical piano compositions, and was subsequently appropriated for ratings of subjective complexity in popular music (North & Hargreaves, 1995, 1997, 1998). However, what constitutes the optimal level of complexity depends on musical context (North & Hargreaves, 1997) and personality (McNamara & Ballard, 1999).

More recently, the inverted U-shaped relationship between complexity and musical appreciation has been studied with greater sensitivity towards musical expertise and genre. Orr and Ohlsson (2005) investigated the relationship between liking and perceived complexity in two contrasting genres, and found that the inverted U-shaped relationship only held for listeners with no training in the relevant musical genre. Their participants – jazz musicians, bluegrass musicians and listeners with either no or only moderate musical training – heard and rated both jazz and bluegrass improvisations for liking and subjectively perceived complexity. For listeners with moderate to professional training, the relationship depended on the musical-aesthetic values associated with the genre: specifically, there was no clear relationship between complexity and liking for professional musicians of jazz, a genre in which structural complexity is featured in both moderate (standard jazz) and extreme (free jazz) amounts. However, there was a negative linear relationship between complexity and liking for bluegrass musicians in response to bluegrass music, due to this genre's aesthetic criterion of simplicity. The inverted U-shaped curve was more consistently found for listeners with no or very little musical training, across genre. Thus, any investigation into the relationship between musical

structures and affective responses should consider the specific aesthetic criteria of the genre, as well as the backgrounds of the listeners.

5.1.2 The Psychology of Groove

The relationship between musical complexity and positive affect may also depend on the type of affective response associated with a genre. For example, while jazz and bluegrass might invite foot-tapping and dancing, a piece of classical music might afford contemplative listening. The former type of behavioural and affective response is the most commonly associated with music of groove-based genres. However, researchers concerned with groove have tended to focus on either the structural or the psychological characteristics, and rarely in combination. The former were originally studied by musicologists and ethnomusicologists, who described the different forms of rhythmic complexity, such as metric ambiguity (Butler, 2006), cross-rhythm (Danielsen, 2006) and microtiming (Carlsen & Witek, 2010; Danielsen, 2006, 2010; Keil & Feld, 1994). The psychological effects of groove were first considered theoretically, in the context of theories of embodied cognition (Iyer, 2002; Zbikowski, 2004) and prediction (Pressing, 2002), and were only later studied empirically. One of the first empirical studies found that 'wanting to move some part of the body in relation to some aspect of the sound pattern' was one of the most significant factors in subjective ratings of short excerpts of 'real' groove-based music (Madison, 2006, p. 201). However, no systematic attempt was made to determine what it was *about* groove that elicited such a response. More recently, in a study that investigated the relationship between similar ratings and a number of musical and acoustic properties of groove excerpts, Madison et al. (2011) found that the salience of the beat and the event density (sub-beat variability) correlated positively with groove ratings.

Janata et al. (2012) related movement-induction in groove more closely to positive affective experiences in an extensive study using short excerpts of 'real' groove-based music. They addressed phenomenological, behavioural and computational aspects of groove as a psychological construct, and showed that groove was consistently defined by listeners primarily as music that depended on its movement-inducing properties, but also that the extent to which they liked the music and felt 'in the groove', and the degree of beat salience, were important contributors to the definition. Next, relative to this definition, they found that participants' enjoyment increased with increasing 'groove' in a task involving passive listening and tapping. Although there was a preference for listening compared to tapping, they found that feelings of being 'in the groove' increased when participants tapped with the music. There was also an effect of groove on tapping difficulty and spontaneous movement, showing that music rated as having 'high' degrees of groove were rated as enabling easier tapping and elicited more task-irrelevant foot- and head-movements. Finally, they measured the degree of synchrony between periodicities in the music and tapping, and found increased tapping synchrony for 'high' grooves, and grooves which were reported as eliciting the experience of being 'in the groove'. Thus, it seems groove quality depends on the degree of sensorimotor coupling in ways that interact with positive affect. This study represents a significant advance towards understanding the relationship between groove, body-movement and pleasure, but, as with previous studies, makes little attempt to relate psychological processes to the structure of the music.

In a study with this aim, Witek (2009) measured listeners' physiological responses to whole pieces of groove-based music and found that during large-scale changes – such as transitions from the main groove to the drum-break in a funk track, and at moments of gradual introduction of new textural layers – levels of heart rate, skin conductance and respiration rate increased. Such physiological responses to music, or 'musical chills', are

indicators of strong emotional engagements with music (see Grewe et al., 2009 for a review). However, the structures that seemed to elicit this effect were similar to those often found to induce physiological arousal in classical music, through the stimulation of large-scale structural expectations (Grewe et al., 2007a, 2007b; Guhn et al., 2007; Nagel et al., 2008; Sloboda, 1991) and were less related to the rhythmic characteristics of groove and its movement-inducing properties.

5.1.3 Groove-Induced Body-Movement and Metre Perception

The body-movement and dance associated with groove-based music is overwhelmingly periodic. Although there are stylistic differences in groove-based genres, most groove-induced dance is synchronised to the metre of the music. In a motion-capture study, Toiviainen et al. (2010) showed that although higher and lower metric levels were embodied in different body-parts during spontaneous dancing to an instrumental tune with a blues progression, the levels of the main pulse and minim were the most salient (depending on whether considered with regard to potential or kinetic energy). One needs only enter a dance club to see that the main pulse is the metric level with which dancers are most consistently synchronised.

In order to understand the synchronisation of body-movements with the main pulse or other metric levels, we need first to consider the psychological mechanisms involved in metre perception. Metre perception involves the perception of a rhythm's regular metric pulses (see Honing, 2012; Jones, 2009 for reviews). Importantly, a pulse can also be perceived when some of the pulse onsets are not acoustically sounded. A syncopated monophonic rhythm is a good example: despite onsets occurring at metric locations that are expected to be rests, and rests occurring at metric locations that are expected to have onsets, the rhythm as a whole is able to establish the metre to a sufficient extent that the

main pulse is perceived. Because the pulse is isochronous, and its IOIs are continuous, the pattern of the pulse can be predicted very quickly from the early events of the rhythm. Thus, occasional omissions of phenomenal events at pulse points (i.e. metric events) do not obscure the sense of the pulse: Indeed, the sense of syncopation itself depends on picking up the pulse. However, if the pulse onsets are omitted to an extent that the pulse cannot be perceived, metre perception breaks down. As noted in Chapter Three, the effect of syncopation on metre perception is often studied by measuring sensorimotor synchronisation and tapping performance, with the assumption that more accurate synchronisation indicates better metre perception (e.g. Fitch & Rosenfeld, 2007). By extension, if groove-induced dance is synchronised to the main pulse of the music, then groove cannot be syncopated to such an extent that the main pulse is obscured and metre perception is prevented.

5.1.4 Effect of Syncopation on Pleasure

Syncopation and other rhythmic structures that rely on temporal expectations, such as microtiming and rhythmic ambiguity, are forms of rhythmic complexity that characterise groove structurally. As mentioned previously, microtiming is often described as rhythmic deviations from metric grid points, while certain forms of metric ambiguity, such as 'turning the beat around', require listeners to 're-align' their metric frameworks. Syncopation is a form of expectancy violation that permeates almost all groove-based music.[1] As reviewed in Chapter Three, the cognitive effect of syncopation on expectancy violation has been studied empirically in a number of ways. However, until recently, studies of the effect of expectation violation on emotional responses have largely focused on melodic and harmonic structures in music (see Grewe et al., 2009 for a review), and the

[1] Some forms of electronic dance music, such as 'happy hardcore' and 'minimal techno', are exceptions.

effects of rhythm and syncopation on positive affect have been ignored (Gomez & Danuser, 2007; Sloboda, 1991 are exceptions). Keller and Schubert (2011) have now not only shown that syncopated melodies were rated as being more enjoyed and 'happy', but that such positive emotional responses were more reliable than ratings of complexity, tension and arousal, indicating that in musical contexts, syncopations are engaged with in more affective than cognitive ways. However, as they point out, their study only considered moderate degrees of syncopation, and they predicted that a more consistent, possibly U-shaped, relationship might exist between a greater spread of syncopation values and complexity, arousal and tension.

5.1.5 Hypotheses

Although syncopation is widely perceived as being an important rhythmic feature in groove, its study has been neglected in favour of other structures of rhythmic complexity, particularly microtiming (e.g. Carlsen & Witek, 2010; Danielsen, 2006, 2010, 2012; Iyer, 2002; Keil & Feld, 1994; Madison et al., 2011; Naveda et al., 2011), and its pleasure- and movement-inducing properties have remained largely unexplored. Since we know that: a) groove elicits the desire to move and feelings of pleasure; b) there is some evidence suggesting that syncopation elicits pleasurable responses; and c) syncopation is an important structural feature of groove, it could be that syncopation is in fact related to the desire to move and feelings of pleasure in groove. Investigating whether there is any basis for this relationship is the principal aim of the study reported in this chapter. Since the body-movements associated with groove-based music are primarily entrained to the main pulse, it is likely that the desire to move is maximised by syncopated grooves that optimise such sensorimotor synchronisation. Hence, grooves that are syncopated to an extent that makes the underlying pulse unperceivable are not likely to elicit a strong desire to move.

Furthermore, grooves with little or no syncopation are also unlikely to elicit the desire to move, since such rhythms lack the rhythmic complexity that defines groove. Rather, grooves with medium degrees of syncopation seem the most likely to elicit body-movement and dance. Thus, it was hypothesised that there would be an inverted U-shaped relationship between syncopation in groove and wanting to move; and since musical complexity is known to relate to pleasurable responses to music in an inverted U-shaped fashion, and pleasure is known to be related to syncopation generally and to body-movement in groove specifically, it was hypothesised that there would be an inverted U-shaped relationship between feelings of pleasure and syncopation in groove. Finally, although syncopation has been shown to relate more closely to affective than cognitive responses in 'real' musical contexts (Keller & Schubert, 2011), musical training is known to affect the perception of syncopated patterns (see Chapter Three). Furthermore, genre expertise affects the relationship between complexity and positive affect (Orr & Ohlsson, 2005) and, according to ecological and embodied theories of perception, the active engagement with music defines the ways in which the music is perceived. This study therefore investigated whether the musical background (musical training, groove familiarity and dance-related experiences) of listeners affects the desire to move and feelings of pleasure induced by syncopated grooves. Finally, the applicability of the polyphonic index of syncopation proposed in Chapter Four in explaining listeners' ratings was compared with previous monophonic measures. The study adopts a web-based rating approach, inviting listeners anywhere in the world to take part.

5.2 METHOD

5.2.1 Participants

66 participants aged between 17 and 63 (Mean = 30.14, SD = 10.79), from countries in Europe, Oceania, Africa, America and Asia, completed the survey on an unpaid voluntary basis. Due to a fault with the demographics questionnaire, sex was only recorded for 44 participants (20 females, 22 males). The questionnaire (Appendix Three) recorded how many years of musical training they had undergone, and at what age they started playing an instrument. Participants also indicated the degree to which they enjoyed listening to groove-based music and dancing to music, and the frequency with which they danced to music, on 5-point Likert scales (from 1 = not at all/never, to 5 = very much/very frequently). Finally, they were asked to report whether they used good quality headphones for the experiment, in order to optimise the technical control of the online experiment.

5.2.2 Stimuli

The stimuli consisted of 50 drum-breaks programmed using a synthesised drum-kit (bass-drum, snare-drum and hihat) in GarageBand 5.1 (Apple, Inc.). Each break consisted of two-bar phrases looped four times in 4/4 time at 120 bpm, each break therefore lasting 16 seconds. Syncopations occurred in a number of configurations among the bass- and snare-drum, while the hihat kept a constant quaver pulse. Appendix Four shows transcriptions of all the drum-breaks and their degree of polyphonic syncopation, beat salience and entropy. Recordings of the drum-breaks are provided on the accompanying cd.

The degree of syncopation was calculated using the polyphonic index of syncopation incorporating the model of metric salience proposed in Chapter Four. Out of the 50 drum-breaks, 36 were transcribed from real funk tracks, while the remaining 14 were constructed for the experiment, in order to increase the spread of syncopation at both

ends of the spectrum (i.e. very unsyncopated, and very syncopated) and to avoid correlations with the number of onsets, as event density has been shown to affect groove responses (Madison et al., 2011).

As the salience of the beat has traditionally been considered an important contributor to rhythmic complexity (Palmer & Krumhansl, 1990), and has been shown to affect movement induction in groove (Madison, et al., 2011), the stimuli were also indexed according to beat salience, computed as the autocorrelation of metric frequencies present in the stimuli (i.e. the self-similarity of energy as a function of time lag), with a sampling rate of 160 lags per second, and measured at five metric levels of each drum-break.[2] The metric levels/frequencies included in the measure were lags at 0.125 seconds (8 Hz, semiquaver), 0.25 seconds (4 Hz, quaver), 0.5 seconds (2 Hz, crotchet), 1 second (1 Hz, minim) and 2 seconds (0.5 Hz, semibreve, or bar). Beat salience was defined as the mean amplitude at each of these lags and five neighbouring lags on either side (i.e. mean across 11 samples). Only lag amplitudes for onsets from bass- and snare-drum sounds were computed, and these were fed into the model as a single stream (i.e. monophonically). The hihat was not considered, as it was held constant on the quaver and would thus cancel out any effects of the snare- and bass-drum if included. Figure 5.1 presents an example of the output of an autocorrelation analysis of the drum-break from 'God make me funky' by the Headhunters (1975), which shows that events at the frequency of the bar level (0.5 Hz) are the most frequent, while there are no events at all at the quaver level (4 Hz). This drum-break had a beat salience value of 10.53.

[2] Despite representing the salience of metric levels, this variable is still referred to as 'beat salience' here, to avoid confusion with the measure 'metric salience' studied and discussed in Chapters Three and Four.

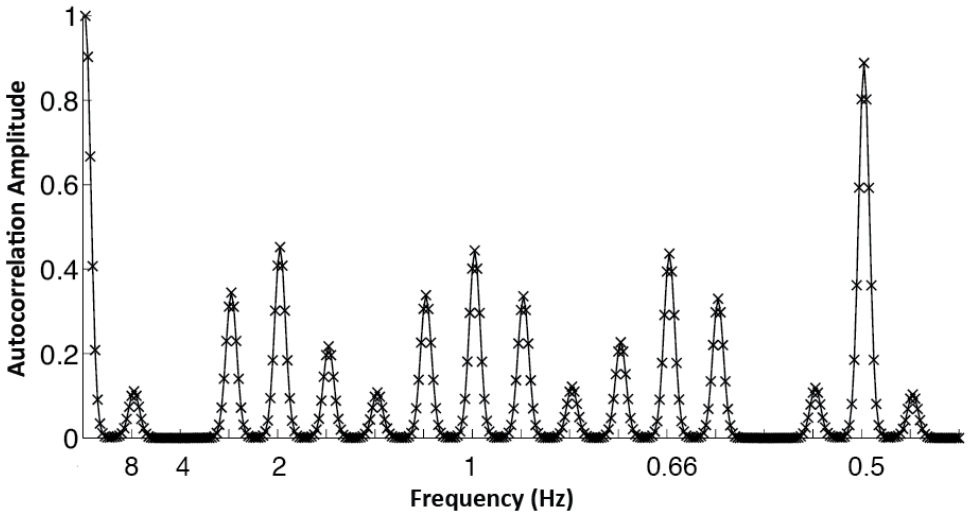


Fig. 5.1 Example of autocorrelation analysis, i.e. beat salience, of drum-break from 'God make me funky' by The Headhunters (1975).

The number of onsets in each drum-break was not held constant and it is possible that this would affect ratings. In order to control for this possible confounding variable, a further measure, here called the 'joint audio entropy' of the drum-breaks, was computed. Joint entropy is defined by the probability of more than one independent event occurring given a particular distribution model (Temperley, 2007). Thus, in the context of the drum-break audio, the joint entropy reflects the probability of each wave data sample occurring in relation to the distribution of data samples in the drum-break as a whole. For example, in rhythms with a fast and variable change in instrumentation, such as a drum-break with many onsets on different drums alternating frequently in complex and syncopated ways, the probability of a specific audio sample is low because it occurs rarely. The joint audio entropy of this drum-break is therefore high. Alternatively, in drum-breaks with few onsets on few drums alternating only rarely, the probability of a specific sample is higher, because it occurs more frequently in the audio. Such a drum-break would have low joint audio entropy. In this way, joint audio entropy represents the objective energy complexity of the audio input, and serves as a reasonable approximation to the event density measure used in the study by Madison et al. (2011), although not confined to the sub-beat level. It

was decided to measure such audio complexity across the whole metric framework, as opposed to just the sub-beat level, since the syncopations were not confined to the sub-beat level. The MATLAB (2012, Mathworks, Inc.) function Joint Entropy was used for this purpose (Dwinnel, 2010), and measurements are reported in bits. It is important to note that beat salience and joint audio entropy are measures entirely derived from the objective acoustic information of the drum-breaks, while the syncopation measure is based on a model derived from empirical data, and represents perceptual properties.

5.2.3 Procedure

Participants were invited to visit a webpage to take part in the survey. After completing the demographics questionnaire, they heard two drum-breaks, which were not part of the experiment, but during which they were asked to adjust the volume on their computers to an enjoyable but comfortable level. Then each experimental drum-break was presented individually, in a fully randomised order. During each drum-break, participants were asked to rate:

- How much does this rhythm make you want to move?
- How much pleasure do you experience with this rhythm?

Ratings were recorded on 5-point Likert scales (from 1 = not at all/none, to 5 = very much/a lot). Participants were able to proceed to the next drum-break only after they had heard the whole of the previous drum-break. The whole experiment lasted 20–30 minutes.

5.3 RESULTS

Overall, the results of this study strongly support an inverted U-shaped relationship between degree of syncopation and ratings of wanting to move and feelings of pleasure. The same pattern was found for the relationship between beat salience and these ratings.

Entropy was a poor predictor of wanting to move and feelings of pleasure but, although a negative quadratic relationship with ratings cannot be ruled out, there were some trends suggesting that entropy was linearly related to ratings, in a positive fashion. In what follows, the ways in which these main results were obtained will be described in detail, and a number of other results reported. The results are divided into sub-sections describing each analysis followed by the results of that analysis.

5.3.1 Correlations

5.3.1.1 Analysis

First, the different stimulus descriptors – syncopation (S), beat salience (BS) and joint audio entropy (JAE) – were tested for correlations, followed by testing for Pearson's correlations between the rating questions.

5.3.1.2 Results

Table 5.1 shows, importantly, that S did not correlate with any of the other descriptors. Thus, we can be confident that the measure of syncopation is not confounded with any of these other stimulus features. However, BS correlated positively with JAE. This can be explained by the fact that more onsets (i.e. greater entropy) cause greater lag amplitudes (i.e. stronger metric frequencies). There was also a strong positive correlation between ratings of wanting to move and feelings of pleasure ($r = .964$, $p < .001$).

	Syncopation	*Beat Salience*	*Joint Audio entropy*
Syncopation		-.261	.259
Beat salience	-.261		.706*
Joint audio entropy	.259	.706*	

Table 5.1 Pearson's *r* for stimulus descriptor correlations. *$p < .05$.

5.3.2 Individual Curve-Fitting

5.3.2.1 Analysis

As a first indication of the relationship between movement- and pleasure-ratings and S, BS and JAE, each subject's ratings were first regressed against the drum-breaks with the three audio descriptors as predictors. Of primary interest was whether the relationships were linear or quadratic. Thus, both a straight line and a parabola were fitted to each subject's ratings as indexed by the descriptors.

5.3.2.2 Results

Figure 5.2 shows each subject's ratings fitted with both linear and quadratic regressors, for predictors and rating questions separately. The black line represents the fit to mean ratings. It can be observed that the quadratic models appear more convergent across participants for S and BS, but that the difference between linear and quadratic fit is less pronounced for JAE.

5.3.3 Model Comparisons

5.3.3.1 Analysis

In order to test whether these observations were statistically significant, a three-way ANOVA was performed on the adjusted R^2 value for each subject's linear and quadratic regression as the dependent variable; and predictor, rating question and model as independent variables. It is important to use the adjusted R^2 when comparing models with different numbers of terms, such as when comparing linear (one-term) with quadratic (two-term) models. In PASW, the adjusted R^2 is derived from the R^2 using Wherry's equation, which is given by the formula (n is number of subjects, k is number of predictors):

$$Adjusted\ R^2 = 1 - (1 - R^2)\frac{(n-1)}{(n-k-1)}$$

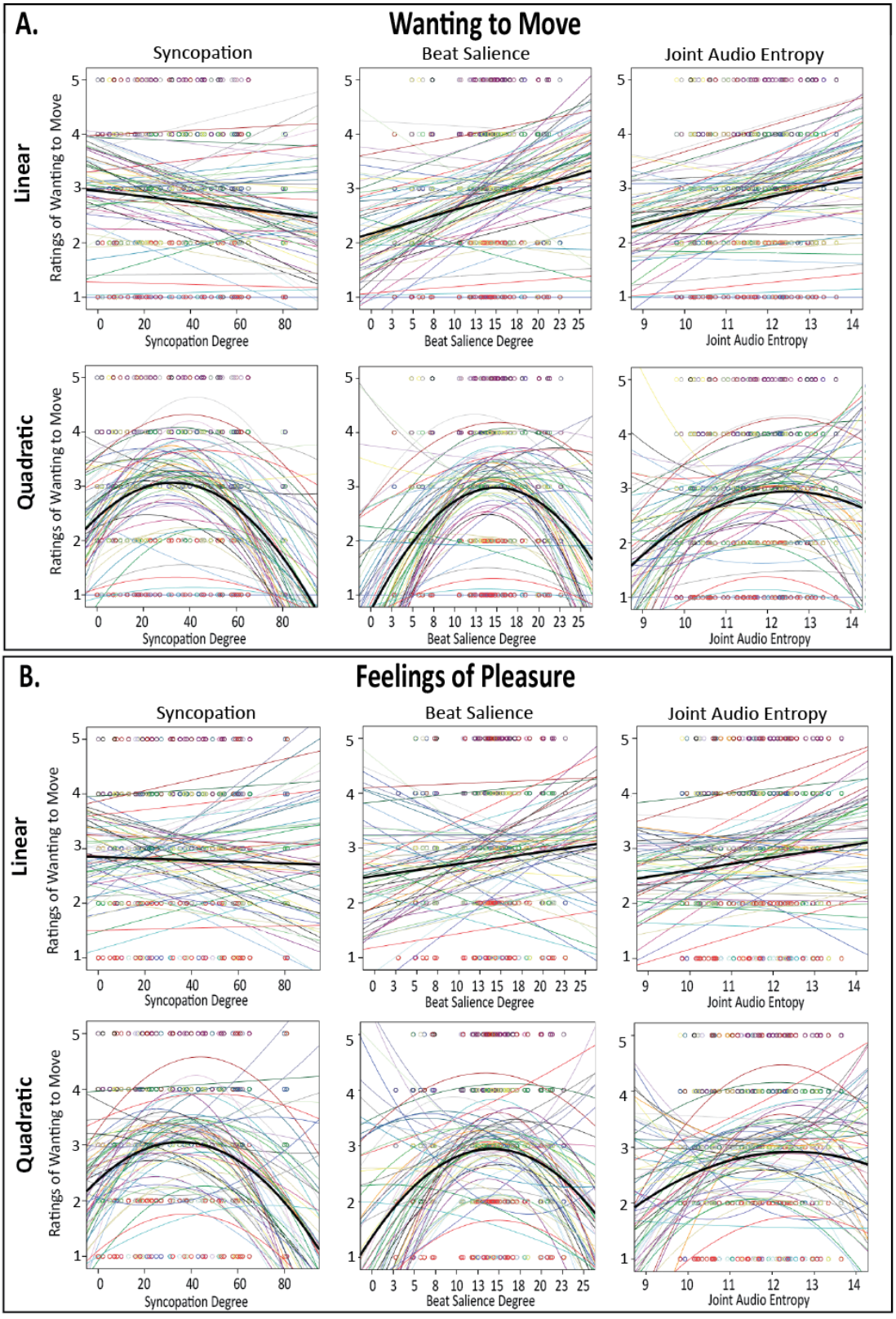


Fig. 5.2 Linear and quadratic curve-fitting of predictors – syncopation, beat salience and joint audio entropy – and ratings of **A.** wanting to move **B.** feelings of pleasure. Coloured lines represent individual subjects' ratings; black line represents mean ratings.

Compared to the normal R^2, which represents the amount of variance in the sample that can be accounted for by the model, the adjusted R^2 represents the amount of variance had the model been derived from the wider population from which the sample is taken. The account of number of subjects in the adjustment controls for the overfitting of data. Importantly, it also includes a penalty for models with higher polynomials: adding terms to a regression increases the R^2, but at the expense of a more complex model. The adjusted R^2 accounts for this complexity, ensuring that when comparing a linear to a quadratic model, the quadratic model has no intrinsic advantage due to its greater complexity. The outcome of the ANOVA indicates how well each model fits across participants, depending on whether the drum-break was considered in terms of syncopation, beat salience or entropy, and with regard to the desire to move or feelings of pleasure. However, it does not indicate whether the best-fitting models are negative or positive. This issue is addressed in subsequent analyses reported below.

5.3.1.2 Results

The results (Table 5.2) show significant main effects of predictor and model, but not of rating question. There were also significant interactions between predictor and model and between rating question and model. The interaction between predictor and rating question approached significance.[3] The interactions were followed up with t-tests, corrected for multiple comparisons. For the interaction of predictor with model, test statistics are reported in Table 5.3 and means depicted in Figure 5.3. It was found that quadratic models fitted the data better than linear models for S and BS, but not for JAE (Contrasts 1–3). There were no significant differences between S and BS for either model (Contrasts 4–5),

[3] For sphericity-assumed degrees of freedom, the alpha was significant at $p = .046$.

but the quadratic models of S and BS had significantly higher adjusted R^2 values than JAE (Contrasts 6 and 8).

Main Effect	*F*	*df(error)*	*p*
Predictor	14.31	1.77(114.96)	<.001
Model	103.26	1(65)	<.001
Rating Question	.03	1(65)	.866
Predictor x Model	25.21	1.49(97.09)	<.001
Rating Question x Model	4.90	1(65)	.030
Predictor x Rating Question	3.14	1.47(95,63)	.063

Table 5.2 Main effects of predictor, model, rating question, and interaction on adjusted R^2. Greenhouse-Geisser corrected df.

	Contrasts		*Mean*	*SE*	*t*	*p*
1	Quadratic vs Linear	Syncopation	.0919	.0120	7.65	<.001*
2		Beat Salience	.0847	.0108	7.83	<.001*
3		Joint Audio Entropy	.0095	.0040	2.38	.020
4	Syncopation vs Beat Salience	Quadratic	0.0102	0.0181	0.56	.574
5		Linear	0.0030	0.0106	0.28	.776
6	Syncopation vs Joint Audio Entropy	Quadratic	0.1010	0.0166	6.08	<.001*
7		Linear	0.0185	0.0138	1.35	.183
8	Beat Salience vs Joint Audio Entropy	Quadratic	-0.0907	0.0131	-6.91	<.001*
9		Linear	-0.0155	0.0082	-1.87	.065

Table 5.3 Paired contrasts for effects of predictor (syncopation, beat salience and joint audio entropy) and model (quadratic and linear) on adjusted R^2. Df = 65, *Alpha adjusted $p < .005$.

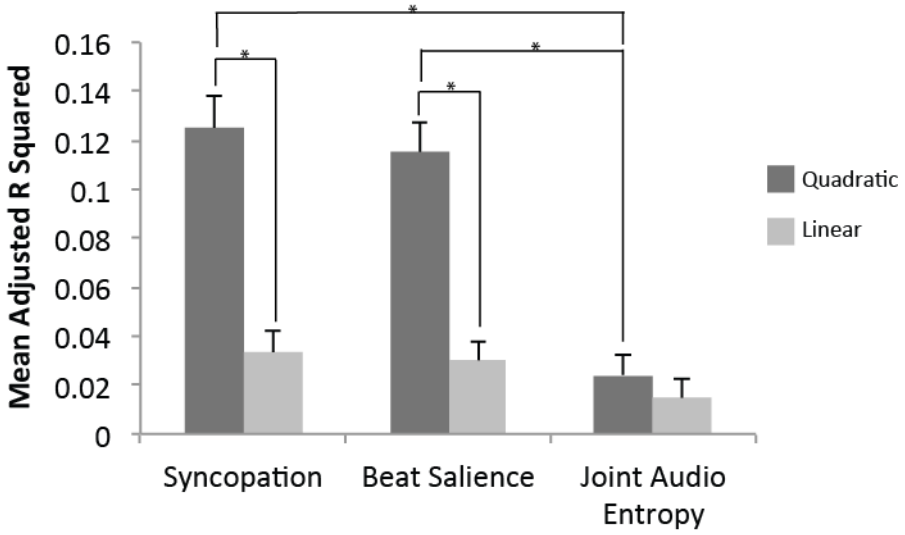


Fig. 5.3 Interaction between predictors (syncopation, beat salience and joint audio entropy) and models (quadratic and linear) on adjusted R^2. Error bars = standard error. *Alpha adjusted $p < .005$.

For the interaction between rating question and model, paired contrasts (Table 5.4) showed that quadratic models had significantly higher adjusted R^2 than linear models for both rating questions (Contrasts 1–2). Furthermore, as Figure 5.4 indicates, while there was a decrease in quadratic model fit when comparing desire to move with feelings of pleasure, there was an increase in linear model fit. However, there were no significant differences for either model between wanting to move and feelings of pleasure (Contrasts 3–4). Thus, although further investigation is needed to confirm this relationship, it might be that the interaction is due to the differing direction of change between movement- and pleasure-ratings for the two models.

		Contrasts	*Mean*	*S.E.*	*t*	*p*
1	Movement	Quadratic vs. Linear	0.0685	0.0072	9.51	<.001*
2	Pleasure	Quadratic vs. Linear	0.0556	0.0063	8.83	<.001*
3	Quadratic	Movement vs. Pleasure	0.0054	0.0072	0.75	0.453
4	Linear	Movement vs. Pleasure	-0.0075	0.0061	-1.24	0.221

Table 5.4 Paired contrasts for rating question (wanting to move and feelings of pleasure) and model (quadratic and linear) on adjusted R^2. Df = 65, *Alpha adjusted $p < .01$.



Fig. 5.4 Interaction between rating questions (wanting to move and feelings of pleasure) and models (quadratic and linear) on adjusted R^2. Error bars = standard error. *Alpha adjusted $p < .01$.

To summarise, the quadratic model explained more of the variability in the data than the linear model, but only when drum-breaks were indexed according to S and BS. In other words, there were U-shaped relationships between syncopation and ratings, and between beat salience and ratings. When drum-beaks were considered in terms of JAE, there was no significant difference between quadratic and linear models. Furthermore, S and BS predicted ratings equally well, and significantly more so than JAE. The models did not fit any better for ratings of wanting to move than for feelings of pleasure, but there was a trend suggesting that the direction of change between wanting to move and pleasure was inverted for quadratic compared to linear models.

5.3.4 Predictor Contributions

5.3.4.1 Analysis

In order to test the relative contribution of the three predictors and determine whether the model had a negative or positive fit, a multiple regression analysis was performed on mean ratings, using only quadratic models, as this model had been shown in the previous analysis to predict ratings more systematically than linear models for S and BS. Although there was no significant difference between models for JAE, a quadratic model was chosen for this predictor, because the mean adjusted R^2 was higher for the quadratic model. Thus, the use of the same model for all predictors was enabled and the use of adjusted R^2 values was avoided.[4] The analyses were performed separately for each rating question, using linear regression with the forward stepwise method. This method adds predictors to the model one by one, in order of their relative contribution to the model, taking possible intrinsic dependency between predictors into account. If a predictor is found not to contribute significantly, it is then removed from the model. However, this method only

[4] The nature of the relationship between JAE and ratings was investigated further in a subsequent analysis, which is reported below.

enables modelling of linearly related variables. Thus, in order to model quadratic relationships, the predictor variables were transformed by centring (subtracting the mean) and squaring. It should be noted that the fit of a straight line to these transformed variables is not exactly the same as fitting a parabola to the original variables. Importantly, the model now has only one linear term, while a true quadratic model has one linear and one quadratic term. Thus, when testing differences between these transformed variables, only the quadratic terms are compared. Nonetheless, as long as all predictors being compared are represented in the same fashion, the output is a good indicator of the relative contribution of predictors that are related to another variable in a quadratic manner.

5.3.4.2 Results

The results showed that, for wanting to move, the multiple R^2 was .7063: using all three predictors, the model was significant ($F(3, 46) = 36.89$, $p < .001$), and could explain 70.63% of the variability of movement ratings. For feelings of pleasure, the multiple R^2 was .7288: 72.88% of the variability in ratings of pleasure could be explained by the three predictors combined ($F(3, 46) = 41.22$, $p < .001$). Table 5.5 presents the models' coefficients, which were all negative, as well as the R^2 change for each predictor and both ratings. Thus, the U-shaped model was confirmed to be inverted. Interestingly, although the standardised beta coefficients (β) for S and BS were very similar, indicating that they both contributed more or less equally to the model, the R^2 change for BS was slightly greater than for S for ratings of wanting to move, while the opposite was the case for ratings of feelings of pleasure. In other words, the desire to move seems more affected by beat salience, while pleasure seems more affected by syncopation. This could be because beat salience relates solely to the regularity of rhythm, and thus might predict body-movement more systematically, while polyphonic syncopation is defined by the thwarting

of expectations that are both temporal and timbral, and thus might reflect pleasurable responses more closely. However, the present analysis does not offer a statistical test of these differences, and in the ANOVA of subjects' adjusted R^2 reported above, the interaction between rating questions and predictors only approached significance. Thus, no strong conclusions regarding the differing effects of syncopation and beat salience on wanting to move and feelings of pleasure can be drawn from the present analysis.

	Wanting to Move				**Feelings of Pleasure**			
	B	*SE B*	*β*	R^2 *change*	*B*	*SE B*	*β*	R^2 *change*
Constant	3.116	.069			3.975	.050		
Syncopation (centred$^{2)}$	-.001	.000	-.493**	.2444	.000	.000	-.565**	.4267
Beat Salience (centred^2)	-.014	.002	-501**	.3972	-.009	.001	-.693**	.2490
Joint Audio Entropy (centred^2)	.162	.052	.327*	.0646	.075	.031	.297*	.0535

Table 5.5 Multiple regression coefficients of centred syncopation, beat salience and joint audio entropy, all squared (quadratic model), for ratings of wanting to move (r = .8404, R^2 = .7063) and feelings of pleasure (r = .8537, R^2 =. 7288); *p < .05, **p < .001.

Although the regression coefficients of JAE were significant, they contributed very little to the model (6.5% and 5.4% of variability for wanting to move and feelings of pleasure, respectively). These results confirm the findings from the previous ANOVA: compared to syncopation and beat salience, entropy is a poor predictor of the desire to move and feelings of pleasure in response to groove. Nonetheless, together, the three predictors are able to explain over 70% of the variability in ratings.

To summarise, using quadratic models, syncopation and beat salience explained the majority of rating variability, with a trend suggesting that syncopation is more closely related to pleasure, while beat salience is related to movement-induction. In comparison, entropy was a poor predictor of ratings. This analysis also confirmed that the U-shaped relationship between syncopation and ratings, and beat salience and ratings is inverted.

5.3.5 Effects of Musical Background

5.3.5.1 Analysis

Although the regression analysis differentiates between the fit of quadratic and linear models to the relationships between predictors and ratings for each drum-break, it ignores the effects of participants' musical backgrounds. Furthermore, any interactions between predictors, musical background and rating question are not addressed (e.g. whether participants rated wanting to move and feelings of pleasure differently depending on the level of syncopation or musical background). To investigate these effects and interactions, the original predictors were transformed from continuous covariates to three-level factors of Low, Medium and High, with almost equal numbers of drum-breaks' ratings in each category. Table 5.6 reports the N, mean, maximum and minimum index values of each category for each predictor. It is important to remember that, as the predictors did not all correlate positively, a stimulus could belong to different categories depending on the predictor. For example, a drum-break with many onsets and little syncopation might belong to the Low category of S, the High category of BS and the Medium category of JAE. Three levels were chosen, enabling the modelling of both linear and quadratic relationships, by contrasting Medium with Low and High.[5]

		N (stimuli)	*Mean Index Value*	*Minimum*	*Maximum*
Syncopation	Low	17	10.82	0	21
	Medium	17	33.53	22	46
	High	16	60.31	49	81
Beat Salience	Low	17	9.33	2.79	13.22
	Medium	17	14.26	13.41	15.19
	High	16	18.24	15.69	22.63
Joint Audio Entropy	Low	17	10.48	9.81	11.18
	Medium	17	11.71	11.26	12.29
	High	16	12.78	12.31	13.64

Table 5.6 Descriptive statistics for three-level categorisation of predictors.

[5] For a given predictor, if Medium is rated significantly higher than Low and High, then the relationship between the predictor and ratings is negatively quadratic; If High is rated significantly higher than Low and/or Medium, and/or Medium is rated significantly higher than Low, then the relationship is positively linear.

To test the effects of musical background, participants were divided into categories according to musical training, groove familiarity and dancing experience. Those who had more than 8 years of formal and/or informal (self-taught) musical training were categorised as 'musicians', while those who had less than 4 years of training were categorised as 'non-musicians'.[6] Nine participants fell outside of these categories, and were excluded from any further analysis, making the total number of participant 57. Those who rated the frequency with which they listened to groove-based music as 4 or 5 on the Likert scale ('often' or 'very frequently') were categorised as 'groove-listeners', while those who rated between 1 and 3 ('never', 'hardly ever' or 'occasionally') were categorised as 'non-groove-listeners'. With regard to dancing experience, those who rated 4 or 5 for the frequency with which they danced to music ('often' or 'very frequently'), and for the extent to which they liked dancing to music ('quite a lot' or 'very much'), were categorised as 'dancers'. Those who rated between 1 and 3 for frequency of dancing ('never', 'hardly ever' or 'occasionally'), and dance liking ('not at all', 'not much' or 'somewhat'), were categorised as 'non-dancers'. Pearson's r test showed that there were no correlations between groove familiarity and dance experience ($r = .209$, $p = .469$), confirming that these two categories could be used as separate between-subjects descriptors and did not represent the same variable. The numbers of participants in each category are reported in Table 5.7.

[6] Although the age at which participants started playing music was recorded in the study, and this aspect is a criterion often used in research regarding the effect of musical expertise (see Ollen, 2006 for a review), it was decided to ignore this information in the present definition of musical training, in order to include as many participants as possible in the two musical-training categories.

Musical Training	*Groove Familiarity*	*Dancing Experience*	*N (Participants)*
Musician	Groove-Listener	Dancer	11
		Non-Dancer	2
		Total	13
	Non-Groove-Listener	Dancer	5
		Non-dancer	4
		Total	9
Non-Musician	Groove-Listener	Dancer	16
		Non-Dancer	6
		Total	22
	Non-Groove-Listener	Dancer	17
		Non-dancer	7
		Total	24
Total	Groove-Listener	Dancer	28
		Non-dancer	9
		Total	37
	Non-Groove-Listener	Dancer	11
		Non-dancer	9
		Total	20
	Total	Dancer	39
		Non-dancer	18
		Total	57

Table 5.7 Between-subjects categories of musical background.

The uncorrelated predictors also meant that each predictor and its interactions with between-subjects factors had to be addressed separately, because each index level had to be re-categorised according to each predictor. This was achieved using three separate five-way ANOVAs (one for each predictor), with predictor (three levels: Low, Medium and High) and rating question (two levels: wanting to move and feelings of pleasure) as independent variables; and musical training, groove familiarity and dancing as between-subjects factors. This also meant that all main effects of rating question and between-subjects factors were the same for all predictors, as the same ratings were used for all analyses (with different parametric index categorisations for predictors). Thus, main effects of rating question and between-subjects factors are only reported once.

5.3.5.2 Results

There was no main effect of rating question ($F(1, 49) = .35$, $p = .556$, sphericity assumed), but a significant between-subjects effect of dancing experience ($F(1, 49) = 13.53$, $p = .001$), showing that dancers rated drum-breaks as more movement- and pleasure-inducing

than non-dancers (Figure 5.5). The effect of musical training approached significance ($F(1, 49) = 3.64$, $p = .062$, musicians Mean = 2.43, S.E = .14, non-musicians Mean = 2.77, SE = .11), but there was no main effect of groove familiarity ($F(1, 49) = .70$, $p = .439$).

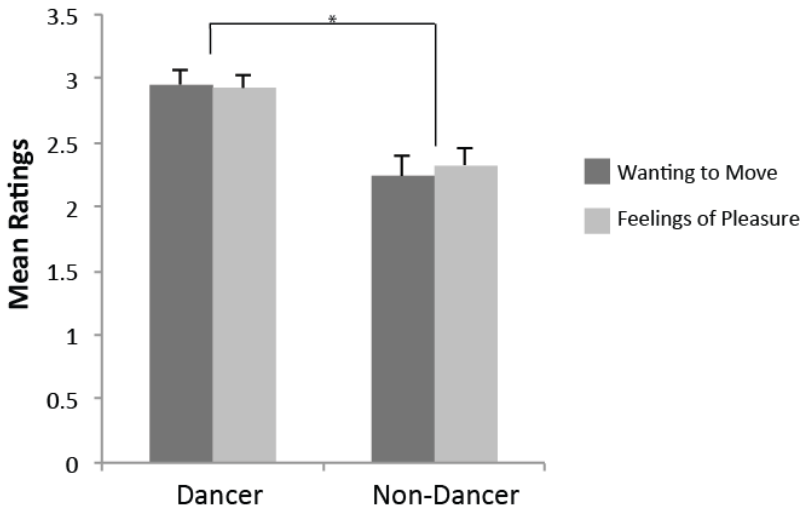


Fig. 5.5 Effect of dancing experience (liking to dance and frequency of dancing) on ratings of wanting to move and experience of pleasure in response to drum-breaks. Error bars = standard error. *$p < .05$

Main effects were found for syncopation ($F(1.62, 79.15) = 15.73$, $p < .001$, Greenhouse-Geisser corrected df). There were no significant interactions between S and any between-subjects factors. There was, however, a significant interaction between S and rating question ($F(1.79, 87.66) = 6.823$, $p = .003$, Greenhouse-Geisser corrected df). T-tests (corrected for multiple comparisons; Table 5.8, Figure 5.6) showed that there were significant differences between all three levels for movement ratings, and that Medium syncopation was rated as eliciting the most desire to move, followed by Low and High, respectively (Contrasts 1–3). For pleasure ratings, Medium S was rated higher than both Low and High, but there were no significant differences between Low and High (Contrasts 4–6). This confirms that there is an inverted U-shaped relationship between S and ratings of wanting to move and experience of pleasure, but further indicates that Low S elicits

more wanting to move than High S, while there is no such difference for ratings of pleasure. This could be because High S involves greater rhythmic complexity, which might prevent metre perception and sensorimotor synchronisation, but still induce non-groove-related pleasure. However, as the contrast between High movement and High pleasure did not survive multiple comparison correction, this finding needs further investigation before conclusions can be drawn. There were also no significant differences between wanting to move and feelings of pleasure for either the Low or the Medium categories (Contrasts 7–9).

	Contrasts	*Mean*	*SE*	*t*	*p*
1	Low Movement vs Medium Movement	-.31	.05	-6.51	<.001*
2	Low Movement vs High Movement	.25	.07	3.41	.001*
3	Medium Movement vs High Movement	.55	.06	8.88	<.001*
4	Low Pleasure vs Medium Pleasure	-.32	.05	-6.07	<.001*
5	Low Pleasure vs High Pleasure	.07	.08	0.77	.441
6	Medium Pleasure vs High Pleasure	.39	.07	5.57	<.001*
7	Low Movement vs Low Pleasure	.05	.05	0.95	.348
8	Medium Movement vs Medium Pleasure	.03	.05	0.60	.552
9	High Movement vs High Pleasure	-.14	.06	-2.38	.020

Table 5.8 Paired contrasts for effect of syncopation (Low, Medium and High) and rating question (wanting to move and feelings of pleasure) on ratings. Df= 49, *Alpha adjusted $p < .005$.

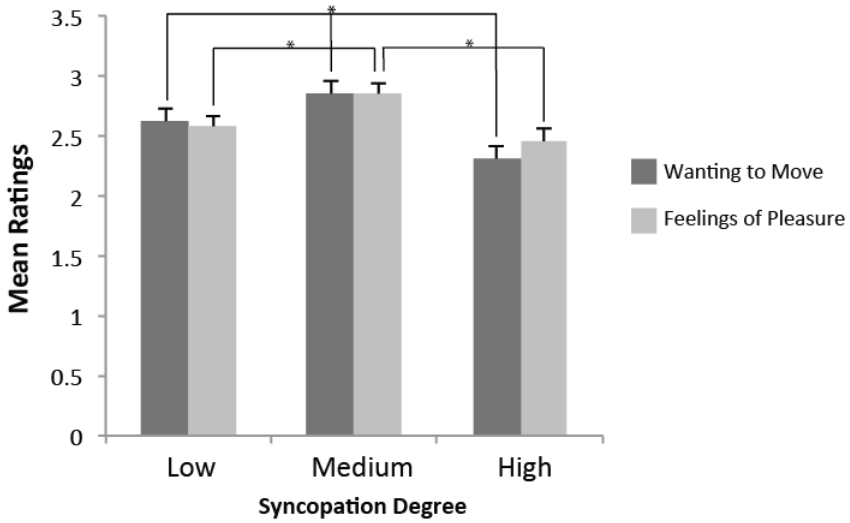


Fig. 5.6 Effect of syncopation (Low, Medium and High) and rating question (wanting to move and feelings of pleasure) on ratings. Error bars = standard error. Alpha adjusted *$p < .005$.

There was a significant main effect of beat salience ($F(1.44, 70.78) = 19.78$, $p < .001$, Greenhouse-Geisser corrected df), which interacted with rating question ($F(1.87, 91.61) = 15.52$, $p < .001$ Greenhouse-Geisser corrected df), but not with any between-subjects factors. Follow-up paired contrasts (corrected for multiple comparisons; Table 5.9, Figure 5.7) showed that drum-breaks with Medium BS were rated as eliciting more wanting to move than both Low and High BS, and that drum-breaks with High BS were rated as eliciting more wanting to move than drum-breaks with Low BS (Contrasts 1–3). The same patterns were found for pleasure ratings (Contrasts 4–6). Thus, the inverted U-shaped relationship indicated in previous analyses was confirmed, along with an indication that drum-breaks with High BS elicit more desire to move and more pleasure than drum-breaks with Low BS. Furthermore, there was a significant difference between ratings of wanting to move and feelings of pleasure for Low BS, indicating that for the drum-breaks in this category, ratings of pleasure were higher than ratings of wanting to move (contrast 7). As with syncopation, it could be that drum-breaks with Low BS include greater rhythmic complexity, and thus can induce non-groove-related pleasure that is a response to the structural complexity. There were no significant differences between the two rating questions for Medium and High (Contrasts 8–9).

	Contrasts		*Mean*	*S.E.*	*t*	*p*
1	Movement	Low vs. Medium	-0.59	0.07	-8.81	<.001*
2		Low vs. High	-0.45	0.06	-6.96	<.001*
3		Medium vs. High	0.14	0.04	3.56	<.001*
4	Pleasure	Low vs. Medium	-0.35	0.07	-4.95	<.001*
5		Low vs. High	-0.22	0.07	-3.15	.002*
6		Medium vs. High	-0.59	0.06	1.36	<.001*
7	Low	Movement vs. Pleasure	-0.17	0.06	-3.07	.003*
8	Medium	Movement vs. Pleasure	0.07	0.05	1.36	.178
9	High	Movement vs. Pleasure	0.05	0.04	1.21	.229

Table 5.9 Paired contrasts for effect of beat salience (Low, Medium and High) and rating question (wanting to move and feelings of pleasure) on ratings. Df= 49, *Alpha adjusted $p < .005$.

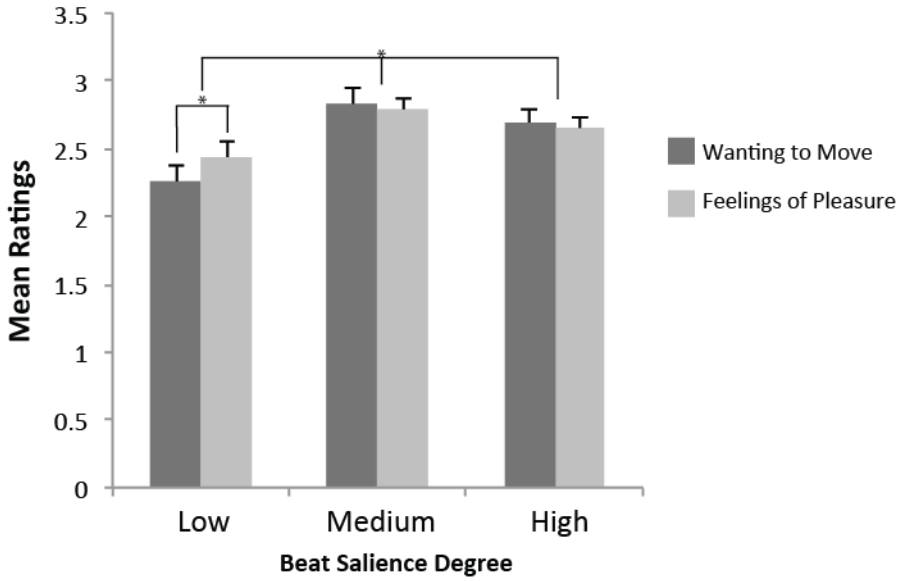


Fig. 5.7 Effect of beat salience (Low, Medium and High) and rating question (wanting to move and feelings of pleasure) on ratings. Error bars = standard error. *Alpha adjusted $p < .005$.

There was a main effect of entropy ($F(2, 98) = 7.80$, $p = .001$), but no interactions between JAE, rating questions or any between-subjects factors. Bonferroni-corrected post-hoc tests showed that High JAE was rated significantly higher than Low JAE ($p = .002$), but that there were no significant differences between Medium and Low ($p = .083$), or Medium and High ($p = .220$) (Figure 5.11). Although High was significantly higher than Low, suggesting a linear relationship between ratings and JAE, the lack of statistical significance for the Medium category echoes the previous uncertainty regarding the difference between linear and quadratic fits between ratings and entropy.

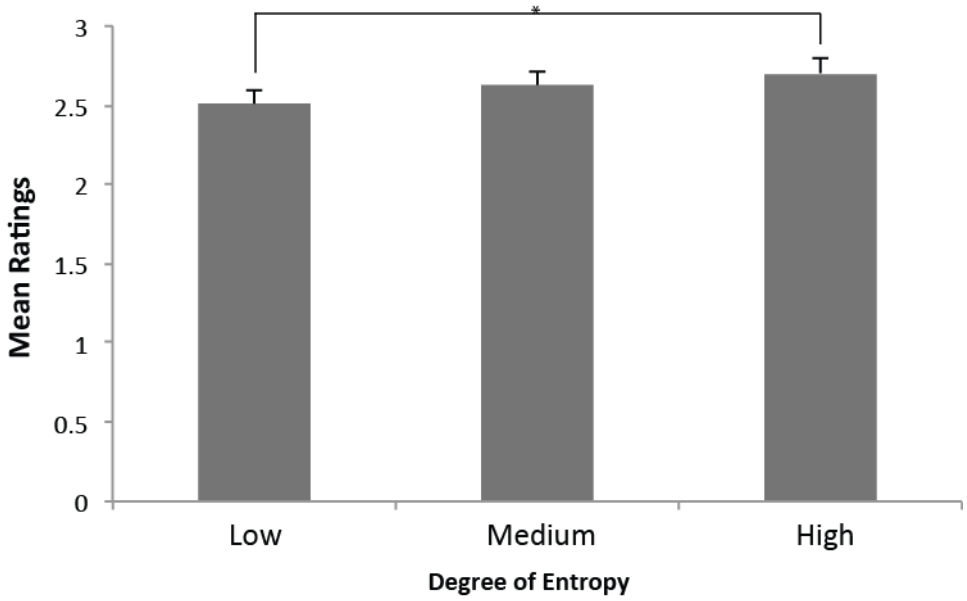


Fig. 5.8 Effect of joint audio entropy (Low, Medium and High) on ratings. Error bars = standard error. *p = .002.

To summarise, of the between-subjects factors, only dance experience affected ratings significantly, showing that dancers wanted to move more and experienced more pleasure with the drum-breaks than non-dancers. The inverted U-shaped relationship was replicated for syncopation and beat salience, while a positive linear relationship, albeit weak, was found for entropy. It was also found that pleasure-ratings were higher than movement-ratings for high syncopation and low beat salience, while movement-ratings were higher than pleasure-ratings for low syncopation and high beat salience.

5.3.6 Goodness of Fit of Polyphonic Index

5.3.6.1 Analysis

A further regression analysis was used to test whether the index of polyphonic syncopation provided a better fit with ratings than the original index of monophonic syncopation proposed by Longuet-Higgins and Lee (1984). For the monophonic indexing, the hihat was excluded from analysis, and the bass- and snare-drum were analysed as one instrumental

layer. The exclusion of the hihat was necessary, since, due to its constant occurrence on the quaver pulse, it would cancel out all syncopations. It should be noted that the need to exclude the hihat and combine the snare- and bass-drum as one layer rendered the comparison between the monophonic and polyphonic indices somewhat biased towards the polyphonic index, since the data as coded with the monophonic index did not fully represent the stimuli that participants heard. In fact, comparing monophonic and polyphonic indices using polyphonic data is more generally biased, since the former was not designed to deal with polyphonic data. However, until now, there has been no way of indexing syncopation in polyphonic rhythms, and thus the comparison indicates the improvement afforded by the new index, compared to existing computational methods, regarding polyphonic rhythms only.

First, regression was performed using a quadratic model, in which average ratings across each drum-break (N = 50) were regressed against syncopation values, once using the monophonic index, and once using the polyphonic index. To test indices, the resulting R^2s were compared. Second, to test differences between the indices more systematically, participants' individual adjusted R^2s from regressions using the monophonic and polyphonic indexes were compared using t-tests. All participants, regardless of musical background, were included in these tests (N = 66).

5.3.6.2 Results

Regression of mean ratings with degree of monophonic syncopation with a quadratic model yielded R^2s of .2726 and .3064 for wanting to move and feelings of pleasure, respectively. With the polyphonic index, the R^2 was .3565 for wanting to move, and .4304 for feelings of pleasure. Thus, compared to the polyphonic index, the R^2s were smaller for the monophonic index, by .084 for wanting to move and by .124 for feelings of pleasure.

T-tests comparing participants' individual adjusted R^2s showed that for wanting to move, the adjusted R^2s using the polyphonic index (Mean = .1179, SE = .0134) were significantly higher than for the monophonic index (Mean = .098, SE = .0132) ($t(65)$ = 3.26, p = .002). Similarly, for feelings of pleasure, the polyphonic index (Mean = .1322, SE = .0151) yielded significantly higher adjusted R^2s than the monophonic index (Mean = .1172, SE = .0157) ($t(65)$ = 2.94, p = .005). These results confirm that the polyphonic index of syncopation proposed in Chapter Four explains listeners' embodied and affective responses to groove-based drum-breaks more consistently than the monophonic index of syncopation proposed by Longuet-Higgins and Lee (1984).

5.3.7 Effect of Headphone Quality

5.3.7.1 Analysis

In order to test whether the quality of the headphones used by the participants affected ratings, a 2 x 3 x 2 ANOVA, with rating question, syncopation degree and headphone quality ('good' or 'not good') as independent variables, was performed. The effect of headphone quality was not tested on the other predictors, as the primary interest regarded overall effects on ratings, and not the nature of the stimuli. According to the questionnaire, 54 participants reported being able to use good quality headphones during the experiment, while only 12 reported not being able to do so.

5.3.7.2 Results

While bearing in mind the difference in sample size in the two groups, it was found that there was no significant effect of headphone quality ($F(1, 64)$ = .01, p = .961), nor any interactions with rating question ($F(1, 64)$ = .31, p = .581) or syncopation degree ($F(1, 64)$ = .77, p = .465). Thus, it is unlikely that the quality of headphones interacted with the

ratings according to the other predictors, and that the experiment overall was not affected by differing audio equipment available to the participants.

5.4 DISCUSSION

To summarise, there is an inverted U-shaped relationship between degree of syncopation in grooves of funk drum-breaks and movement- and pleasure-ratings. In other words, intermediate degrees of syncopation elicit the most desire to move and feelings of pleasure; as syncopation increases, so do ratings, but only to an optimal point, after which a continued increase in syncopation causes decreasing movement induction and pleasure. The same relationship was found between ratings and the salience of the beat, and this stimulus descriptor explained the variability in ratings equally as well as syncopation. By contrast, joint audio entropy was a poor predictor of wanting to move and feelings of pleasure. Linear and quadratic fits between entropy and ratings could not be properly distinguished, but a weak trend towards a positive linear relationship was found. Although ratings of wanting to move and feelings of pleasure correlated strongly, ratings interacted with predictors in a number of ways. There were some trends indicating that beat salience in drum-breaks was better explained by wanting to move, while pleasure was more strongly associated with syncopation. However, further research is needed to determine whether these trends are statistically significant. More convincingly, it was shown that different levels of syncopation and beat salience elicited ratings of wanting to move and feelings of pleasure to a differing extent: in particular, pleasure-ratings were higher than movement-ratings for drum-breaks with high degrees of syncopation and low degrees of beat salience, while movement-ratings were higher than pleasure-ratings for drum-breaks with low degrees of syncopation and high degrees of beat salience. This may be because high degrees of syncopation and low degrees of beat salience elicit pleasurable responses

that are unrelated to groove, as in free jazz, while low degrees of syncopation and high degrees of beat salience may elicit the desire to move, due to the regularity of the drum-breaks, without the accompanying pleasure normally associated with groove. This suggests that drum-breaks with intermediate degrees of syncopation are the better examples of groove, since they elicit the desire to move and feelings of pleasure equally, and to a greater extent than drum-breaks with either too little or too much syncopation.

Interestingly, it was not only found that drum-breaks with medium degrees of syncopation and beat salience were rated higher than both low and high degrees, but also that low and high degrees of syncopation and beat salience were rated differently. Specifically, low degrees of syncopation were rated higher than high degrees for wanting to move, while high degrees of beat salience were rated higher than low degrees for both wanting to move and feelings of pleasure. Low degrees of syncopation and high degrees of beat salience seem more likely to elicit body-movement and pleasure than high degrees of syncopation and low degrees of beat salience, since in the latter, the degree of rhythmic complexity caused by the syncopation might prevent metre perception. It may be that for drum-breaks with high syncopation and low beat salience, compared to drum-breaks with low syncopation and high beat salience, the underlying pulse is obscured by syncopation, decreasing the desire to move. In order to be able to synchronise body-movements to music at all, listeners must be able to perceive the underlying pulse. Thus, although the drum-breaks with low syncopation might not elicit movement desire as much as drum-breaks with medium syncopation, at least synchronised body-movement is possible. Although this pattern was less systematic for pleasure-ratings (it was only found for beat salience, not for syncopation), a similar explanation might be imagined: unlike drum-breaks with low beat salience, at least drum-breaks with high beat salience enable sensorimotor synchronisation and thus also the pleasure associated with movement-

induction. However, it is possible that this relationship was found due to the specific drum-breaks used in the study or the ways in which they were categorised into three levels. For example, if more drum-breaks with high degrees of syncopation had been included in the study, or if the boundary between the High, Medium and Low categories had been set differently, then different results might have been found. Thus, the exact nature of the inverted U-shaped relationship between syncopation, beat salience and wanting to move and feelings of pleasure needs further research.

The only between-subjects factor that affected ratings significantly was the extent to which participants liked to dance, and the frequency with which they danced to music. Thus, it seems that the type of active engagement that defines groove most consistently – namely dance and body-movement – is more closely related to the desire to move and feelings of pleasure than listeners' experience of listening to groove-based music and their general musical training. It is interesting that the effect of musical training was only close to significant, as musical expertise has been shown to affect sensorimotor synchronisation to syncopated rhythms and perceived stability of syncopated rhythms more generally (see Chapter Three). It could be that in more ecological contexts, such as groove-based drum-breaks, responses to syncopation are better defined by listeners' active and embodied engagements with music, rather than their performance skills. It seems unlikely that embodied and affective responses to music should be significantly affected by the extent to which someone can play an instrument or compose music. Musical training is not available to everyone, yet people all over the world express strong musical preferences. However, since this study only considered subjective reports of wanting to move and feelings of pleasure, it remains to be determined whether more objective measures of pleasure differ

for musicians and non-musicians and if musical training, groove familiarity and dance experience affect overt sensorimotor synchronisation.[7]

Importantly, it was found that the polyphonic index of syncopation provided a better fit with ratings of wanting to move and feelings of pleasure than the monophonic index proposed by Longuet-Higgins and Lee (1984). A model of syncopation that takes into account the changes in perceived stability caused by different instrumental streams seems to reflect listeners' embodied and affective experiences with groove more closely than one that ignores instrumentation and streaming. It remains to be determined if a polyphonic index is an improvement on a monophonic index for rhythms with forms of instrumentation other than the drum-kit and for different kinds of responses, such as the more perceptual and cognitive responses that have been studied in previous empirical investigations of syncopation (e.g. Fitch & Rosenfeld, 2007; Ladinig et al., 2009).

Finally, responses remained the same despite some participants reporting not being able to use good quality headphones during the experiment. Thus, the lack of experimental control in sound equipment, due to the use of a web-based survey, did not significantly affect the results of the experiment. There are, of course, other aspects of online experiments that could not be controlled in the present study, such as deliberate skewing of data or poor attention to the completion of the ratings. Confounds of this kind can only be addressed by comparing results from a web-based survey to a laboratory experiment. Such a comparison is presented in Chapter Six, where similar ratings were collected in a laboratory setting.

A number of limitations to the study should be noted. First, although the syncopation measure was sensitive to polyphonic music, the beat salience index was not. Since the hihat was not indexed and the bass- and snare-drum were combined in the

[7] These questions are addressed in the empirical studies reported in Chapters Six and Seven, respectively.

calculation of beat salience degree, the measure did not reflect the musical stimulus exactly. Until models of polyphonic beat salience are available, such limitations cannot be overcome. Second, more sophisticated measures of entropy exist (e.g. Temperley, 2007, 2010), which might be more able to model the degree of complexity in drum-breaks than the measure of joint audio entropy used in the present study. However, since syncopation relies on perceptual mechanisms, it is unlikely that such objective measures of complexity will have significantly better explanatory power than was found in the present study. As mentioned, entropy has been found to be a poor predictor of the perception of rhythmic complexity in previous research (Thul & Toussaint, 2008). Finally, although the present study shows that there is a strong association between wanting to move and feelings of pleasure in groove, it cannot determine how these psychological feelings are causally related. In the next section, a theoretical hypothesis about the causal relationship between syncopation, wanting to move and feelings of pleasure is proposed. Although it is speculative at this point, it draws on the present results and puts forward an ecological and embodied theory of why syncopated music makes us want to move and why it feels good.

5.4.1 A Proposal for the Causal Relationship between Syncopation, Body-Movement and Pleasure: Embodied Metrical Enactment

Although the study reported above shows for the first time that difference in syncopation degree affects the desire to move and feelings of pleasure in groove, it cannot determine the causality between movement-induction and pleasure: it has only been shown that these two psychological components of groove experience correlate strongly and positively. Whether it is movement-induction that causes pleasure, or pleasure that causes movement-induction, whether the two are mutually dependent in groove, or one is more affected by syncopation than the other, is unknown. Here, a theoretical hypothesis for how structural,

embodied and affective factors are causally related is proposed, based on a notion of *perception of metric events*. As described in Chapter One, *phenomenal events* are actual physical events in a rhythm, the actual notes that are acoustically measurable in the external stimulus. *Metric events,* however, are rhythmic events that demarcate the metric frameworks and the main pulse in the rhythm – the referential grid according to which the phenomenal events are heard. In a rhythm with no syncopation, all phenomenal events coincide with metric events, and thus the main pulse has phenomenal events at each pulse onset. This is an example of perception of *sounded* metric events. In a syncopated monophonic rhythm, some metric events do *not* have phenomenal events on them, but due to the dynamic and self-sustaining properties of entrainment, which is the perceptual mechanism on which metre perception is based, the metre remains perceptually intact: *silent* metric events are perceived. Other examples of the perception of silent metric events are the persistence of metre for a listener after a piece of music has faded out or is suddenly interrupted (elsewhere referred to as beat continuation; see Grahn & Rowe, 2012); or the 'earworm' phenomenon in which a piece of metrical music 'plays', often involuntarily, in the mind of a listener (Williamson et al., 2012). However, the silence of the metric events does not mean that they are in any way abstracted or disembodied. According to ecological and embodied theories of perception, metric events are just as much perceived as are phenomenal events, despite not being physically demarcated in the stimulus. Furthermore, through sensorimotor synchronisation – such as foot-tapping, dancing or head-nodding – the metric events are actively and overtly manifested in the body. Because the metre can still be perceived through entrainment, body-movements can be synchronised to the metric events, regardless of whether they are marked by phenomenal events. In this way, the metric events afforded by the syncopation are *made phenomenal* by the body, and the internally perceived metric events are *externally enacted*

through body-movement. Here, it is proposed that the *desire* to synchronise body-movements to groove is *caused* by syncopation, because it invites the body to express silent metric events externally. It is a way of corporeally enacting the expectation that the syncopation violates, namely that metric events will coincide with phenomenal events. In the absence of phenomenal events at metric events, the body 'fills in', both physically and metaphorically.

As reviewed in Chapter One, humans are predisposed at a biological level to prefer fulfilled expectations and predictions, since successful prediction promotes successful survival (Mandler, 1975), and it has been proposed that emotional engagement with music can be explained by the stimulation of expectations and predictions afforded by the musical structure (Huron, 2006; Meyer, 1956). However, the study of overt expressions of such affective responses has largely been devoted to the measurement of 'chills', using tonal and harmonic materials (see Grewe et al., 2009 for a review). Here, it is proposed that similar mechanisms can account for the desire to move to, and the pleasure elicited from, rhythmic syncopation in groove. Because syncopation thwarts the expectation that metric events will coincide with phenomenal events, the listener is given the opportunity to enact the expectation herself using her own body. Thus, it is proposed that *the desire to move is caused by the thwarting of expectation in syncopation, and the pleasure is caused by the embodied enactment of the expected event.* Importantly, the tension between the thwarting and the enactment is what binds the movement, desire and pleasure together in the experience of the syncopated groove. Thus, the process is not linear, as in the theories proposed by Meyer and Huron. It is not that the syncopation thwarts the expectation, entrainment enables the prediction of the metre, the body subsequently fulfils the expectation and prediction, and pleasure ensues, in a sequential and teleological fashion. Rather, the process is more situated and reciprocal: in groove, syncopation thwarts

schematic expectations and entrainment enables the prediction of the metric events despite phenomenal absence. This metrical perception is manifested in overt or covert sensorimotor synchronisation, through physical dance or embodied simulation. The desire to enact *overtly,* as opposed to *covertly,* the thwarted expectation depends on 'veridical', expectations about the musical genre and the musical background of the listener (such as her enjoyment and frequency of dancing). The pleasure results from the fulfilment of the embodied desire and the corporeal enactment of the thwarted expectation. It is *not* that syncopations are 'de-syncopated' by body-movement in groove, but that the tension caused by syncopation is physically explored and directly embodied.

This theory could explain why, in the present study, it was found that medium degrees of syncopation and beat salience elicited the strongest desire to move and the most pleasure. In drum-breaks with little syncopation and a very salient beat, metric events largely coincide with phenomenal events and the metre is mostly physically present in the stimulus. Thus, the metric expectations are fulfilled by the musical structure itself, and there is less need to enact the metre in body-movement, attenuating the pleasure offered by such embodied enactment. In drum-breaks with very high degrees of syncopation, and very weak beat salience, the events at metrical locations are phenomenally absent to such an extent that entrainment and metre perception are unachievable. The consequence is a decreased desire to move to these drum-breaks because the metre cannot be perceived, and sensorimotor synchronisation is prevented. As a result, there is less pleasure, not just because there is no opportunity for enacting metric expectations, but because the metre cannot be perceived at all. This might be why the present study found that drum-breaks with a high degree of syncopation and low degree of beat salience were rated as eliciting less desire to move and less feeling of pleasure compared to drum-breaks with low degrees

of syncopation and high degrees of beat salience: in the latter, although it is not *necessary* to embody the metre, it can at least be perceived.

Although the theory is most clearly applicable to monophonic syncopation, it can be applied to polyphonic syncopations too. In fact, if this were not the case, the theory would not be relevant for the results of the present study at all, as all the syncopations in all the drum-breaks were polyphonic and had at least the hihat on every main pulse onset. In other words, the metric events in the drum-breaks used in the study were never literally silent. However, despite these syncopations not consisting of true rests of acoustic silence, expectations about the *instrumentation* of the pulse onset are violated. Thus, although the metric events technically coincide with phenomenal events at the pulse onset, the body is invited to *strengthen* these events, since their instrumentation is unexpected. There *is* an instrument 'phenomenalising' the metric event, but an instrument with insufficient 'phenomenal weight'. Again, it is not that the body 'de-syncopates' these syncopations, but that it compensates for the phenomenal weakness and the tension afforded by the violated expectation, through physical enactment.

The claim is not that syncopation is the only source of movement-induction and pleasure in groove. As mentioned, other forms of rhythmic complexity, such as microtiming and rhythmic ambiguity, also stimulate temporal expectations and metre prediction. Furthermore, it has been suggested that the alternation of 'high' and 'low' sounds in groove, such as between the snare- and bass-drum in a drum-kit, invite 'up' and 'down' body-movements in dance via cross-modal mapping from auditory movement to motor-mimetic movement (Zeiner-Henriksen, 2010). As suggested in the interpretation of the present results, pleasure might also be elicited by drum-breaks with high degrees of syncopation due to non-groove-related aesthetic appreciation of rhythmic complexity, such as in contemporary art music with free metre. But a groove with a degree of syncopation

and beat salience that prevents metre perception is arguably simply not groove – phenomenologically. A salient metre is central to subjective definitions of groove (Janata et al., 2012; Madison et al., 2011), and drum-breaks with a degree of complexity that prevents metre perception cannot be experienced as syncopated, since without metre perception there is no temporal expectation to be violated through syncopation. Thus, it is proposed that the following should be added to the definition of groove:

> *Groove is a rhythmic pattern with a degree of syncopation that enables embodied perception of metric events.*

To conclude, the present study demonstrates an inverted U-shaped relationship between the degree of syncopation and beat salience in groove and ratings of wanting to move and feelings of pleasure. The perceptual and embodied relationship between metric events and phenomenal events – particularly the weak or absent phenomenal events of syncopated rhythm sequences, and the resulting desire to enact those phenomenal absences physically – is proposed to explain this relationship. Since recent neuroimaging evidence suggests that there are specific neural substrates of metre perception (Grahn & Rowe, 2012), measuring listeners' neuropsychological responses to groove might further determine the role of the perception of metric events in groove. With this and other aims in mind, the next chapter reports a study in which the neural correlates of syncopated grooves were investigated.

CHAPTER SIX

The Neural Correlates of Syncopation in Groove

6.1 INTRODUCTION

Emotional effects and rhythmic features of music elicit patterns of activity in the brain associated with reward processing (for a review, see Koelsch, 2010) and motor cognition (e.g. Bengtsson et al., 2009; Chen, Penhune, et al., 2008; Grahn & Brett, 2007). The former is associated with activity in a number of reward-related structures that are conventionally studied in relation to pleasures of more obvious biological significance, such as food and sex. However, other areas, such as the auditory cortex and the insula, also show activity in response to musical pleasure (Koelsch et al., 2006). Rhythm and metre cognition involve the basal ganglia and secondary motor areas (Bengtsson et al., 2009; Grahn & Brett, 2007, 2009). However, the extent to which the pleasurable effect of movement-inducing music, such as groove, integrates reward, motor or other areas in the brain is unknown. This chapter reports a study in which the neural responses to groove were investigated. Drum-breaks with varying degrees of syncopation were listened to and rated according to how much they elicited pleasure and the desire to move, while participants' blood-oxygenated level-dependent (BOLD) responses were recorded using fMRI. The inverted U-shape between ratings and degree of syncopation found in the online survey reported in Chapter Five was replicated in behavioural measurements. Furthermore, this inverted U-shape also reflected patterns of activity in the auditory cortices. In contrast, a negative linear relationship was found between syncopation and activity in the basal ganglia and anterior inferior insula, although the response approached the shape of an inverted U-curve for musicians in the left putamen and pallidum. It is proposed that regions showing significant activity as a function of syncopation in drum-breaks connect in a striato-insulo-auditory

network. In this network, metre perception is regulated in the basal ganglia, in response to the regularity of syncopated rhythm as encoded by the anterior insula, while activity is modulated by top-down attention in the auditory cortex, in response to subjective experiences of wanting to move, feelings of pleasure and individual musical background.

6.1.1 Neural Correlates of Musical Pleasure

Research into the pleasurable effects of music has largely favoured the study of two aspects: the 'chill-effect' and familiarity. The former is primarily studied using physiological measurements and it has been shown that certain kinds of musical structures are associated with physiological arousal in parameters such as heart rate, galvanic skin response, respiration, skin temperature, muscle tension, salivation and hormonal levels (Craig, 2005; Grewe et al., 2009; Grewe et al., 2007a, 2007b; Guhn et al., 2007; Krumhansl, 1997; Nagel et al., 2008). What these musical structures often have in common is that they stimulate listeners' expectation through building up, delaying and releasing structural tension.[1] Researchers addressing the issue of familiarity have shown that the 'chill-effect' is particularly strong when listeners are familiar with the music, and argue that familiarity increases pleasure by maximising the prediction effect (Panksepp, 1995; Salimpoor et al., 2009).

Furthermore, it has been shown that music recruits areas of the brain associated with reward and more evolutionarily functional pleasures, such as food and sex. The Positron Emission Tomography (PET) study by Blood and Zatorre (2001) is well known for demonstrating for the first time that 'chills' elicited by subject-chosen musical excerpts were accompanied by activity in reward areas in the brain, including the ventral striatum, midbrain, amygdala, orbitofrontal cortex (OFC) and ventral-medial prefrontal cortex. Their

[1] However, the direct link between experimentally controlled structures thought to stimulate expectations and physiological arousal has been difficult to establish.

findings were recently strengthened by a study using the same design, in which evidence of the release in the ventral and dorsal striatum of dopamine, a neurotransmitter strongly associated with reward, was found in connection with musical 'chills' (Salimpoor et al., 2011). For the first time, these researchers also showed an anatomical-functional dissociation between different subcomponents of the pleasure experience elicited by music: the structural build-up in the music and the anticipation it induced in listeners were correlated with increased activity in the right caudate, which is part of the dorsal dopaminergic system in the striatum, while the release of musical-structural tension and the experience of the 'chill' were associated with more activity in the right nucleus accumbens (NAc), a ventral-striatal structure.

The results from this study are suggested to demonstrate the musical dimensions of what is largely accepted as two separate aspects of reward, namely 'wanting' and 'liking', the former amounting to musical anticipations in the caudate, and the latter to tension release and 'chills' in the NAc. The dissociation of such psychological and neural components of reward, at the subconscious level, was first proposed by Berridge, who showed that the dopamine system is involved in the *anticipation* of food reward (or 'incentive motivation'), while other neurotransmitters, such as opioids and GABA/benzodiazepine are involved in the *consumption* of food (the hedonic pleasure) (Berridge, 1996; Smith et al., 2010). As reviewed previously, a 'pleasure cycle' has been proposed (see Figure 1.3, Chapter One), according to which the dynamic development from 'wanting' to 'liking' and 'learning' during pleasure can be defined with regard to psychological and neural processes (Berridge & Kringelbach, 2011; Kringelbach & Berridge, 2009).

A number of other studies have shown that the neural correlates of strong emotional experiences with music can be found in emotion- and pleasure-related areas of

the brain (see Koelsch, 2010; Vuust & Kringelbach, 2010 for reviews). For example, the insula, which is part of the larger emotion circuit in the brain (Smith et al., 2010), is believed to be involved in normal emotional processing of music, according to a lesion study in which a 52-year-old man's emotional sensitivity to music was affected while his ability to perceive sound and music was spared, following a stroke affecting the left insula (Griffiths et al., 2004). Other neuroimaging studies have found increased activity in the anterior insula during emotional experiences with music in healthy listeners (Koelsch et al., 2006; Menon & Levitin, 2005).

Aside from traditional reward areas, there is some evidence suggesting that subjectively pleasurable experiences modulate responses in primary sensory regions (Vuilleumier, 2005) and that emotionally charged musical stimuli recruit primary auditory cortices (Brattico et al., 2011). Indeed, Koelsch et al. (2006) found that pleasant compared to unpleasant music showed activity in, among other areas, the Heschl's gyrus in the primary auditory cortex. This region is normally associated with musical processing of a more basic acoustic nature, but is also affected by top-down modulation (Liégeois-Chauvel et al., 1998; Zatorre & Schönwiesner, 2011). The authors suggest that attentional mechanisms might explain this finding, as pleasurable stimuli are known to invite increased attention and greater activity in the auditory cortex (Jäncke et al., 1999).

6.1.2 Neural Correlates of Rhythm and Metre Perception

A number of studies have shown activity of the motor system in the brain when listening to rhythmic music (e.g. Bengtsson et al., 2009; Chen et al., 2006; Chen, Penhune, et al., 2008; Chen, Zatorre, et al., 2008; Grahn & Brett, 2007; Grahn & Rowe, 2009, 2012; Popescu et al., 2004). In sum, it appears that activity in secondary motor areas, such as the premotor cortex (PMC), supplementary motor area (SMA), cerebellum and basal ganglia, increases

during listening to rhythm. These areas are secondary in the sense that they are involved in processes *related* to movement, such as planning, monitoring or imagining actions, as opposed to being directly responsible for overt movement (Thaut, 2005). For example, a very recent study by Cameron et al. (accepted), found that single-pulse Transcranial Magnetic Stimulation (TMS) of the primary motor cortex elicited motor-evoked potentials in an ankle muscle to a greater extent during strongly metric, compared to weakly metric sound sequences. Earlier, Chen et al. (2008) conducted an fMRI study in which activity in the PMC, SMA and cerebellum increased during passive listening to musical rhythms with no indication of overt motor relevance. Related to these findings, and of particular relevance to the present study, Grahn & Brett (2007) found that, along with the superior temporal gyri, left inferior gyrus, SMA and pre-SMA, activity in the caudate, putamen and pallidum of the basal ganglia, which are involved in the initiation of movement, increased during listening to metrically simple rhythms, compared to metrically complex or nonmetric rhythms. In other words, a negative linear relationship was found between rhythmic complexity and basal ganglia activity. The authors suggest that since simple rhythms elicit stronger metre perception, these areas should be understood as modulating metre perception in a linear fashion.

In a more recent study, Grahn and Rowe (2012) investigated whether activity in different structures of the basal ganglia could differentiate between processes involved in metre perception. Of particular interest was whether 'beat continuation' relies on different neural processing than 'beat finding' or 'beat adjustment'. Beat continuation refers to the process of predicting the main pulse, which has been induced in the listener. Importantly, the process enables, but does not require, perception of metric events. If a rhythm is simple and has all its main pulse onsets present, then beat continuation is a simple case of pulse tracking (every predicted event coincides with metric events in the music). If the rhythm

stops, or some of the rhythm's pulse onsets are absent, as in a syncopated rhythm, then the prediction during beat continuation involves perception of metric events. Grahn and Rowe found that when listeners engaged in the activity of continuing an induced pulse after the rhythm had stopped (i.e. perception of metric events), activity in the putamen was greater than during beat finding (i.e. initial entrainment to the pulse) and beat adjustment (i.e. shifting of the pulse following a tempo change). Thus, they propose that beat continuation (and thus perception of metric events) is particularly instrumental in inducing putamen activity. This proposal is supported by a previous study by Grahn and Brett (2009), in which it was found that adults with Parkinson's disease (PD), whose motor initiation deficits result from dysfunctions in the basal ganglia, are impaired in discriminating between metric rhythms, but their ability to perceive and find the main pulse is spared. As rhythm discrimination benefits from the ability to perceive metric events (a strategy akin to chunking in memory), these findings suggest that the basal ganglia, and the putamen in particular, are necessary for perception of metric events, but not for simple metre perception.

Metre perception relies on the ability to adjust the interpretation of a pulse in a rhythm following a perturbation. One theory of how the brain is successful at this task centres on the notion of predictive coding. First proposed by Friston (2002), the theory provides a model of the hierarchical neural processing of input–output perceptual prediction, in which lower-level brain areas predict the input based on higher-level contextual information. The comparison of predicted and actual input provides a variable representing the 'prediction error', which reflects the difference between the predicted and actual input, and subsequently affects future lower-level predictions. In this way, the

process is cyclical, reciprocal and dynamic.[2] Vuust et al. (2009) set out to investigate this theory in the rhythm perception domain, using magnetoencephalography (MEG). They found that metric deviations in rhythmic drum-patterns elicited the mismatch negativity (MMN) response and a p3a response in the auditory cortices of their participants. The MMN responses were stronger in musicians compared to non-musicians in the left hemisphere. Since the MMN represent a prediction-error term, and the size (i.e. salience) of the error term is seen as reflecting the degree of sensitivity to metric incongruity, they take their findings to support the predictive coding theory. The p3a is thought to reflect neural processing involved in involuntary attentional orientation, and the authors suggest that it is involved in the low-to-high hierarchical network interaction posited by the predictive coding theory, connecting the auditory cortex with other cortical areas, such as the parietal and frontal regions. Thus, metrically deviating patterns might be encoded in the auditory cortex via the error-correction mechanism of MMNs and the attention-orientating mechanism of p3a, which also provides connectivity with other areas of the brain involved in rhythm and metre perception more broadly.

A number of other studies have found that regions in the temporal lobe, such as the primary and secondary auditory cortices, superior temporal gyri (STG) and planum temporale, are involved in rhythm-complexity perception (Bengtsson et al., 2009; Chen et al., 2006; Grahn & Brett, 2007; Grahn & Rowe, 2012), and Chapin et al. (2010) found increased activity in the STG during attending to and mentally rehearsing a syncopated rhythm compared to a similar visual stimulus. In fact, greater activity in the STG, along with the putamen and the caudate, was found during a period of the task that the authors believe involved a type of metre perception that can be seen as involving metric events. Thus, it could be that areas in the temporal lobe, such as auditory cortices and the superior

[2] However, the theory is less dynamic than Dynamic Attending Theory (see Jones, 2009), due to its focus on point-based error correction, rather than dynamic adjustment.

temporal gyri, could be particularly important in the processing of syncopated grooves.

6.1.3 Pleasure and Movement Interactions

Of further interest to the present study, Grahn and Rowe (2012) also showed that, compared to nonmetric rhythms, metric rhythms showed activity in the medial OFC, an area implicated in reward processing (Kringelbach, 2005). Although not explicitly referring to this finding, the authors situate their results within the research that has shown implementations of the basal ganglia in reward from prediction (Schultz, 2006). Thus, it could be that, at a low level, rhythms that enable the prediction of metre are more pleasurable than rhythms that do not, because such rhythms enable more efficient processing and learning.

With regard to this, the role of dopamine in both pleasure and motor control seems pertinent (Keitz et al., 2003). As mentioned, dopamine release and uptake is a sign of the 'wanting' associated with pleasure (Berridge, 1996; Smith et al., 2010), and activity in areas known to be part of the dopaminergic pathway, such as the caudate and putamen, has been demonstrated during musical pleasure (Salimpoor et al., 2011). However, dopamine is also involved during the controlling of fine motor movements and timing of actions (Harrington et al., 1998). The motor dysfunction of adults with PD is largely due to dopaminergic deficiencies following progressive cell death in the substantia nigra (Jellinger, 2001). Interestingly, other non-movement-related Parkinsonian deficits, affecting cognition and reward-motivated learning, are also believed to result from dopaminergic dysfunction (Rowe et al., 2008). Furthermore, adults with PD often experience depression, although it is unclear whether this results from reward-related dopamine deficits directly or is an indirect consequence of the challenges associated with motor and cognitive difficulties caused by the condition (Remy et al., 2005). It has been

proposed that the predictive coding theory can account for both rhythmic and emotional effects of music, via the dopaminergic system (Gebauer et al., in prep). The authors propose that the anticipatory dimension of musical-structural processing is the primary source of pleasure, and that the hierarchical error-correction mechanism can account for the distribution of neural processing during emotional experiences with music. However, no empirical evidence exists to support the predictive coding theory in the domain of music and reward. In fact, it is unclear whether dopamine regulates the reward and motor systems separately, or whether there is some interaction between these systems. The latter seems a particularly tantalising possibility in the context of the present research, as rhythm and pleasure are often essential features of music in general, and are intimately linked in groove in particular.

The idea of interaction between body-motion and emotion in music is not a new one. Molnar-Szakacs and Overy (2006) propose that one way in which music conveys meaning is through the coupling between perception and production of musical structure, via which emotion is both perceived and, through empathy, induced. Underpinned by the Mirror Neuron System in the brain (e.g. Gallese, 1996; Kohler et al., 2002; Rizzolatti et al., 2004, 2008), meaning and emotion in music is manifested via the observation and potential contagion of intentions and emotions as expressed by the 'motion' in the musical structure. In a later paper (Overy & Molnar-Szakacs, 2009), this hypothesis is extended and developed into a theory of Shared Affective Motion Experience (SAME), and the notion of interactive synchronisation is posited as one route to musical affective and embodied experiences. Through a shared sense of pulse, listeners' metre perception and prediction give rise to pleasurable experiences that are interpersonal, and via which emotion is transferred.

In both papers (Molnar-Szakacz & Overy, 2006; Overy & Molnar-Szakacs, 2009),

the authors suggest that the anterior insula supports this affective linking of perceptions and actions in music, via connections with limbic and motor networks (Carr et al., 2003), particularly considering its known involvement in regulating affective body-states (A. D. Craig, 2003). It has also been suggested that a neural network involving the Mirror Neuron System, auditory cortex, limbic system and anterior insula underpins the experience of musical structure as specifying movement and conveying emotion, with the potential to elicit feelings of co-subjectivity in music (McGuiness & Overy, 2011). This idea resonates with common views of the role of the anterior insula in cognition in general. Despite the apparent breadth of involvement of the insula – including auditory, viscerosensory, motor, vestibular and somatosensory functions – Singer et al. (2009) propose a unified model of its anterior division, in which viscerosensory, empathic and complexity-processing features of the anterior insula are considered. They claim that the anterior insula maps bodily sensations – such as 'chills' and a racing heart – onto conscious feeling states, which can subsequently be appropriated to a simulation of how others feel, through empathy. This mapping is modulated by uncertainty ensuing from the prediction of an anticipated internal state compared to a current state, after which the 'prediction error' facilitates learning and adaptation. This is why activity in the anterior insula is observed during tasks that involve autonomic sensation (Craig, 2003), empathy (Singer & Leiberg, 2009), uncertainty (Preuschoff et al., 2008) and complexity (Grinband et al., 2006). The latter has in fact been shown in the context of musical rhythm: Platel et al. (1997) found increased activity in the left anterior insula during a judgement task that involved identifying whether a rhythm was regular or irregular. Although the authors only consider this finding in relation to its implications for memory for sound, it is possible, as others have suggested (Bamiou et al., 2003), that the anterior insula is involved in the extrapolating of a rhythm's regularity. Together with its involvement in musical-emotional experiences, as reviewed above (e.g.

Koelsch et al., 2006), it may be that the body-emotion-uncertainty integrating role of the anterior insula applies to the experience of affective and embodied engagement with rhythmically complex music, such as groove.

6.1.4 Neural Correlates of Dance

The neural correlates of dance have been studied to a much lesser extent than music, partly for the obvious reason that the confinements of the scanner and movement artifacts prevent participants from actually dancing during experiments (see section 2.4, Chapter Two). However, areas of the brain associated with movement (including areas suspected to be involved in the Mirror Neuron System) have shown increased activity during observation of dance (Calvo-Merino et al., 2005). Such responses have also been found to be modulated by the dancing experience of the observers, indicating that previous active engagement with the task affects perception (Cross et al., 2006), echoing theories of embodied and ecological perception.

Only one study has attempted to address the neural basis of overt dance: Brown et al. (2005) recorded neural activity with PET and body-movement using video-based motion-capture techniques while subjects performed the steps of tango. While lying in the scanner, recordings were taken as they moved their feet on a flat smooth surface on the outside of the scanner's bore. The data showed that entraining dance movements to music recruited the cerebellum, and when such entrainment was in response to regular rather than irregular rhythms, the right putamen showed increased activity. No dance-induced activity was recorded in areas associated with reward. However, it might be that the inability of participants to move their heads and core bodies prevented the fully pleasurable experiences normally associated with dance. In fact, it could be argued that synchronising

and patterning leg-movements to music on a flat surface while lying on one's back is not really dancing at all.

Interestingly, the movement constraints of the scanner and practical limitations of neuroimaging have not stopped researchers from being able to show that physical exercise is associated with activity in the opioid-system in the brain (Dishman & O'Connor, 2009; Ekkekakis, 2003). Boecker et al. (2008) put their participants into the PET scanner immediately after a session of intense running and found significantly increased opioid binding in, among other structures, the OFC, ACC and insula, and that the degree of binding correlated with subjective ratings of euphoria. Dance is, among other things, a form of exercise, and thus it could be that the physical exertion involved in dance might contribute to the release of pleasure-associated neurotransmitters in areas of the brain associated with reward. However, the music can only be seen to have an indirect effect on eliciting this kind of pleasure, by being an external incentive that contributes to the experience by motivating the dance movements, the physical exertion from which causes the euphoric feelings.

6.1.5 Neural Correlates of Groove

Vuust and Kringelbach (2010) refer to the feeling of rhythmic 'swing' as a musical emotion. Based on the hypothesis that music elicits pleasure by stimulating expectations, they claim that the sensation of swing depends on the tension caused by the relationship between the metric framework and the polyrhythmic patterns of the groove. While some studies have used groove-based music in trying to elicit and measure physiological arousal and activity in the reward system in the brain (e.g. Bernardi et al., 2006; Gerra et al., 1998; Salimpoor et al., 2011), few have been concerned with what characterises physiological and neurophysiological responses to groove in particular, let alone its pleasure- and

movement-inducing properties. For example, researchers have either studied structures with effects similar to classically composed 'chill'-inducing music (Witek, 2009), or used grooves as stimuli simply due to subject-based choices, in order to maximise familiarity-based affect (e.g. Blood & Zatorre, 2001; Salimpoor et al., 2009). In the former example, pleasurable responses are not directly related to movement, while in the latter, the musical structures of groove are often not addressed at all.

One exception is a study by Danielsen et al. (2011). They showed a functional-anatomical dissociation between listening to parts of groove-based music with continuously repeating rhythmic phrases that included momentary large-scale changes, such as instrumental breaks. Specifically, instrumental breaks were associated with increased activity in the cerebellum, which has been linked to time-tracking (Ivry & Keele, 1989); and the parahippocampal gyrus, inferior frontal gyrus and superior medial gyrus, which are known to be involved in processing of musical and linguistic syntax (Koelsch, 2012; Kristensen et al., 2013). The continuously repeating rhythmic phrases were associated with increased activity in the supramarginal gyrus and SMA, which the authors suggest is explained by a strengthening of embodied pulse synchronisation. Although not directly addressing groove, Thaut et al. (2008) found that both tapping in cross-rhythmic relationships with musical rhythm and tapping in one-to-one synchrony elicited activity in a number of motor related areas, such as the cerebellum, SMA, PMC and basal ganglia, but that the basal ganglia activity was *decreased* during cross-rhythmic tapping. Thus, it could be that the cross-rhythmic tension associated with groove is inversely related to neural activity in the basal ganglia. Another exception is found in a study by Vuust et al. (2006), who found that tapping along to the pulse of polyrhythms correlated with activity in a number of areas of the brain associated with language processing and bi-stable percepts, such as Brodmann's Area (BA) 40 in the inferior parietal lobe and BA 47 in the inferior

frontal gyrus. The only area of activity discovered in this study associated with reward was the anterior cingulate cortex (ACC), which is a part of the mesolimbic system known to be involved in emotional states (Kringelbach, 2005).

6.1.7 Hypotheses

But what characterises groove-elicited pleasure? As there is no defined 'peak' moment in groove, rather a web of constantly repeating cross-rhythmic relationships, it is likely that the dissociations between 'wanting', 'liking' and 'learning' in the groove pleasure cycle are more blurred, and that the pleasure rarely culminates in 'chills' (see Figure 1.4, Chapter One). Furthermore, as the pleasure experienced with groove seems closely linked with its movement-inducing properties, as empirically demonstrated in the online rating survey in Chapter Five, it seems pertinent to ask to what extent the neural processes underpinning groove reflect this relationship. Specifically, if grooves that particularly elicit the desire to move and feelings of pleasure can be identified, to what extent do such grooves affect reward and motor networks in the brain?

Considering the relevant studies reported above and the results found in the online rating survey, there are four possible relationships between neural activity and syncopated groove that seem most likely:

1) *An inverted U-shaped relationship between syncopation and neural activity.*

This would suggest that the subjectively experienced desire to move and pleasure reported in the rating survey is reflected in neural correlates. Furthermore, it might indicate which areas are modulated by the perception of metric events. Similarly, it would support the theory of predictive coding (Gebauer et al., in prep; Vuust et al., 2009), if it is accepted that grooves with a medium degree of syncopation afford the most prediction and prediction error.

2) *A positive correlation between activity and syncopation*.

Such a finding would indicate regulation of the objective degree of rhythmic complexity, supporting previous research demonstrating the effect of stimulus complexity on neural activity, such as in the basal ganglia (Chen, Penhune, et al., 2008; Chen, Zatorre, et al., 2008) and the insula (Singer et al., 2009). In accordance with information processing theory (Singer et al., 2009), increasing activity with increasing complexity would imply an input–output process by which the objective degree of uncertainty in the music is encoded by the brain, in a one-to-one relationship.

3) *A negative correlation between activity and syncopation.*

A result showing this trend would indicate regulation of the degree of rhythmic complexity in an inverted way, in line with previous studies into the neural correlates of simple metre perception (Grahn & Brett, 2007; Thaut et al., 2008). Thus, the less syncopated rhythm, the more easily the main pulse can be perceived and the greater the neural activity. Such a finding would, as in the point above, also indicate an objective correlation with activity, albeit based on the degree of regularity, rather than complexity.

4) *No significant modulation of activity as a result of changing degree of syncopation.* This would suggest either that relevant areas are not involved in the experience of syncopated groove at all, or that such areas are equally activated (or deactivated) during groove, regardless of the degree of syncopation.

The present study used an fMRI paradigm to investigate the extent to which these relationships are reflected in neural activity in the brain associated with reward and movement. As dance experience was found to affect subjective reports of syncopated drum-breaks in the online rating survey, and musical training, familiarity and dance

experience have been shown to affect neural responses to rhythmic, embodied and affective stimuli in previous research (Cross et al., 2006; Salimpoor et al., 2011; Vuust, 2005), these between-subjects effects on neural activity were also addressed.

6.2 METHOD

6.2.1 Participants

26 right-handed Danish-speaking participants (7 females, 19 males) aged between 21 and 40 (Mean = 25.13, SD = 5.34) were recruited through adverts and opportunity sampling and were scanned at the Center of Functionally Integrative Neuroscience (CFIN), Aarhus University Hospital, Denmark. All received a small payment for their participation. Participants completed a demographics questionnaire which asked the same questions (in Danish) as the questionnaire used in the online rating survey reported in Chapter Five, recording their musical training, groove familiarity and experience of dancing, with one additional question relating to their liking of groove.[3]

However, as the demographics questionnaire showed that most participants liked and frequently listened to groove, and enjoyed dancing and frequently danced to music, the categories for groove familiarity and dance experience were defined differently compared to the online rating survey. As expected, there were strong correlations between liking and frequency of listening to groove ($r = .642$, $p < .001$) and between liking and frequency of dancing ($r = .625$, $p < .001$). Thus, a principal component analysis (PCA) was run on these two-group measures, and the resulting first principal components were used as measures of groove familiarity and dance experience. Participants were then defined as belonging to groups based on their position on the spectrum of groove familiarity and dance experience, i.e. whether they were below or above the mean. This yielded the following numbers in

[3] In the online rating survey, only frequency of listening to groove, not liking of it, was recorded.

each category: frequent groove-listener N = 12; infrequent groove-listener N = 14; frequent dancer N = 12; infrequent dancer N = 14. Importantly, groove familiarity did not correlate with dance experience (r = .243, p = .231), confirming that these categories represented different psychological traits. In the following, in which effects of groove familiarity and dance experience are interpreted, the nature of this analysis should be kept in mind, as it does not strictly represent participants who do not listen to groove or do not dance, but different *degrees* of groove familiarity and dance experience, relative to the particular sample of participants.[4] The classification of musical training was categorical, as in the online rating survey, albeit with different criteria for inclusion in the two categories, in order to prevent the exclusion of any participants. Those who had more than six years of musical training were categorised as musicians (N = 12), and those who had less than five years of training were categorised as non-musicians (N = 14).[5]

6.2.2 Stimuli

During scanning, participants heard 15 synthesised drum-breaks with various degrees of syncopation according to the index of polyphonic syncopation proposed in Chapter Four. The drum-breaks were chosen from the larger pool of 50 funk drum-breaks, which were used in the online survey reported in Chapter Five, and consisted of 16-second-long repeated 2-bar drum-kit patterns of bass-drum, snare-drum and hihat, at 120 bpm. In the online survey, these drum-breaks had shown an inverted U-shaped relationship between degree of syncopation and ratings of wanting to move and feelings of pleasure (see section 5.2.2 in Chapter Five for a detailed description of the drum-breaks). A three-level parametric design was used in the fMRI study, with 5 drum-breaks for each level: Low,

[4] For this reason, the categories were referred to as frequent and infrequent dancers/groove-listeners rather than dancers/groove-listeners and non-dancers/groove-listeners.

[5] The age at which participants started playing, which is often a criterion in musical training categorisation (Ollen, 2006), was ignored, in order to include as many participants as possible.

Medium and High. For the Low category, 5 drum-breaks with the lowest degree of syncopation that had been rated as eliciting the least desire to move and the least pleasure were chosen. The Medium category included the 5 drum-breaks that had been rated as eliciting the most desire to move and the most pleasure in the online survey, yet had a medium degree of syncopation. For the High category, 5 drum-breaks were chosen that had the highest degree of syncopation, but had been rated as eliciting less desire to move and pleasure than the Medium degree. The reason for choosing the extremes of each category was in order to maximise the likelihood of modelling the linear and U-shaped relationships found in the online rating survey. Importantly, the relationship between syncopation, beat salience and joint audio entropy was similar for this sample of 15 drum-breaks as for the total 50 drum-breaks used in the online survey: there was a negative correlation between beat salience and syncopation, and a positive correlation between beat salience and entropy, but no significant correlation between syncopation and entropy (Table 6.1 below; see section 5.2.2, Chapter Five, for descriptions of these properties).

Although beat salience and syncopation had been shown to be equally explanatory of the relationship between the drum-breaks' complexity and ratings (albeit with different degree depending on whether the question regarded desire to move or pleasure), it was here decided to only model the drum-breaks in terms of syncopation, and not beat salience. Although the two measures were uncorrelated in the full set of 50 drum-breaks in the online survey, they *did* correlate in the smaller subset of 15 chosen for the fMRI study. In other words, in this set of stimuli, syncopation and beat salience were not orthogonal. Thus, in the fMRI analysis, it would not be possible to determine whether a significant BOLD response was a consequence of the drum-break's syncopation or beat salience. Furthermore, the primary interest of the study was syncopation, as opposed to beat salience. Beat salience had been added as an audio descriptor in the online survey in order

to explain any rating variability that could not be explained with measures of syncopation. Since the measures were uncorrelated in this study, the addition of beat salience was able to contribute to the explanation of ratings. Nonetheless, since beat salience is a measure of purely acoustical properties, while syncopation reflects a psychological mechanism, namely the experience of stability as a response to rhythmic expectancy violation, it is believed that syncopation more accurately represents the experience of rhythmic complexity in groove.

However, it was decided to measure the drum-breaks' total number of onsets, since it is known that the brain is sensitive to such temporal variation, particularly the auditory cortex (Zatorre & Belin, 2001). Furthermore, event density has been shown to significantly affect groove ratings (Madison, et al., 2011). For this measure, the hihat was ignored, since it was held constant across stimuli. As table 6.1 indicates, number of onsets correlated significantly with beat salience and entropy, but not with degree of syncopation. Appendix Five shows notational transcripts of the 15 drum-breaks used in the study, the individual drum-break's audio descriptor values, as well as average values across the three categories. Of the 15 drum breaks, 6 were transcribed from 'real' drum breaks from the funk repertoire, while 9 had been composed specifically for the purpose of the research, in order to increase the spread of syncopation and avoid correlations of syncopation degree with event density (see section 5.2.2 in Chapter Five for a more detailed explanation).

	Syncopation	*Beat Salience*	*Joint Audio entropy*
Syncopation		-.805*	-.224
Beat salience	-.805*		.674*
Joint audio entropy	-.224	.674*	
Total number of onsets	.220	771*	929*

Table 6.1 Pearson's *r* for stimulus descriptor correlations. *$p < .01$.

6.2.3 Procedure

All participants received written information about the study and its implications and were informed of safety and practical issues involved in the study. Prior to the experiment, participants were briefed and gave informed consent. Before entering the scanner room, participants attended a training session during which they familiarised themselves with the tasks to be performed inside the scanner. Only when they felt comfortable with these tasks were they invited to enter the scanner room.

Figure 6.1 is a visual representation of the experiment paradigm, which had a parametric block design. During scanning, participants heard each drum-break four times over the course of two main rating tasks. The first main rating task was a 'pleasure rating task', during which participants heard each drum-break twice; once in a 'pleasure rating subtask', and once in a 'passive listening subtask'. Each subtask was divided into two parts, each lasting 8 seconds, corresponding to two halves of the 16-second-long drum-breaks. The first part, referred to as 'listening', was identical for all subtasks. It involved looking at a red fixation cross on a screen visible from within the scanner, while listening to the drum-break and awaiting a visual cue that would trigger the second half of the task. The second part of each subtask was triggered after 8 seconds by the presentation of a visual analogue scale (VAS) on the screen. Depending on the colour of the VAS, participants performed one of the two subtasks. A red VAS cued the 'passive listening subtask', in which participants were instructed to continue listening passively to the drum-breaks. If the VAS was blue, participants performed the 'pleasure rating subtask', by using the VAS to rate: 'to what extent do you experience pleasure with this rhythm?' Ratings were recorded using a response box with one blue and one yellow button, held in their right hand. The scale was continuous, and the poles were indicated by a plus and minus sign at the top and bottom of the scale, respectively. The bar inside the VAS was moved up

and down by pressing the appropriate button on the response box, with the middle finger on the blue button to move it up and indicate increased pleasure, and the index finger on the yellow button to move it down and indicate decreased pleasure. Participants needed to press the button once to make the bar move in the desired direction, and a second time to make it stop at the desired location on the VAS. When the VAS first appeared on the screen, the bar was always placed in the middle of the scale, and participants had been instructed to use it as a positive scale, ranging from 'not at all' to 'very much'.

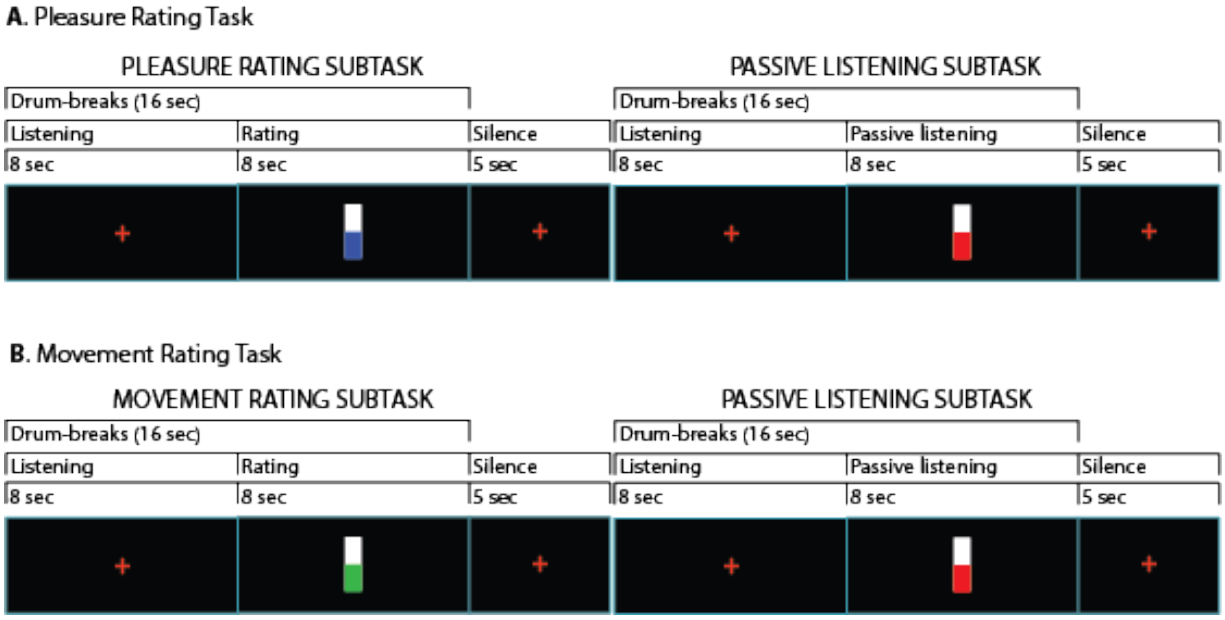


Fig. 6.1 fMRI experiment paradigm. **A.** Pleasure rating task. **B.** Movement rating task.

There were 5-second silence periods, accompanied by the red fixation cross, between each subtask (that is, between the end of a subtask and the onset of 'listening' for the next subtask), as well as 4 silent 'null events', during which participants would see the fixation cross and the VASs (twice with each colour), but no music was heard. These null events were to help prevent the accumulation of scanner signal drift caused by long periods of scanning activity. The orders of the subtasks and drum-breaks were fully randomised, and thus, during 'listening', participants did not know which subtask they would be

required to do in the second half of the drum-break. Importantly, this not only helped to prevent boredom and maintain attention, but also to ensure that the 'listening' of the first 8 seconds of each subtask was identical.

The whole 'pleasure rating task' lasted approximately 12.5 minutes, after which new instructions appeared on the screen, preparing participants for the 'movement rating task', lasting for the same amount of time. In this second main task, participants heard the stimuli again and were asked to do exactly the same as in the 'pleasure rating task', only this time, a green-coloured VAS was the cue for the 'movement rating subtask', during which participants were asked to rate: 'to what extent does this rhythm make you want to move?' As in the previous task, each stimulus was played twice, once with the green VAS (for the 'movement rating task'), and once with the red VAS (for the 'passive listening subtask'). Thus, within each session and across both subtasks, each stimulus was heard four times; and in total, across both main rating tasks, participants performed 15 'pleasure rating subtasks', 15 'movement rating subtasks', 30 'passive listening subtask' and 60 'listening subtasks'.

There were various motivations for incorporating four different tasks into the design. It was decided to ask the two rating questions during two separate tasks to minimise workload and the potential confusion between, or 'blending' of, the pleasure- and movement-ratings. The 'passive listening subtask' was included to avoid the continuous motor planning involved in anticipation of button pressing. As mentioned, the 'listening' ensured that, during half of every drum-break across both main tasks, all aspects – apart from the critical factor of degree of syncopation – were identical: visual stimulus, attentional focus and cognitive workload. Only responses during 'listening' were later modelled in the fMRI analysis.

Total scanning time for each participant was approximately 24.5 minutes.[6] After scanning and a short break, participants were taken to another site where they took part in a motion-capture experiment, which will be reported in the following chapter. After this experiment, they completed the demographics questionnaire.

6.2.4 fMRI Acquisition

Scanning was performed on a 3 Tesla Siemens Trio scanner. High-resolution T_1-weighted rapid acquisition gradient echo planar structural scans were collected (voxel size: 0.98 x 0.98 x 1 mm^3, TR: 1.9 s, TE: 2.26 ms, inversion time: 900 ms, flip angle: 90^o). 616 volumes were obtained during functional T_2*-weighted gradient echo planar scans (voxel size: 3 x 3 x 3.03 mm, matrix size: 64 x 64 x 40, FOV: 192 (64 x 3) mm, TR: 2.43 s, TE: 30 ms, flip angle: 90^o).

6.3 ANALYSIS

6.3.1 Rating Analysis

Since the inverted U-shaped relationship between degree of syncopation and ratings of wanting to move and feelings of pleasure had been thoroughly demonstrated in the online survey, both within and across participants, it was decided to apply only the final stage of analysis to the current ratings performed in the scanner (see section 5.3.5, Chapter Five). This involved a 5-way mixed ANOVA, using PASW 17.0 (IBM, Inc.), with syncopation (three levels; Low, Medium and High) and rating question as independent variables, and musical training, groove familiarity and dancing experience as between-subjects factors.

[6] Before leaving the scanner room, participants took part in another fMRI study, with the same design but using different stimuli, which is not reported here. The order of the two experiments was counterbalanced across participants.

6.3.2 fMRI Processing and Analysis

All fMRI processing and analyses were performed in SPM8 (Wellcome Trust, Inc.) via MATLAB (2012 Mathworks, Inc.). Each subject's scans were realigned to the middle image of the time series and registered to the standard brain of Montreal Neurological Institute (MNI). Functional images were smoothed with a Gaussian kernel of 8 mm, and a high pass filter of 128 Hz was used. In order to maximise the possibility of retrieving data from areas susceptible to noise (e.g. Orbitofrontal Cortex and Frontal Poles), all signal was included in the analyses, as opposed to only signal of above 8% (the standard setting in SPM), and an explicit mask that includes all of the brain was used (see O'Connor, 2010, for a description and justification of this procedure, and a link to the brain mask).

The analysis involved three types of contrasts: drum-breaks versus silence, effect of syncopation degree, and interactions with musical background. The overall effect of drum-breaks versus silence was investigated by contrasting the last 5 seconds of all 8-second 'listening' conditions with the 5-second silence condition and four 'null events' at first (single-subject) level. In this way, the comparison controlled for any effect of sound onset. The contrast images were entered into a second-level (across-subject) mixed-effects t-test, and whole-brain analysis was thresholded at $p < .001$, corrected for false discovery rate (FDR).

To test the effect of syncopation degree, the 8-second 'listening' conditions for the three syncopation levels – Low, Medium and High – were compared at first level. Then, the factorial main effect was investigated at second level, with individual subjects modelled as covariates. Results were masked with a statistical map derived from positive effects of 'listening', in order to exclude areas that showed no significant activity during 'listening' compared to 'rating' and silence. Whole-brain analysis was thresholded at $p < .05$, using FDR correction.

Differences between the syncopation levels and interactions with between-subjects factors were tested in an ANOVA using PASW Statistics 17.0 (IBM, Inc.), with extracted statistical data based on 8 mm spheres at peak voxels in statistically significant areas (according to the main effect). All brain images in this chapter show statistical maps and MNI (Montreal Neurological Institute) standard brains in 1x1x1 mm space.

Finally, the analysis in SPM was rerun with an additional covariate, which represented the drum-breaks' total number of onsets as a continuous regressor.

6.4 RESULTS

6.4.1 Behavioural Results

The inverted U-shaped curve between degree of syncopation and ratings of wanting to move and feelings of pleasure found in the online rating survey was largely replicated with the scanner ratings: there was a main effect of Syncopation (Table 6.2), and Bonferroni post-hoc tests showed that ratings for Medium syncopation were significantly higher than for High ($p < .001$), and close to significantly higher than for Low ($p = .054$). There were no significant differences between High and Low ($p = .99$). Figure 6.2 depicts the mean ratings. There were no effects of rating question or any between-subjects factors, nor any significant interactions.

Main Effect	*F*	*df(error)*	*p*
Syncopation	12.65	2(38)	< .001
Rating Question	3.41	1(19)	.081
Musical Training	1.71	1(19)	.207
Groove Listening	.64	1(19)	.432
Dancing	.46	1(19)	.505

Table 6.2 Main effects of syncopation, rating question and between-subjects factors on mean ratings.

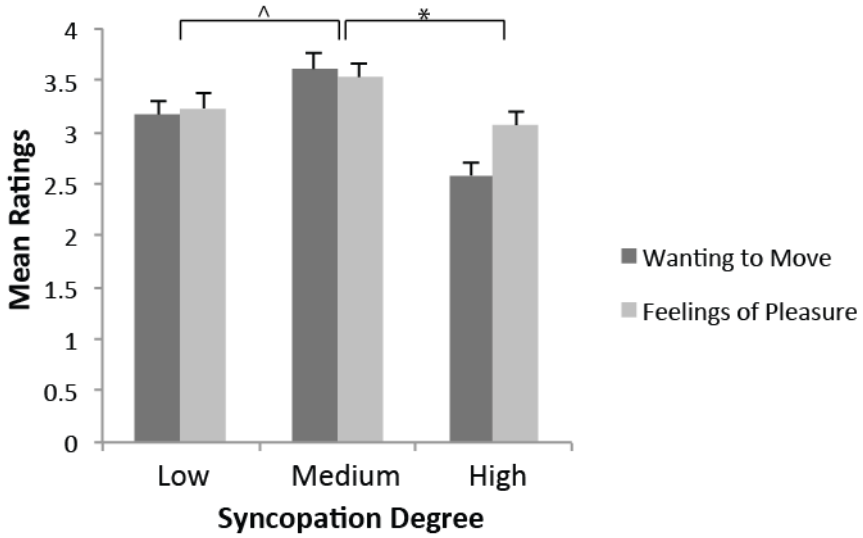


Fig. 6.2 Effect of syncopation on ratings of wanting to move and feelings of pleasure. Error bars = standard error. *$p < .05$, ^Approaching significance at $p = .054$.

6.4.2 fMRI Results

6.4.2.1 Drum-breaks versus Silence

As expected, a large number of brain regions in both hemispheres were recruited during listening to the drum-breaks in the 'listening' condition compared to silence (Table 6.3). Aside from the expected auditory regions, the regions that showed the most activity were secondary motor areas (SMA, pre-SMA, PMC) and the intraparietal cortex. Furthermore, thalamic and occipital areas, the insula, anterior cingulate cortex, brainstem, cerebellum and basal ganglia (putamen, pallidum and caudate) were also recruited. When lowering the threshold (pFDR < .05), orbitofrontal areas also showed significant activity.

6.4.2.2 Effect of Syncopation

There was a main effect of syncopation in primary and secondary auditory cortices, the anterior inferior insula and three structures in the basal ganglia, specifically the putamen, the pallidum and the head of the caudate. Main-effect peak voxel statistics are given in Table 6.4. As shown in Figure 6.3, there were significant differences between all

Brain Region	Hemisphere	Statistic	Coordinates (MNI)		
		t	*x*	*y*	*z*
Supplementary motor area (rostral cingulate zone)	R	17.48*	6	14	48
	L	11.46*	-8	10	46
Auditory cortex (primary and secondary areas)	L	17.14*	-38	-28	14
	R	12.78*	46	-22	8
Pre-supplementary motor area	L	13.14*	-14	2	64
	R	12.70*	8	4	62
Intraparietal cortex	L	13.77*	-48	-36	48
	R	11.40*	48	-32	46
Dorsal premotor cortex	L	13.31*	-6	-6	62
	R	12.70*	8	4	62
Precentral gyrus	L	12.53*	-26	-6	60
Anterior inferior insula	L	11.95*	-28	18	6
	R	11.65*	32	22	4
Superior parietal cortex	L	11.90*	-32	-44	48
	R	8.83*	28	-46	48
Midbrain		10.70*	4	-18	-8
Thalamus (prefrontal and sensory)	L	10.46*	-6	-18	-2
	R	9.98*	8	-16	-4
Brainstem (periaqueductal grey)		10.70*	4	-18	-8
Brainstem (medulla)		5.54*	0	-32	-38
Cerebellum	R	10.14*	24	-50	-26
	L	8.49*	-28	-56	-26
Middle premotor cortex/BA44	R	9.51*	56	10	18
	L	8.92*	-56	6	22
Anterior cingulate cortex	L	9.24*	-8	20	30
	R	9.12*	10	20	30
Precuneus	R	8.06*	12	-66	46
Superior parietal cortex (precuneus)	L	8.49*	-20	-58	54
Premotor cortex	R	7.60*	36	0	58
Fusiform cortex	R	7.21*	34	-52	-14
	L	6.37*	-34	-62	-10
Occipital cortex	L	7.21*	-22	-68	30
	R	6.76*	28	-68	34
Occipital pole	L	7.11*	-34	-92	-2
	R	6.30*	34	-88	6
Posterior cingulate cortex		6.68*	-4	-26	26
Dorsolateral prefrontal cortex	R	6.28*	30	46	26
	L	5.68*	-30	42	18
Putamen/pallidum	R	6.76*	16	2	0
	L	5.64*	-20	6	2
Secondary visual cortices	L	5.99*	-48	-70	6
Caudate	R	4.99*	-4	10	10
	L	4.93*	6	6	8
Mid-anterior orbitofrontal cortex	R	3.98**	20	40	-16
	L	3.78**	-24	44	-16
Posterior orbitofrontal cortex	R	2.91**	22	16	-20
	L	3.38**	-22	12	-16

Table 6.3 Brain regions in order of statistical t-values (within bilateral activity), coordinates (mm) of peak voxels in MNI space for listening vs. silence. Df(error) = 1(25). **p*FDR < .001,***p*FDR < .05.

Brain Region	Hemisphere	Statistic		Coordinates (MNI)		
		F	*Z*	*x*	*y*	*z*
Primary Auditory Cortex	L	41.80	6.59	-48	-18	2
	R	42.33	6.62	54	-12	2
Putamen/ Pallidum	L	13.07	4.04	-18	2	-4
	R	9.29	3.37	18	6	-2
Anterior Inferior Insula	L	14.46	4.24	-40	26	4
	R	8.88	3.29	38	24	-2
Caudate	R	8.21	3.15	16	10	6
	L	6.56	2.75	-8	12	10

Table 6.4 Brain regions, F- and Z-values and coordinates (mm) of peak voxels in Montreal Neurological Institute space for significant main effect of syncopation, *p*FDR < .05.

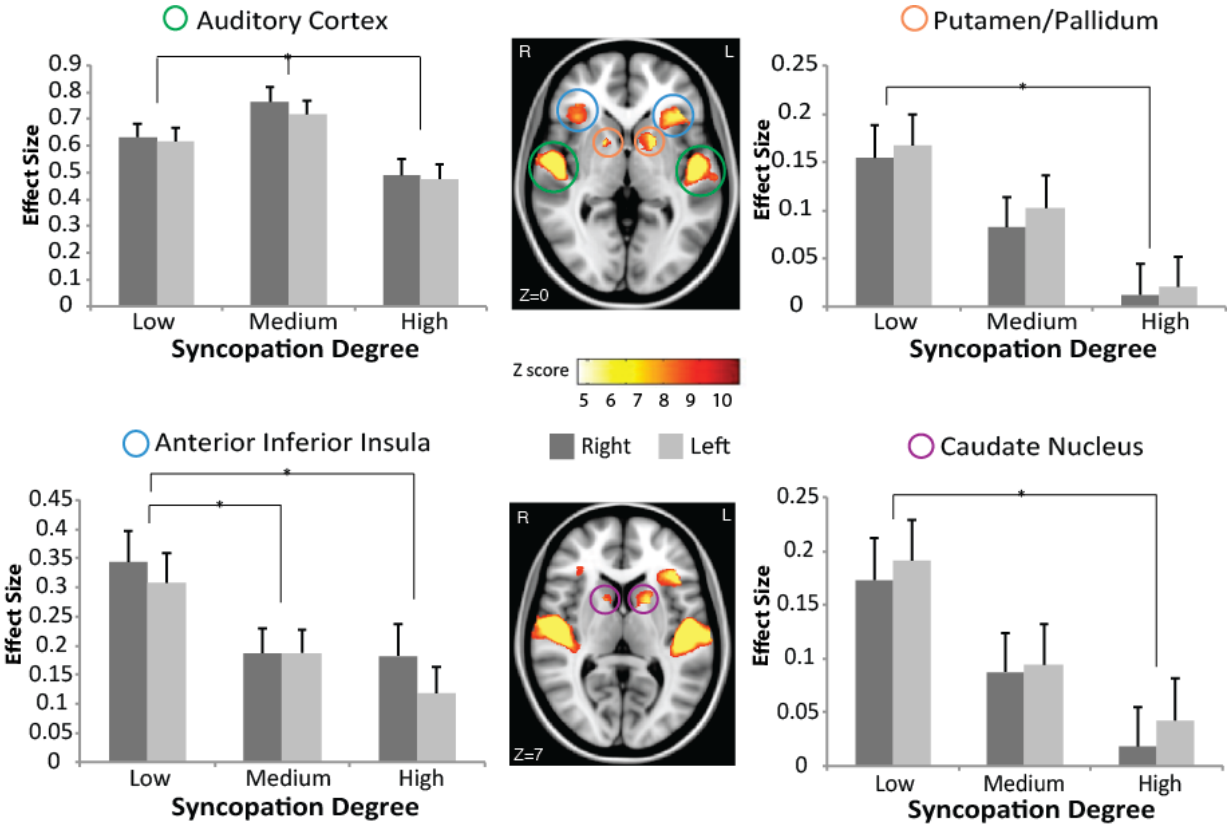


Fig. 6.3 Effect of syncopation degree on bilateral BOLD response in auditory cortex, putamen/pallidum, anterior inferior insula and caudate nucleus, *p*FDR < .05.

conditions in the auditory cortices. Specifically, Medium syncopation afforded the highest BOLD response, followed by Low and High respectively (all $p < .05$). In other words, there was an inverted U-shaped relationship between activity in the auditory cortex and syncopation, and Low syncopation activated the auditory cortex more than High

syncopation. The remaining areas showed a negative linear trend. In the putamen/pallidum, Low syncopation elicited the strongest responses compared to High ($p < .001$), but there were no significant differences between Medium and Low ($p = .23$) or Medium and High ($p = .165$). There was a similar negative linear relationship between degree of syncopation and the response in the caudate; Low degrees showed significantly higher activity than High degrees ($p < .001$), but there were no significant differences between Medium and Low ($p = .109$) or Medium and High ($p = .525$). For the anterior inferior insula, Low syncopation was associated with the most activity, compared to Medium and High, respectively (all $p < .05$), but there was no significant difference between Medium and High ($p = .99$). No positive linear correlations with syncopation were found. Finally, there were no significant hemispheric main effects (auditory cortex $F(1,26) = .53$, $p = .474$, anterior inferior insula $F(1,25) = 2.82$, $p = .105$, putamen/pallidum $F(1,25) = 2.69$, $p = .113$, and caudate $F(1,25) = 2.86$, $p = .103$).[7]

6.4.2.3 Effect on the Basal Ganglia

A closer look at the significant main effect in the basal ganglia can be seen in Figure 6.4. The probabilistic atlas of the basal ganglia and thalamus proposed by Ashan et al. (2007), which is based on structural data of 30 healthy participants, was used to determine the likelihood of the peak voxels' anatomic locations. According to the atlas probabilities, the peak voxel in the left hemisphere had a putamen probability of 5% and a pallidum probability of 67.5%. Right-laterally, the peak voxel had a putamen probability of 10% and

[7] In studies investigating the extent to which a specific function is lateralised, it is common to apply an analysis in which a 'symmetric template' is generated on the basis of 'flipping' statistical maps from one hemisphere to the other (due to anatomical asymmetries in the common standard brains used, such as the MNI template) (e.g. Good, et al., 2001). However, since in the present case the primary interest relates to the extent to which the BOLD signal associated with a specific function is stronger in one hemisphere than the other, the statistical analysis used is appropriate (and has previously been used in related research, e.g. Vuust, et al., 2006).

a pallidum probability of 17.5% (see Table 6.4 for coordinates). In other words, the strongest activity was more likely in the pallidum than the putamen in the left hemisphere, while both probability statistics were relatively low and the difference between them relatively small on the right side of the brain. The atlas also indicates that the strongest activity was in the external globus pallidus, bilaterally, although some of the weaker responses extended into the ventral pallidum.

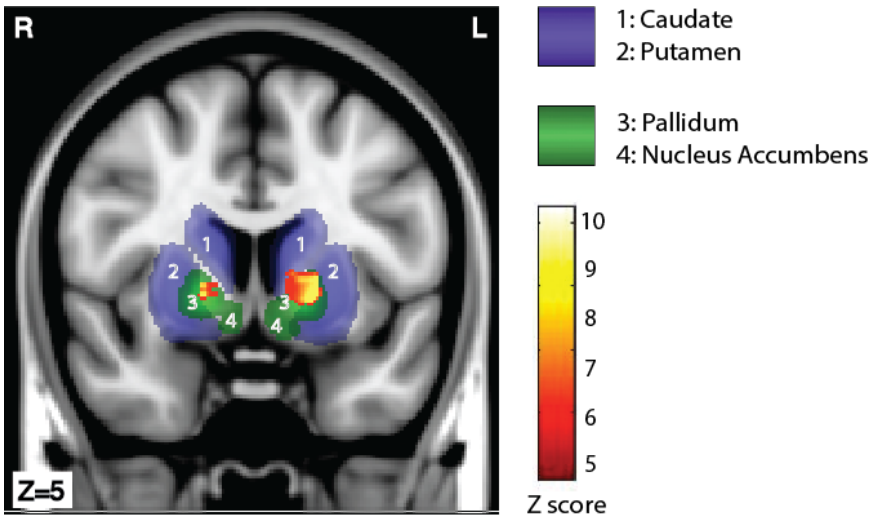


Fig. 6.4 Statistical map, in red-to-yellow, of significant main effect of syncopation overlaid on probabilistic atlas (Ashan et al. 2007) of the basal ganglia. Purple 1: caudate, 2: Putamen. Green 3: Pallidum, 4: Nucleus Accumbens.

6.4.2.4 Effects of Musical Background

There were no main effects of musical background on neural activity, but the effects of syncopation on the regions reported above interacted with participants' musical training, groove familiarity and dance experience in various ways. There was a significant three-way interaction between syncopation, laterality and dance experience ($F(2,36) = 4.49$, $p = .018$) in the auditory cortices. Table 6.5 reports follow-up paired contrasts for frequent dancers and infrequent dancers and Figure 6.5 shows the mean values. These suggest that drum-breaks with Medium degrees of syncopation were associated with greater activity

bilaterally in the auditory cortex compared to drum-breaks with High degrees of syncopation for both frequent and infrequent dancers. When comparing drum-breaks with Low syncopation and those with High syncopation, there were only significant effects in the right and left hemispheres of infrequent dancers, not of frequent dancers. There was a close-to-significant difference when comparing drum-breaks with Low syncopation with those with Medium syncopation in the right hemisphere of frequent dancers, but not in the left hemisphere, nor on either side of the brains of infrequent dancers. Finally, there were no significant differences between activity in the auditory cortex between the right and left hemisphere, for either group.

Auditory Cortex Contrasts			*Mean*	*SE*	*t*	*p*
Frequent Dancer	Right vs. Left	Low	-.01	.03	-.27	.792
		Medium	.01	.04	.14	.891
		High	.01	.03	.38	.707
	Low vs. Medium	Right	-.14	.05	-2.88	.013
		Left	-.13	.04	-3.30	.006^
	Low vs. High	Right	.08	.04	1.87	.084
		Left	.10	.04	2.48	.027
	Medium vs. High	Right	.22	.04	5.36	< .001*
		Left	.23	.05	4.78	< .001*
Infrequent Dancer	Right vs. Left	Low	.02	.07	.36	.726
		Medium	.08	.07	1.13	.282
		High	-.01	.06	-.14	.892
	Low vs. Medium	Right	-.14	.05	-2.58	.026
		Left	-.08	.05	-1.66	.125
	Low vs. High	Right	.22	.04	5.00	< .001*
		Left	.18	.04	3.94	.002*
	Medium vs. High	Right	.36	.04	7.33	< .001*
		Left	.26	.04	5.84	< .001*

Table 6.5 Paired contrasts for interaction of syncopation, dancing experience and laterality in the auditory cortex. *Alpha adjusted $p < .005$. ^Approaching significance at $p = .006$ Frequent dancers: N(df) = 14(13), infrequent dancers: N(df) = 12(11).

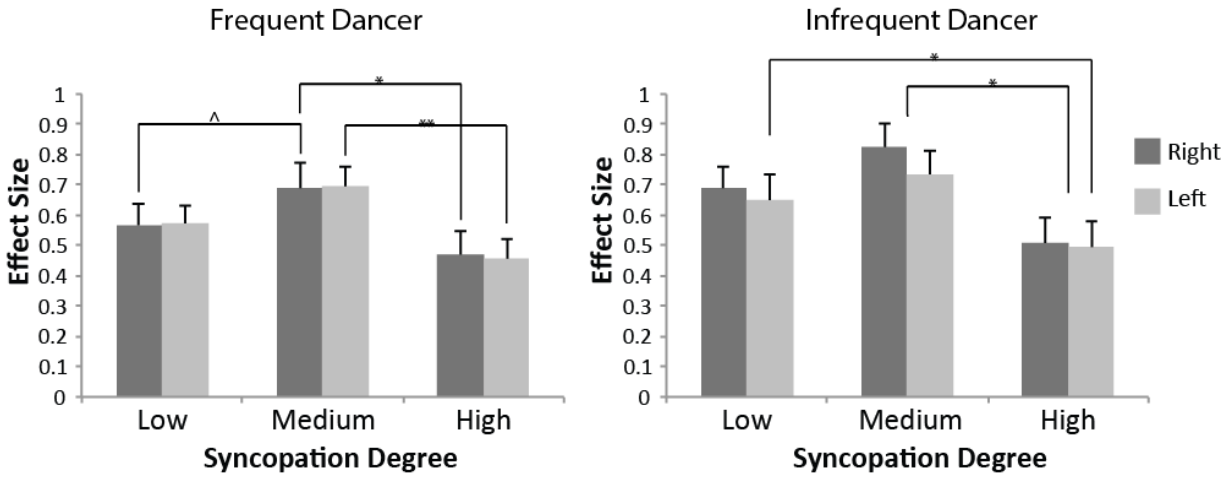


Figure 6.5 Interaction between syncopation, dancing and laterality in the auditory cortex. *Alpha adjusted $p < .005$. ^Approaching significance at $p = .006$

In the putamen/pallidum, a significant three-way interaction was found between syncopation, laterality and musical training ($F(2,36) = 4.69$, $p = .015$). Table 6.6 and Figure 6.6 report follow-up paired contrasts and mean values. These results indicate that the negative linear relationship between syncopation and activity in the putamen/pallidum was confined to musicians, specifically for when comparing High with Low and High with Medium (although there was no significant difference between High and Low in the musicians' left hemisphere). As the graph indicated a greater activity for drum-breaks with Medium syncopation for musicians compared to non-musicians, another t-test was performed to determine the significance of this difference. An independent-samples t-test showed that the activity during Medium syncopation was significantly greater for musicians compared to non-musicians in both right ($t(24) = 1.67$, $p = .035$) and left ($t(24) = 2.3$, $p = .049$) hemispheres. No interactions with between-subjects factors or laterality were found in the caudate.

Putamen/Pallidum Contrasts			*Mean*	*S.E.*	*t*	*p*
Musician	Right vs. Left	Low	.01	.02	.47	.648
		Medium	-.04	.02	-2.55	.027
		High	-.01	.02	-.43	.674
	Low vs. Medium	Right	.07	.06	1.16	.270
		Left	.02	.05	.28	.782
	Low vs. High	Right	.18	.04	4.95	< .001*
		Left	-.15	.06	-2.55	.027
	Medium vs. High	Right	.11	.06	1.77	< .001*
		Left	-.17	.03	-5.56	< .001*
Non-Musician	Right vs. Left	Low	-.03	.01	-2.24	.043
		Medium	.001	.02	.09	.926
		High	-.01	.02	-.41	.686
	Low vs. Medium	Right	.07	.05	1.42	.180
		Left	.11	.05	2.13	.052
	Low vs. High	Right	.11	.04	2.44	.029
		Left	-.02	.04	-.51	.621
	Medium vs. High	Right	.03	.05	.67	.513
		Left	-.10	.04	-2.27	.041

Table 6.6 Paired contrasts for interaction of syncopation, musical training and laterality in the putamen/pallidum. *Alpha adjusted $p < .005$. Musicians: N(df) = 12(11), non-musicians: N(df) = 14(13).

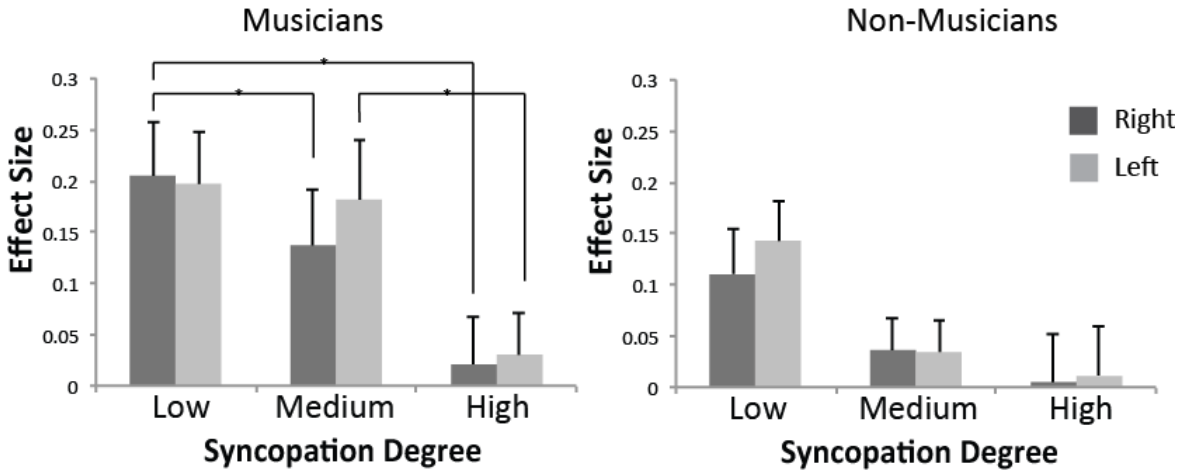


Figure 6.6 Interaction between syncopation, musical training and laterality in the putamen/pallidum. *Alpha adjusted $p < .005$.

Finally, for the anterior inferior insula, a significant two-way interaction was found between syncopation and groove-familiarity ($F(2,36) = 4.01$, $p > .027$). Table 6.7 and Figure 6.7 show that the negative linear relationship only applied to infrequent groove-listeners, and that there were no significant differences between syncopation levels for frequent groove-listeners.

Anterior Inferior Insula Contrasts		*Mean*	*SE*	*t*	*p*
Groove-Listener	Low vs. Medium	.06	.07	.86	.406
	Low vs. High	.04	.04	1.05	.315
	Medium vs. High	-.02	.07	-.29	.777
Non-Groove Listener	Low vs. Medium	.21	.06	4.03	.001*
	Low vs. High	.30	.05	5.33	< .001*
	Medium vs. High	.09	.04	1.91	.078

Table 6.7 Paired contrasts for interaction of syncopation and groove familiarity in the anterior inferior insula. *Alpha adjusted p = .017. Frequent groove-listener: N(df) = 12(11), infrequent groove-listener: N(df) = 14(13).

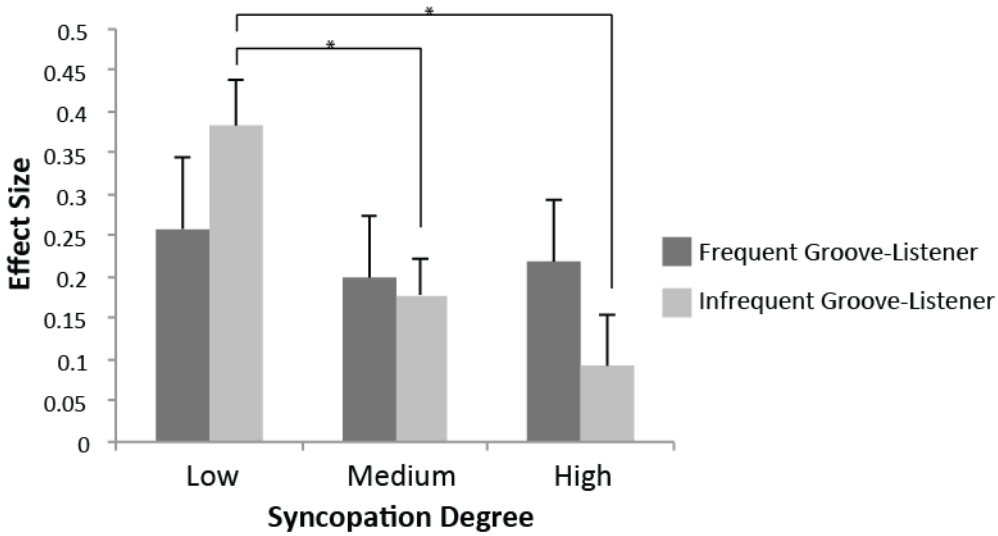


Figure 6.7 Interaction between syncopation and groove familiarity in the anterior inferior insula. *Alpha adjusted p = .017.

6.4.2.5 Effect of Total Number of Onsets

The analysis as run with the total number of onsets added as a continuous covariate showed a significant effect of number of onsets on neural activity, with peak activations in the auditory cortex, bilaterally (coordinates left: 56, -16, 4; Z = 7.75. Coordinates right: -44, -22, 6; Z = 6.96, *pFDR* < .001), and the brainstem (coordinates: 4, -36, -8; Z = 3.28, *pFDR* < .05). These results are in line with previous research into the processing of sound information by the auditory system (Zatorre & Belin, 2001). Based on these findings, it could not be ruled out that the main effect of syncopation discovered in the auditory cortex was not in fact an effect of number of onsets. However, the contrast showing a significant

negative linear function in the basal ganglia and anterior inferior insula survived the covariate analysis, suggesting that a negative linear relationship truly reflects the effect of syncopation on neural activity in this region.

6.5 DISCUSSION

To summarise, this study found that the degree of syncopation in drum-breaks was related to ratings of wanting to move and feelings of pleasure in an inverted U-shaped way, largely replicating findings from the online rating survey reported in Chapter Five. One difference was that low syncopation was not rated differently from high syncopation in the scanner, while in the survey, the former had been rated higher than the latter. When comparing listening to drum-breaks with silence, a number of brain regions showed significant increase in BOLD responses, including motor, reward, attentional and sensory areas. More interestingly, both inverted U-shaped and negative linear relationships between activity and syncopation degree were found in a smaller number of regions, and the directions of these relationships depended on the region. Thus hypotheses 1 and 3 could both be supported. No positive linear relationships between syncopation and neural activity were found, ruling out hypothesis number 2. Furthermore, listeners' musical training, familiarity with groove and experience of dancing interacted with activity patterns, often depending on the brain hemisphere. An inverted U-shaped relationship was found in the auditory cortices, which was manifested somewhat differently across the two hemispheres depending on the participant's experience of dancing. A linear negative relationship was found between syncopation and activity in the putamen/pallidum and caudate of the basal ganglia, but in the putamen/pallidum, the effect was only found for musicians and only for high syncopation compared with low and medium syncopation. Furthermore, the activity was higher in the putamen/pallidum during medium syncopation

for musicians compared to non-musicians. A closer inspection of the anatomical location of these responses (regardless of musical training) showed that, in the right hemisphere, the activity was most likely localised in the pallidum, while in the left hemisphere, there was greater overlap between the pallidum and the putamen. Furthermore, the pallidal activity centred on the external pallidum, with extensions into the ventral pallidum. There was also a negative linear relationship between activity in the anterior inferior insula and syncopation degree, but only for listeners less familiar with groove.

The areas showing increased activity during drum-breaks compared to silence are largely consistent with previous research investigating the effect of music on the brain (for reviews, see Koelsch, 2005, 2012). A number of motor (SMA, pre-SMA, PMC, cerebellum, basal ganglia), emotional-evaluative (ACC, OFC, anterior insula, basal ganglia), attentional (intraparietal, superior parietal, precuneus, temporal) and sensory (auditory, occipital) regions were recruited. However, at this stage of the analysis, the findings are inconclusive regarding the effect of syncopation. Nonetheless, these patterns of activity provide a backdrop to the modulatory influence of syncopation degree in drum-breaks, and are likely to interact with such modulating areas. In other words, they could support hypothesis number 4, which stated that neural activity would remain unchanged for all drum-breaks, regardless of syncopation degree.

On the whole, the significant modulation of the auditory cortices by syncopation degree is in accordance with previous studies showing the involvement of the temporal lobes (STG and planum temporale) in processing of rhythmic complexity (Bengtsson et al., 2009; Chen et al., 2006; Grahn & Brett, 2007; Grahn & Rowe, 2012) and syncopation (Chapin et al., 2010). Furthermore, the inverted U-shape of the activity, which is in accordance with the subjective ratings of wanting to move and feelings of pleasure, may indicate that the auditory cortices are modulated by syncopated groove at a conscious

level. As reviewed above, although primary sensory cortices are not part of the core reward circuits, unlike areas such as the OFC and ventral striatum, the auditory cortices are involved in a broader pleasure network in the brain, due to their modulatory effect on top-down attentional mechanisms (Liégeois-Chauvel et al., 1998; Zatorre & Schönwiesner, 2011). It could therefore be that, in the present study, the auditory cortices showed the most activity during drum-breaks with medium degree of syncopation because these drum-breaks elicited the most desire to move and the most pleasure at a subjective level and thus attracted the most attention. In fact, the differences between syncopation levels in BOLD response and ratings in the online survey corresponded exactly: not only were drum-breaks with medium syncopation associated with the highest BOLD response and the highest ratings, but drum-breaks with low syncopation showed higher BOLD response and higher ratings than drum-breaks with high syncopation.[8] This suggests a close relationship between subjective pleasure and desire to move, and activity in the auditory cortex. However, when dancing experience was taken into account, this characteristic U-shape looked somewhat different for the two groups. Activity in the auditory cortices only increased during low compared to high syncopation for infrequent dancers. Furthermore, there was no difference in activity in the left auditory cortex for frequent dancers when comparing medium syncopation with low syncopation. Nonetheless, the patterns are largely U-shaped for both groups. In the online rating survey, it was found that, overall, dancers rated drum-breaks higher for both movement induction and pleasure, compared to non-dancers. No such main effect was found in the ratings of the fMRI study. However, this could be due to the difference in categorisation criteria. Thus, the relationship between dance experience, syncopation in groove and activity in the auditory cortex remains unclear.

[8] However, as mentioned, the difference between low and high syncopation was not found in the scanner ratings.

It is also possible that attention was greatest during medium syncopation due to the increased workload associated with perception of metric events. Activity in the primary auditory cortex is known to correlate with increased demands on working memory (Hickok et al., 2003). Thus, in order to maintain the main pulse during rhythms containing some metric events without phenomenal events, attention and working memory is required to a greater extent than during rhythms in which all or no metric events coincide with phenomenal events. At low and high levels of syncopation, working memory is either superfluous (the metric events are given in the stimulus) or avoided (metre perception is entirely impossible).

With regard to the inverted U-shape found in the auditory cortex, the predictive coding model appears compatible. As the MMN and p3a responses found to relate to rhythmic-metric incongruity in the study by Vuust et al. (2009) were localised in the auditory cortex, it could be that the inverted U-shape found in activity of the auditory cortex in the present study reflects the increased prediction-error coding and attentional reorientation afforded by drum-breaks with intermediate degrees of syncopation. Similar to the idea of increased working memory mentioned above, the degree of syncopation at medium levels is such that prediction error is highest. This is because at low levels, there is little metric incongruity because the majority of phenomenal events coincide with metric events, and thus structural predictions are largely met. At high levels, the degree of metric incongruity is such that the brain is unable to make predictions at all, since so few metric events coincide with phenomenal events. Furthermore, the attentional reorientation mechanism shown by Vuust et al. is in accordance with the hypothesis of increased attention during drum-breaks with a medium degree of syncopation, potentially relating to the subjective wanting to move and feelings of pleasure. However, the BOLD results found in the present study cannot be directly equated with the event-related potentials found in

the study by Vuust et al., as they represent different neural mechanisms (albeit the former an indirect measure of the latter). The present findings are also consistent with the hypothesis that predictive coding accounts for the rewarding aspects of music, as proposed by Gebauer et al. (in prep.). However, the involvement of predictive coding in the affective regulation of groove experience would require that a neural network connects the prediction-error coding in the auditory cortex with other areas regulating reward in the brain.

In the basal ganglia, including the putamen, pallidum and the caudate, a negative linear relationship was found between neural activity and degree of syncopation. This is in accordance with previous research showing that the basal ganglia respond to metrically simple rhythms more than metrically complex and nonmetric rhythms (Grahn & Brett, 2007), and to metric rhythms compared to nonmetric rhythms (Grahn & Rowe, 2009); and that activity in the basal ganglia decreases during tapping in cross-rhythmic relationship to rhythm (Thaut et al., 2008). However, this negative linear relationship may at first seem to contradict the hypothesis that the basal ganglia are particularly responsive to perception of metric events, if we assume that medium degrees of syncopation promote the highest degree of perception of metric events and we accept the recent proposal that the putamen in particular regulates beat continuation (i.e. perception of metric events) (Grahn & Rowe, 2012). In other words, if the putamen regulates perception of metric events, and medium degrees of syncopation optimise perception of metric events, an inverted U-shaped relationship would be expected in response to degree of syncopation in the basal ganglia. However, taking the three-way interaction with musical training and laterality into account, the findings seem to fit this hypothesis of an inverted U-shape somewhat better. The interaction showed that the negative linear relationship was only reflected in the basal ganglia of musicians, as opposed to non-musicians, and that low and medium syncopation

recruited the putamen/pallidum to a similar extent in the left hemisphere, although both significantly different from high syncopation. Furthermore, bilateral putamen/pallidum activity during medium syncopation was significantly higher for musicians compared to non-musicians. It has been shown that musicians are better at perceiving a rhythm's underlying main pulse than non-musicians (Palmer & Krumhansl, 1990), and that this expertise-related effect is left-lateralised in the brain during rhythm perception and production: Vuust et al. (2005) found that pre-attentive neural activity as elicited by syncopation and metric displacement, measured using MEG, was stronger in the left hemispheres of musicians compared to non-musicians. In a later study, Vuust et al. (2006) also found some trends (i.e. a close-to-significant correlation) suggesting that the accuracy of tapping to the main pulse during polyrhythms (i.e. a form of metre perception) was related to activity in the *left* BA 47 (an area known to be involved in linguistic-semantic processing). Thus, it could be that the musicians in the present study were able to perceive the metric events in the drum-breaks with medium degree of syncopation to a greater extent than non-musicians, resulting in increased activity in the left putamen/pallidum. In fact, the findings might suggest that musicians are equally able to perceive the main pulse in rhythms with low and medium syncopation, while non-musicians are less able to perceive the pulse in the latter. However, since low syncopation was found to increase activity in the putamen/pallidum to a greater extent than medium syncopation in musicians' *right* hemispheres, these preliminary interpretations and their relevance to an understanding of perception of metric events, syncopation and the basal ganglia must be approached with caution.

The findings of a negative linear relationship between syncopation degree and activity in the anterior inferior insula contradict the first and second hypothesis proposed and previous studies reporting positive correlations between activity in the anterior insula

and perceptual complexity, uncertainty and emotion (see Singer et al., 2009 for a review): according to these theories, the drum-breaks expected to elicit the most activity would be those with a degree of syncopation that elicits the most pleasure, or presents the most rhythmic complexity. Subjectively, the drum-breaks with a medium degree of syncopation are the most pleasurable, while objectively, those with a high degree of syncopation are the most complex. However, overall, it was the drum-breaks with a low degree of syncopation that elicited the most activity in the anterior insula in the present study. Thus, it could be that the negative linear relationship reflects the encoding by this area of the objective rhythmic *regularity* of the rhythm. In fact, it is possible that a measure of the drum-break's beat salience, which is the objective degree of regularity in rhythm (as measured in the online rating survey), would show a *positive* linear relationship. In this way, the lower-level perception of syncopated drum-breaks is linearly regulated by the anterior insula with regard to objective structural regularity, with increased activity during low syncopation and decreased activity during high syncopation. However, as an interaction was found with groove familiarity, it could be that the role of the anterior insula in regulating objective rhythmic regularity only applies to listeners who do not listen to groove-based music very often. More research is needed to determine how the insula and its anterior division contribute to the experience of groove.

Nonetheless, the results show that the auditory cortex, putamen, pallidum, caudate and anterior inferior insula are instrumental in the perception of syncopated drum-breaks. Here, it is proposed that these areas are part of a network (Figure 6.8). It is well known that the basal ganglia project neural information to the auditory cortex, and it has been shown that these projections are stronger during the perception of metric rhythms compared to nonmetric rhythms (Grahn & Rowe, 2009). Thus, it could be that after the drum-break enters the network through the auditory cortex, the degree to which it requires metre

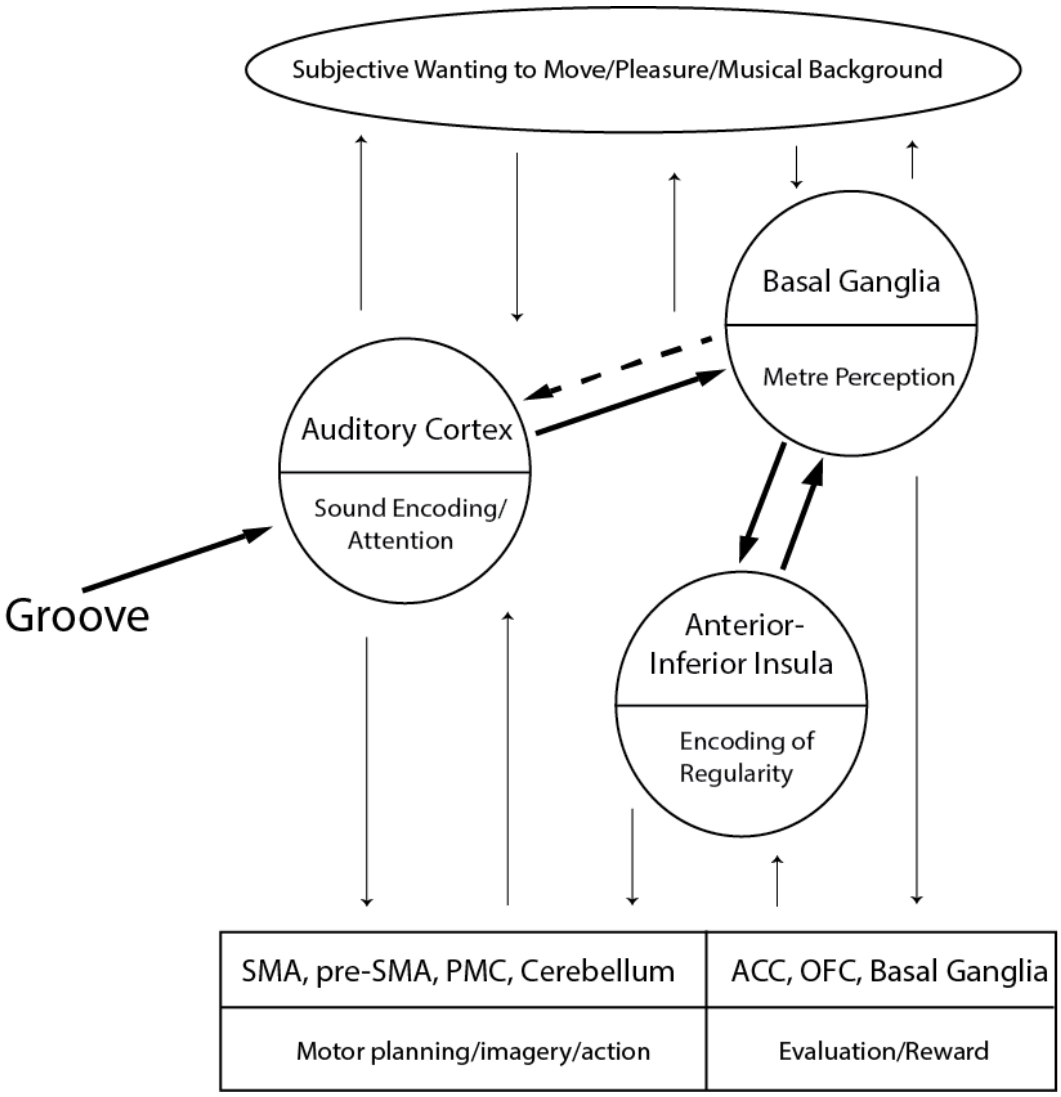


Fig. 6.8 Neuropsychological network of groove. After the groove enters the brain, its pitch, timbre and rhythm features are first encoded in the primary auditory cortex. Then, the extent to which the degree of syncopation in the groove requires perception of metric events is regulated in the basal ganglia, with afferent and efferent information about the objective degree of rhythmic complexity afforded by the syncopation provided by the anterior inferior insula. Activity in the basal ganglia is modulated by musical background, in response to individual abilities to perceive metric events. Subjective experience of pleasure and wanting to move induce top-down modulation of the auditory cortex. Throughout the process, baseline structures, which respond to drum-breaks regardless of syncopation degree, such as motor and reward areas, interact with the more central regions of the network to underpin the pleasurable and movement-inducting effect of groove.

perception (of both phenomenal and metric events) is established in the putamen, pallidum and caudate, which is modulated by the listener's musical training. Based on the present findings, it is suggested that the anterior inferior insula contributes to the encoding of the drum-break's objective degree of rhythmic regularity. Both afferent and efferent projections between the insula and the basal ganglia have been shown (Flynn, 2010), and thus it could be that the metre perception regulated in the basal ganglia is negotiated reciprocally with the degree of rhythmic regularity encoded by the insula. Subsequently the working memory needed to perceive metric events, or the prediction-error correction afforded by the degree of syncopation, and the increased attention necessary for these purposes, modulates activity in the auditory cortex, which also responds at a higher level to the degree to which a listener wants to move, how much pleasure is experienced and the listener's previous experience of dancing. Furthermore, activity of the insula has been consistently found in neural networks involved in cross-modal operations, although the nature of the response has depended on experimental design (Calvert, 2001). It could be that the auditory-motor coupling characterising groove is supported by this cross-modal integration regulated by the insula. Thus, the basal ganglia negotiate the level of metre perception in interaction with information about rhythmic regularity from the anterior inferior insula, which more generally integrates motor-auditory processes. Metre perception is subsequently modulated by attentional demand and individually predisposed embodied and affective salience in the auditory cortex. Furthermore, areas that are active as a function of groove-based drum-breaks regardless of syncopation degree, such as motor and reward areas, interact and contribute to the neural processing and subjective experience of groove. However, such an insulo-striato-cortical network for syncopated groove and the role of metre perception in the interaction of such areas remains hypothetical at the neural level.

The higher attentional level at which pleasurable and movement-inducing properties of groove are engaged with might also explain why few lower-level reward areas and no cortical motor areas were significantly modulated by degree of syncopation in the present study. Two important exceptions to the former should be noted. First, an effect of syncopation degree in the caudate was demonstrated, which has been shown to be involved in musical pleasure (Salimpoor et al., 2011). Although a negative linear relationship was found in the caudate, there were no significant differences between drum-breaks of medium levels of syncopation and other levels. In other words, it remains unclear how the drum-breaks that were subjectively rated as eliciting the most pleasure and the most desire to move are processed by the caudate. Second, the activity found in the globus pallidus showed extensions into the ventral pallidum, an essential area in reward processing (Berridge, 1996; Smith et al., 2010). Nonetheless, although other non-sensory reward areas, such as the OFC and cingulate cortex, showed increased activity during drum-breaks compared to silence, activity in these areas did not change significantly with variations in syncopation. First, it could be that groove-related pleasure is more difficult to measure using fMRI, compared to 'musical chills', since 'chills' are more delineated and less temporally distributed. Second, it could be that core reward areas are equally active during all types of groove-based drum-breaks, possibly due to non-groove-related pleasure during drum-breaks with low and high degrees of syncopation. For example, drum-breaks with low degrees of syncopation might elicit pleasure associated with simpler rhythmic patterns, such as in standard backbeat rock, while drum-breaks with high degrees of syncopation might elicit pleasure of the kind associated with free jazz. In other words, musical pleasures in which the rhythmic aesthetic values are either very simple or very complex might also affect low-level reward areas of the brain and might have cancelled out the effect of pleasure associated with intermediate degrees of syncopation.

Similarly, it could be that the drum-breaks only showed activity in the cerebellum and cortical motor areas (as opposed to subcortical, i.e. basal ganglia), such as the PMC, SMA and pre-SMA when contrasted with silence, because syncopated rhythms might increase the neural activity in such areas to the same extent, regardless of the degree of syncopation. Certainly, it is possible that drum-breaks with both low and medium degrees of syncopation involve motor priming and thus might equally recruit the PMC, SMA and pre-SMA, since the metre is at least perceivable in such grooves. In fact, the online survey showed that although ratings of wanting to move were highest during medium syncopation, ratings were higher during low levels of syncopation compared to high. However, this does not explain why activity in secondary motor regions was no greater during medium and low degrees of syncopation, compared to high. Although a number of studies have shown the involvement of cortical motor areas in rhythm and metre perception (Bengtsson et al., 2009; Chen et al., 2006; Chen, Penhune, et al., 2008; Chen, Zatorre, et al., 2008; Grahn & Brett, 2007; Grahn & Rowe, 2009), the direction of change as related to rhythmic complexity is inconsistent across studies. For example, Chen et al. (Chen, Penhune, et al., 2008; Chen, Zatorre, et al., 2008) found that activity in the SMA, pre-SMA, PMC and cerebellum increased as a function of listeners' tapping error to rhythms with increasing rhythmic complexity, while Grahn and Brett (2007) found the opposite effect in the same areas, albeit using a somewhat different design. In other words, the simpler the rhythm, the more activity in cortical secondary motor areas. The first group of researchers attribute their findings to the motor network's modulation of rhythm perception in relation to rhythmic complexity, while the last group argue for the involvement of the motor network during metre perception. In another study, Grahn and Rowe (2009) found that different parts of the motor network responded differently to metric rhythms compared to nonmetric rhythms, depending on the way the metre was

expressed (dynamic, durational or isochronous, i.e. undifferentiated accents). Furthermore, Thaut et al. (2008) found that both simple *and* polyrhythmic tapping activated secondary motor areas. It is possible that cortical motor areas are involved in both the tracking of rhythmic complexity and the regulation of metre perception, perhaps in an interactive way. This might be why no significant activity in such areas as a function of syncopation was found in the present study, because these two mechanisms interact, rather than relate to each other linearly, at a neural level during the perception of groove.

Moreover, it could be that the drum-breaks used in the present study did not afford embodied and affective responses to an extent that would be measurable at lower level reward areas and cortical motor areas in the brain because, despite their ecological validity, they are not the kinds of grooves listeners most commonly engage with in everyday life. In the circumstances of 'real' club dance music, drum-breaks are a brief episode within the much longer time-period of a groove, which otherwise consists of polyrhythmic and melodic patterns with many other instrumental and vocal layers. A study that uses 'real' instrumental grooves of this kind might better reveal whether the desire to move and the feelings of pleasure in groove are modulated by reward and motor networks in the brain. Furthermore, as the constraints of the scanner and the requirement to lie completely still during scanning prevented participants from actually moving their bodies in response to the drum-breaks, it is possible that motor inhibition prevented the full-blown experience of wanting to move and pleasure. Until novel neuroimaging techniques can overcome such limitations, the neural correlates of groove cannot be directly measured while listeners are dancing.

Finally, it could not be ruled out that the effect of syncopation in the auditory cortex was not in fact an effect of the total number of onsets in the stimuli, as suggested by the analysis in which total number of onsets was added as a covariate. As mentioned above,

Madison et al. (2011) found that event density significantly affects groove ratings. Specifically, event density of real musical examples correlated positively with ratings of the music having 'groove' qualities. Here, it is shown that this correlation is quadratic with regards to activity in the auditory cortex. In order to determine whether the activity in the auditory cortex is due to syncopation or number of onsets, the two audio descriptors would need to be further orthogonalised in the stimuli. For example, using drum-breaks in which the total number of onsets is constant, but syncopation is varied, could help address this question. However, with the 15 stimuli used in the present study, controlling for number of onsets would present a number of challenges and dilemmas. Specifically, there is an intrinsic dependency on degree of syncopation and number of onsets, to a certain degree. For example, the more syncopations you have in a rhythm, the more onsets. Furthermore, there are only a certain number of onsets you can have in patterns with high degree of syncopation until the rhythm starts becoming less syncopated. This is because there are a limited number of metric locations with low metric salience on which onsets can be placed. Once all these weak metric locations have onsets on them, adding more onsets will require that they be placed on metric locations with strong metric salience, which would ultimately 'desyncopate' the rhythm as a whole. Madison et al. (2011) ran into similar tendencies; they found that, contrary to their hypotheses, event density could better explain groove ratings than microtiming. In their stimuli, event density correlated strongly with microtiming, thus they suggest that the effect of microtiming was absorbed by the effect of event density. It could be that, as with microtiming, syncopation and number of onsets are co-dependent in their effect on subjective experience, such as desire to move and experience of pleasure, and neural activity, such as in the auditory cortex. In other words, groove might both subjectively and neurophysiologically rely on the intrinsically related combination of the two.

Nonetheless, the present findings indicate that syncopation in groove-based funk drum-breaks relates to activity in the auditory cortex, the basal ganglia and the anterior inferior insula in inverted U-shaped and linear ways, which interact with listeners' musical training, familiarity with groove, and dance experience. These results suggest a brain network that integrates a listener's ability to perceive metre in relation to a rhythm's structural regularity and subjective experiences of wanting to move and feelings of pleasure. In the next chapter, a study is reported that investigates whether similar relationships can be reflected in listeners' overt body-movements to syncopated drum-breaks, using motion-capture recordings outside the scanner.

CHAPTER SEVEN

Moving to the Groove: A Motion-Capture Study

7.1 INTRODUCTION

The body is posited as the central site for cognitive processes, according to the embodied approach to perception. For music, a context more obvious than dance as an illustration of that claim is hard to imagine: through body-movement, music is actively perceived and physically embodied in ways that correspond to the structure of the music. Motion-capture studies, which enable the measurement of spatio-temporal movement properties, are rapidly replacing more traditional tapping designs in investigations of sensorimotor synchronisation to rhythm, and provide more ecologically valid ways to address these complex and fascinating issues than have previously been studied using narrowly 'laboratory-based' approaches. However, incompatibilities exist between findings from studies of synchronisation accuracy in response to syncopation and behavioural trends suggesting a positive drive towards body-movement as a function of syncopation in groove. This chapter reports a study in which the effect of varying degrees of syncopation in drum-breaks on the force, synchrony and periodicity of the lower back and right hand movements during spontaneous dance was investigated using motion-capture technology. The study shows that force and synchrony are largely correlated across body-parts and degree of syncopation: generally, the less syncopation, the more people move and the better they synchronise their body-movements in dance. However, there were some indications of interference with subjective feelings of wanting to move and pleasure, causing the linear trend to approach an inverted U-shape. It was also found that only non-musicians showed changes of synchrony in relation to changing degrees of syncopation, suggesting a decreased ability to perceive the underlying pulse in syncopated rhythm,

compared to musicians. For both groups, the hand was more synchronised and more forceful, compared to the lower back. In contrast, periodicities were stronger in the lower back, compared to the hand, suggesting an interaction between synchrony, periodicity and body-part. A number of metric periodicities were entrained to, most prominently the main pulse and other duple metric levels. The prominence of metric periods interacted with body-part and degree of syncopation. This study thus shows that body-movement is related to syncopation in groove in many different and intricate ways, implying that dancers do not simply synchronise in one-to-one relationships with music, but entrain their bodies to the rhythmic structure in complex manners.

7.1.1 Music and Body-Movement

The embodied theory of cognition posits that thinking, imagining, remembering and all other mental activities are grounded in the body, and that the sensory modalities are active both during overt action and covert cognition (e.g. Barsalou, 1999; Lakoff & Johnson, 1980; Varela et al., 1991). Recent years have seen a surge in embodied approaches to music cognition (e.g. Johnson & Larson, 2003; Leman, 2007; Zbikowski, 2004), and with it, empirical studies have investigated the relationship between music and body-movement. One strand of this research has focused on the notion of 'musical gestures' in claiming that perceiving movement in music involves the imagination of physical movement (e.g. Godøy & Leman, 2010; Gritten & King, 2006). Godøy et al. (2006) used the playing of air-instruments as an example of how cross-modal imitation, which they call 'motor-mimetic sketching', is a resource for making sense of sounds by means of the body. This surge in embodied music research has been amplified by the development of sophisticated motion-capture systems for measuring body-movements in space and time. For example, Leman and Naveda (2010) measured movement patterns of Samba and Charleston and

extrapolated spatio-temporal reference frames (i.e. gestures) that were synchronised with the music's structural characteristics. They propose that these spatio-temporal reference frames afford the coupling of perception and action in music-listening and dance. In another study, Burger, Saarikallio, et al. (2012) investigated the relationship between emotions perceived in music from a number of popular genres (rock, pop, jazz, funk, techno and Latin) and spontaneous body-movements, and found significant mappings between musical and embodied expression. For example, 'happy' music was associated with more body-rotation and greater complexity in movement, 'angry' music with irregular and jagged movements with little rotation, 'sad' music with simple movements and 'tender' music with a forward-tilted torso, fluid movements and low acceleration. From another study (Burger et al., 2010), they report similar mappings between body-movements and musical structure more generally: in relation to the beat, they found that the clearer the beat, the faster and jerkier the movements and the more people moved overall, while an unclear beat fostered more movements in the hand in particular. The authors suggest that listeners/dancers use their bodies to explore and 'make sense' of the emotional expressions and structural properties in the music, by imitating and attuning to the music's expressive cues.

7.1.2 Rhythm and Body-Movement

Some motion-capture studies have focused on rhythm, metre and body-movement in particular. Toiviainen et al. (2010) asked participants to move freely to an instrumental 12-bar blues and measured periodicities in body-joints corresponding to the metric framework by recording body-marker locations in time. Results showed that the most prominent periodicities corresponded to the main pulse, minim and bar-level. Furthermore, there was a difference between what they call 'eigenmovements' (i.e. gestures) in the vertical plane,

which were entrained to the pulse, in comparison to mediolateral movements, which were entrained to the bar-level.[1] More detailed kinematic analyses showed that faster metric levels were embodied in the extremities (hands) and slower metric levels were embodied in core body parts (torso). Overall, the most prevalent periodicity in the kinetic energy of 'eigenmovements' was at the minim level, as opposed to the expected main crotchet pulse, but the authors suggest this finding may result from measurements being based on marker locations, rather than marker speed or acceleration.

In another study, Burger, Thompson, et al. (2012) studied the relationship between temporal and spectral regularity in music (using the same musical genres as reported in their studies above) and temporal and spatial regularity in motion-capture recorded body-movements. They found that the clearer the pulse and the more percussive the music, the less spatially variable and the more temporally regular the body-movements. Temporal regularity of movements also correlated with greater sub-band flux, i.e. spectral change over time in the sound signal, particularly at low and high frequencies. As in their other studies reviewed above, they suggest that their findings support an embodied theory of music cognition and demonstrate how listeners/dancers corporeally imitate spatial-temporal changes in the sound and use their bodies to navigate through the music. Furthermore, the greater spatial complexity of movements during temporally irregular and less percussive music reflects how listeners/dancers 'search for the beat' with their bodies.

Synchronising body-movements to the rhythm of music is a universal human trait (Bispham, 2006; Merker et al., 2009), believed to be largely unique to humans (although some cases of sensorimotor entrainment to music has been observed in vocal-learning birds; see Patel et al., 2009). Neonates show sensitivity to metre (Winkler et al., 2009) and

[1] The authors refer to gestures as 'eigenmovements' due to the use of Principal Component Analysis (PCA) to compile the movements across dimension, markers and joints. They used the first five principal components (i.e. eigenvectors) for further analysis.

older infants' perceptions are affected by bodily rhythmical experiences: Phillips-Silver and Trainor (2005) found that 7-month old babies preferred (i.e. listened longer to) auditory rhythms with accent patterns to which they had previously been bounced, indicating that rhythmic correspondences between proprioceptive feeling and audition are perceived early in life. Infants also exhibit spontaneous rhythmic (although rarely strictly isochronous) 'rocking' or 'kicking' for what is believed to be pleasurable self-stimulation (Thelen, 1979). Zentner and Eerola (2010) measured this spontaneous rhythmic movement in infants and found significantly more rhythmic entrainment to music compared to speech, but no difference when comparing 'real' music with simpler rhythms or an isochronous beat. Interestingly, a positive relationship (albeit weak) was found between duration of rhythmic movement and frequency of smiling, indicating that sensorimotor synchronisation to music is pleasurable for babies. Thus, it could be that the positive drive towards body-movement characteristic of the experience of groove is developed early in life and has origins extending beyond any specific musical genre.

Despite this demonstration of a natural ability people have to synchronise their body-movements to rhythmic music, a small number of individuals report having difficulty perceiving metre in music and consequently fail to synchronise their movements accordingly. However, although there has been a substantial increase in studies of pitch-related amusia in recent years (see Stewart, 2011), little attention has been given to such rhythmic 'disorders'. One exception is a study by Phillips-Silver et al. (2011), in which the rhythmic perception and production of 23-year-old 'Mathieu', who reported life-long difficulties in entraining to music, was investigated. Referred to as 'beat-deaf', the authors found that, compared to controls, Mathieu's 'bouncing' to music was significantly less forceful and less synchronised to the main pulse. However, compared with 'real' music, Mathieu's sensorimotor synchronisation was somewhat improved when bouncing to a

metronome, indicating that the less complex the musical stimulus, the easier it was to find the beat. A similar improvement was found when the music was popular, suggesting that familiarity benefits sensorimotor synchronisation. Finally, Mathieu was also significantly impaired in a tapping task and a rhythm perception task, showing that his deficit was not confined to whole-body-movements but related to his ability to perceive metre in rhythm and embody the main pulse more generally.

7.1.3 Sound and Body-Movement

Although it is likely that Mathieu finds his rhythmic deficit a challenge, particularly in social situations involving interpersonal dance, body-movement in response to music may be afforded by other acoustic cues, which rely less on metre perception in the strict sense, and more on sound. For example, some 'beat-deaf' people might map their movements to the dynamic flux of the melody of music, rather than synchronise bounces or body-jerks to the metre (as studied by Burger et al. in the studies reported above, and reported during the present author's personal communication with a 'beat-deaf' person). In this regard, it has been suggested that dance-music, particularly electronic dance music, affords body-movement due to the alternation of high and low frequency sounds in the drum mix: Zeiner-Henriksen (2010), studying the 'poum-chack' pattern (an onomatopoetic term describing the sound difference in the alternation between the bass-drum and snare-drum, respectively) in techno and house music, proposes that such alternating frequencies invite the body to move up and down via spatio-temporal mimetic mapping between sound and vertical movement. In this way, movement is guided by frequency-based properties rather than durational accents. Furthermore, the digital filters used on the bass-drum in much of this music are often characterised by a downward 'sweep' (i.e. a gradual dynamic change across frequency spectrum), which adds to the incentive to move the body downwards.

The role of the bass-drum in dance music has not gone unnoticed in research. Van Dyck et al. (2010) increased the sound level and moved the location of the bass-drum forwards in the mix of experimenter-composed dance tracks and measured the movements of participants in groups of five using motion-capture. The participants also heard the bass-drum patterns monophonically at various sound-levels. The researchers found a positive linear relationship between the prominence of the bass-drum sound and the amount of movement in the hip and head, for both music and bass-drum patterns. Furthermore, movements depended on participants' genre preferences: those who liked jazz and classical music were found to move their heads to a greater extent than those who had other preferences. However, the spatial volume enclosed during dancing decreased with increasing augmentation of the bass-drum, suggesting that dancers focus on the main pulse of the music when the bass-drum is particularly prominent, leading to faster and shorter movements. This finding echoes the relationship found between percussiveness in music and spatial regularity in movement in the study by Burger, Thompson, et al. (2012).

With regard to sound and movement, it has been suggested that the relationship is not only mediated via embodied mapping or attuning, but that, in certain circumstances, sound may directly trigger movement. Todd (1999; Todd & Cody, 2000) claims that listeners feel movement in music due to two distinct (but not mutually exclusive) mechanisms. One is similar to the one proposed in embodied theories of music cognition and involves audio-motor mapping. The other is a vestibulomotor mechanism, which operates at a purely physiological level and does not rely on any form of mapping or attunement. The vestibular apparatus is primarily associated with our sense of balance and spatial orientation and constitutes the primary sensory input about self-motion. It also happens to be located close to the cochlea and is sensitive to acoustic information. Thus, Todd proposes that modulations of sound, in tempo, amplitude or articulation, may directly

give rise to corresponding sensations of motion, and that in dance music, this mechanism might account for the initiation of synchronised body-movement (Todd, 1999). In other words, there may be a 'hard-wired' link between sound and movement, which becomes particularly active during loud rhythmic music.

Of particular relevance to this hypothesis is a study carried out by Phillips-Silver et al. (2008). They found that the perception of a metrically ambiguous rhythm depended on the metric ratio with which participants were rocked while lying passively in a seesaw, suggesting the involvement of the vestibular system. They further supported this theory by showing that the effect of metric movement on metre perception was only found for passive head-motion, and not for legs or feet, suggesting that motor, tactile and proprioceptive input was not enough to cause the effect. Thus, auditory stimulation of the vestibular apparatus may not only cause body-movement, but motion stimulation of the vestibular system may affect the perception of sound, specifically metre perception. This latter effect suggests that when people navigate through music with their bodies, as suggested by other researchers (Burger, Thompson, et al., 2012), the vestibular system at least *contributes* to the coupling between sound, body and mind.

7.1.4 Music, Body, Personality and Genre

A number of other factors affect the relationship between body-movement and music, including the body size, weight, and personality of the dancer. For example, preferred tapping tempo has been suggested to depend on the biomechanical properties of the body, and Todd et al. (2007) showed that anthropometric properties, such as stature, mass, sitting height, body breadth, and an interaction between age and sex, affected preferred tapping rates. Luck et al. (2010) tested the effect of 'the Big Five' personality characteristics on the body-movements of people dancing to a number of popular music genres, including

techno, rock, Latin, jazz and funk. Of 'the Big Five', they found that, in particular, 'extraversion' and 'neuroticism' correlated with a number of patterns in body-movement.[2] The authors suggest that people's personalities and emotional tendencies are expressed in the way they move to music. They also found that participants moved differently to different genres: techno elicited local movement and greater head speed; rock was associated with greater head speed; and Latin music showed more global movement, suggesting that participants moved around the room – these attributes in all three cases being associated with typical features of the conventional dance styles associated with these musical genres (e.g. 'head-banging' in the case of rock). Thus, it seems that different genres afford different kinds of body-movement in dance, which are measurable with a motion-capture system. Similarly, it might be expected that individual preferences, such as the liking for specific genres (Van Dyck et al., 2010) and personal enjoyment of dancing, affect the ways in which people move to music. Since pleasure and dance are intimately linked in engagement with groove-based music, it is important to take individual liking and predisposition to dance into account when studying spontaneous dance to groove.

7.1.5 Sensorimotor Synchronisation and Syncopation in Groove: A Paradox?

There is a lack of empirical studies investigating the relationship between syncopation and dance. This is surprising, considering the prominence of syncopation in most music genres associated with dance, such as groove-based music. The study by Burger, Thompson, et al. (2012) reported above, in which it was found that more temporally and spectrally complex popular music (largely groove-based) elicited more temporally and spatially complex dance movements, comes closest to addressing the relationship between rhythmic complexity and dance. However, their measure of musical temporal complexity is one that

[2] The other three categories were openness, conscientiousness and agreeableness.

does not consider syncopation or any other rhythmically complex structure as a perceptual property, but simply reflects the overall entropy of the musical stimulus. In the online rating survey reported in Chapter Five, it was found that, compared to the degree of syncopation and beat salience, the joint audio entropy of syncopated drum-breaks was a poor predictor of participants' ratings of wanting to move and feelings of pleasure. Furthermore, Burger, Thompson et al.'s study did not address whether the relationship between musical and corporeal complexity in dance was characterised by changing degree of synchronisation accuracy.

The measure of synchronisation accuracy is, as reviewed in Chapter Three, the primary measure in studies investigating the relationship between sensorimotor synchronisation and syncopation. Most of these studies have recorded tapping performance to simple monophonic rhythmic patterns (Fitch & Rosenfeld, 2007; Ladinig, 2009; Palmer & Krumhansl, 1990). The overall finding is a negative linear relationship between syncopation and synchronisation accuracy. In other words, the more syncopated a rhythm, the less accurate the tapping synchronisation. However, there are some indications of other musical properties improving sensorimotor synchrony. As reviewed in Chapter Five, Janata et al. (2012) found that the more a piece of 'real' music was perceived as having groove (i.e. a positive drive towards body-movement), the more accurately participants synchronised their tapping to the pulse of the music. This finding seems immediately intuitive, since a positively valenced motivation towards a certain kind of behaviour seems likely to invite particularly 'dedicated' behaviour. However, in the online rating survey of Chapter Five, it was found that the grooves that elicited this positive drive towards body-movement had *medium* degrees of syncopation. Considering these results in view of Janata et al.'s findings, there seems to be contradictory evidence regarding the relationship between syncopation and synchronisation accuracy: tapping studies show a negative linear

relationship, while studies involving groove suggest that there might be a U-shaped relationship between the two.

There are a number of potential explanations for this paradox. First, it might be that there are other structural characteristics of groove that improve synchronisation accuracy, despite the degree of syncopation. For instance, the dynamic prominence of certain instruments, such as the bass-drum on the main pulse, might aid synchronisation, despite other instruments being syncopated. In other words, the musical context in which the syncopation is featured might override the destabilising effect of syncopation. Second, since Janata et al. (2012) did not measure syncopation directly, it might be that the grooves that elicited the most accurate synchronisation in their study in fact had the least syncopation. However, this is unlikely, since it was found in the online rating survey reported in Chapter Five that drum-breaks with intermediate degrees of syncopation elicit the most positive drive towards body-movement, and thus should be defined as the drum-breaks with the most groove. Third, it could be that the degree to which syncopation affects sensorimotor synchronisation accuracy depends on the motivation to move the body in response to the music. In the online rating survey, the relationship between syncopation and desire to move and feelings of pleasure was inversely U-shaped, demonstrating that intermediate syncopation elicits the most desire to move and the most pleasure. It could be that syncopation in simple monophonic rhythms (i.e. as used in studies showing detrimental effects of syncopation on tapping accuracy) does not elicit the desire to move, and thus reduces the incentive to synchronise accurately. In 'real' groove, the incentive comes from the full ecological context, and could thus improve sensorimotor synchronisation. Fourth, although it seems immediately intuitive that a positive drive towards body-movement will improve synchronisation, it is entirely possible that this is not the case. It is possible that, despite an increased pleasurable desire to move to grooves

with medium syncopation, the movements are only 'loosely' synchronised to the groove, that body-movements microtemporally lag and/or lead, and that this loose entrainment is the most pleasurable. In other words, the *quality* of sensorimotor synchronisation might not necessarily mean maximal *accuracy*, in the context of groove. Finally, compared to full body-movement and dance, tapping is an ecologically impoverished measure of embodied synchronisation. In fact, dance is one of the most common ways of actively engaging with music, particularly groove. Thus, the desire to move might primarily relate to full body-movements, while synchronisation accuracy might have a greater bearing on finger-tapping accuracy. No one has yet recorded full-body-movements in dance to more ecological stimuli, such as groove, with varying degrees of syncopation.

7.1.6 Hypotheses

The study reported here investigates the relationship between degree of syncopation and body-movement in dance using motion-capture. In the light of the earlier finding of an inverted U-shape between syncopated drum-breaks and both the desire to move and feelings of pleasure, which was also reflected in patterns of activity in the auditory cortex (Chapter Six), it was hypothesised that a similar inverted U-shape would be found between the amount of movement and the degree of syncopation. In other words, participants move more to drum-breaks with a medium degree of syncopation. Second, it was hypothesised that synchronisation accuracy would change as a result of varying the degree of syncopation. However, due to the conflicting evidence from previous research, this hypothesis remained bidirectional. In other words, there was no specific hypothesis as to whether the synchronisation would improve or deteriorate, and whether the relationship was anticipated to be linear or U-shaped. The possible effect of changes in degree of syncopation on the most prominent periodicities in people's movements was also

investigated, on the basis that people might change the metrical level to which they synchronise according to the degree of syncopation in the drum-break. Finally, since the online rating survey found that people who enjoy dancing, and dance frequently, rate syncopated drum-breaks as making them want to move more than those who do not enjoy dancing, and rarely dance, and personality and genre preferences have been found to affect body-movements in dance (Luck et al., 2010; Van Dyck et al., 2010), the effects of dancing experience were addressed, as well as musical training and groove familiarity.

7.2 METHOD

7.2.1 Participants

The same 26 right-handed Danish-speaking participants (7 females, 19 males) aged between 21 and 40 (Mean = 25.13, SD = 5.34) who took part in the fMRI study participated in the motion-capture study, and the same demographic information was used to address musical training, groove familiarity and dance experience (see section 6.2.1, Chapter Six).

7.2.2 Stimuli

The same stimuli as were used in the fMRI study were used in the motion-capture study. Participants heard 15 midi drum-breaks consisting of 16-second-long repeated 2-bar drum-kit patterns of bass-drum, snare-drum and hihat, at 120 bpm. In the online survey (as part of a bigger sample of drum-breaks) and the fMRI study, these drum-breaks had shown an inverted U-shaped relationship between the degree of syncopation and participants' ratings of wanting to move and feelings of pleasure (see section 5.2.2 in Chapter Five for a detailed description of the drum-breaks). As reported in Chapter Six, the relationship between syncopation, beat salience and joint audio entropy was similar for this sample of

15 drum-breaks as for the full set of 50 drum-breaks used in the online survey: there was a negative correlation between beat salience and syncopation, and a positive correlation between beat salience and entropy, but no significant correlation between syncopation and entropy (see Table 6.1, Chapter Six). For the motion-capture study, the drum-breaks were indexed according to syncopation degree only, using the polyphonic index of syncopation proposed in Chapter Four. As in the fMRI study (Chapter Six), beat salience was excluded since syncopation and beat salience in the drum-breaks used in the study were strongly negatively correlated, indicating that the two measures represent similar musical properties (i.e. rhythmic complexity). Equally, entropy was excluded as it was shown to be a poor predictor of ratings of wanting to move and feelings of pleasure in the online survey. Appendix Four shows transcripts of the drum-breaks used in the study.

7.2.3 Apparatus

Participants' body-movements were measured using the accelerometer data generated by the Wiimotes (i.e. remote controllers) of the wireless motion-sensor video game console Wii (Nintendo, Inc). One Wiimote was strapped to the lower back, and another held in the right hand (Figure 7.1). Previous research has found that movements in these body-parts were the most consistently entrained to the main pulse during spontaneous dance to music (Toiviainen et al., 2010). Acceleration in all three Euclidian dimensions (two horizontal, one vertical) was recorded simultaneously for both Wiimotes via WiiDataCapture 2.1 (University of Jyvasklya) on a Macbook laptop running OSX 10.4. The drum-breaks were presented to participants over loudspeakers, and the order was logged using Presentation (Neurobehavioral Systems, Inc.) on a Sony Vaio laptop.

7.2.4 Procedure

After scanning in the fMRI experiment (Chapter Six), participants were taken to another laboratory in which the motion-capture took place. The room was large and mostly empty, apart from a table by one wall on which the laptops controlling the experiment and the speakers were placed, facing the middle of the room. A strip of tape was stuck to the floor 130 cm from the speakers (Figure 7.1), and participants were told not to move beyond the tape during the experiment, in order to keep the loudness level as stable as possible across participants. The loudness of the drum-breaks as projected from the speakers was held constant for all participants, and was measured at the tape location, using a DAWE D-1422C digital sound-level meter, with a 30–135 dB sound range. The mean loudness for the drum-breaks was 75 dB (SD = .97 dB).

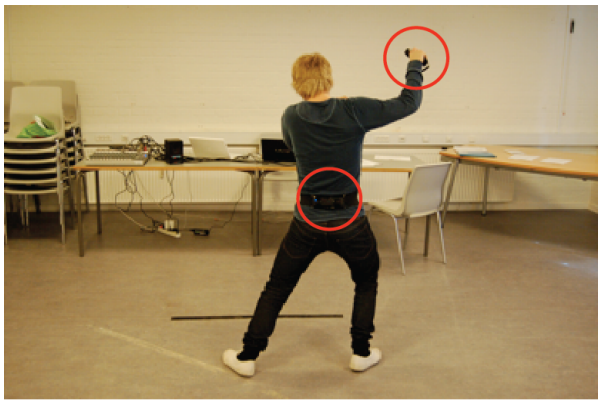


Fig. 7.1 Motion-capture set up. Participants moved freely to the drum-beaks behind a piece of tape stuck to the floor, in front of the laptops and speakers that were controlling motion-capture recording and the presentation of the drum-breaks. Body-acceleration was recorded from one Wiimote strapped to the lower back, and one held in the right hand.

The motion-capture recording was triggered by a one-second-long loud beep, and 16 seconds later the first drum-break was presented. In this way, the motion-capture recording was time-locked to the stimuli. During the first 16 seconds of silence, the experimenter left the room, thus leaving participants to perform the motion-capture task

completely alone. Participants were asked to move freely to the drum-breaks, each of which was heard twice during the course of the experiment, in randomised order. All drum-breaks were heard once before the repetitions were presented. There was no gap between drum-breaks, which followed on from one another continuously. This prevented any disruption to the regularity of the metre, which was continuous across drum-breaks, avoiding a loss of flow in body-movements. After the last drum-break, the experimenter entered the room and stopped the recording. Finally, subjects completed the demographics questionnaire, the data of which were used in both the fMRI and motion-capture studies. Although a pilot participant (not included in the data analysis) had reported that the task was enjoyable, the impression of the experimenter was that some participants found the task somewhat unnatural, due to the laboratory environment – though no formal feedback on this was collected.

7.2.5 Processing

The first four seconds of the acceleration data for each drum-break (i.e. the first 2-bar rhythmic unit of each 8-bar drum-break) were excluded, to avoid the effect of transfer from one drum-break to the next. Three properties of movement were extracted from the acceleration: force (power), synchrony and periodicity. Data were analysed using the MoCap Toolbox 1.2.2 for MATLAB (Toiviainen & Burger, 2011), MATLAB and PASW 17.0 (IBM, Inc.), and preprocessing was performed in a number of ways, depending on the variable of interest, as described below. The design of force and synchrony analyses, once processing was complete, was largely analogous to the analyses performed with rating data in the online survey (excluding multiple regression, since only one predictor was used) and is thus not repeated in full detail here (see section 5.3, Chapter Five).

7.2.5.1 Force

Force was taken as a measure of amount of movement, and was defined by the average acceleration over time across the three dimensions (as normalised using the mcnorm function in the MoCap toolbox) and the two repetitions of each drum-break. There were thus 15 measures of force for each participant, corresponding to the 15 drum-breaks.

7.2.5.2 Synchrony

To investigate whether participants' synchronising to the drum-breaks depended on degree of syncopation, the temporal-spatial component of movements was correlated with the temporal-spectral component of the main pulse of the drum-breaks in the following way, adopting data-filtering and transform methods that have been used previously in music and motion-capture research using Wii (Phillips-Silver et al., 2010). The acceleration data in the three dimensions were first transformed using PCA, rather than the mcnorm function in the toolbox, since normalising would shift the temporal peak points of movements and thus affect the synchrony analysis. Subsequent processing and analyses were performed on the first principal component. The data were filtered with a Gaussian kernel distribution, centred on the frequency of the main pulse of the stimuli (2 Hz, given the tempo 120 bpm and the sampling frequency of 100 samples per second), including 20% of variability on either side of the centre frequency. In this way, only movements on and around the main pulse were analysed. Then, the filtered data were transformed using the Hilbert transform, to estimate the phase of the movements. The Hilbert transform is a mathematical function used in signal-processing analysis, which convolutes the signal. However, unlike the Fourier transform, the signal remains in its original domain (time) after transformation, which allows for phase-related analyses, such as cross-correlation. A variable representing the main pulse in the stimulus (a single value at each sample representing the 2 Hz

frequency, i.e. the main pulse) was also processed with the Hilbert transform. Cross-correlations were then calculated between the filtered Hilbert-transformed movement data and the Hilbert-transformed main pulse variable, which produced measures of lag between the main pulse and the movements. Measures of synchrony were taken as the average absolute cross-correlation coefficients for each drum-break (mean absolute lag), averaged across repetitions.

7.2.5.3 Periodicity

For the purpose of obtaining participants' movement periodicities, the maximum amplitude, i.e. the most prominent periodicity during dancing to each drum-break, was extracted, using the mcperiod function in the MoCap toolbox. The dimensions of the acceleration data were reduced using PCA, using the first component in subsequent analyses. The two repetitions of each drum-break for each subject were then categorised according to three discrete levels of syncopation (Low, Medium and High). Thus, each level consisted of 260 periodicity values (26 subjects x 2 repetitions x 5 drum-breaks), and the percentages of instances of no periodicities, metric periodicities, and non-metric periodicities within each level (Low, Medium and High) were calculated. Metric periodicities in the movements were defined as those corresponding to metric levels in the drum-breaks (semi-quavers, quavers, crotchets, minim and semi-breve), plus any periodicities that differed from these by less than 10%.

7.3 RESULTS

7.3.1 Individual Curve-Fitting for Force

7.3.1.1 Analysis

The effect of syncopation on force was analysed in a similar manner as in the online rating survey. That is, each subject's mean force was first regressed individually against syncopation for each drum-break, and a two-way ANOVA tested the effects of model (linear and quadratic) and body-part (lower back and hand) on resulting adjusted R^2s, to give a first indication of whether the relationship between movement amount and syncopation was linear or quadratic.

7.3.1.2 Results

Figure 7.2 shows linear and quadratic regressions modelled with syncopation for each participant separately, using the force measures for lower back and hand as dependent variables. Based on qualitative observation of these graphs, no clear difference between linear and quadratic models was evident. Furthermore, the ANOVA of adjusted R^2s did not show a significant effect of model ($F(1,25) = 1.01$, $p = .324$), body-part ($F(1,25) = .02$, $p = .889$), nor interaction between model and body-part ($F(1,25) = .01$, $p = .902$). Thus, no conclusion about the specific form of the relationship between movement force and syncopation could be drawn from this analysis.

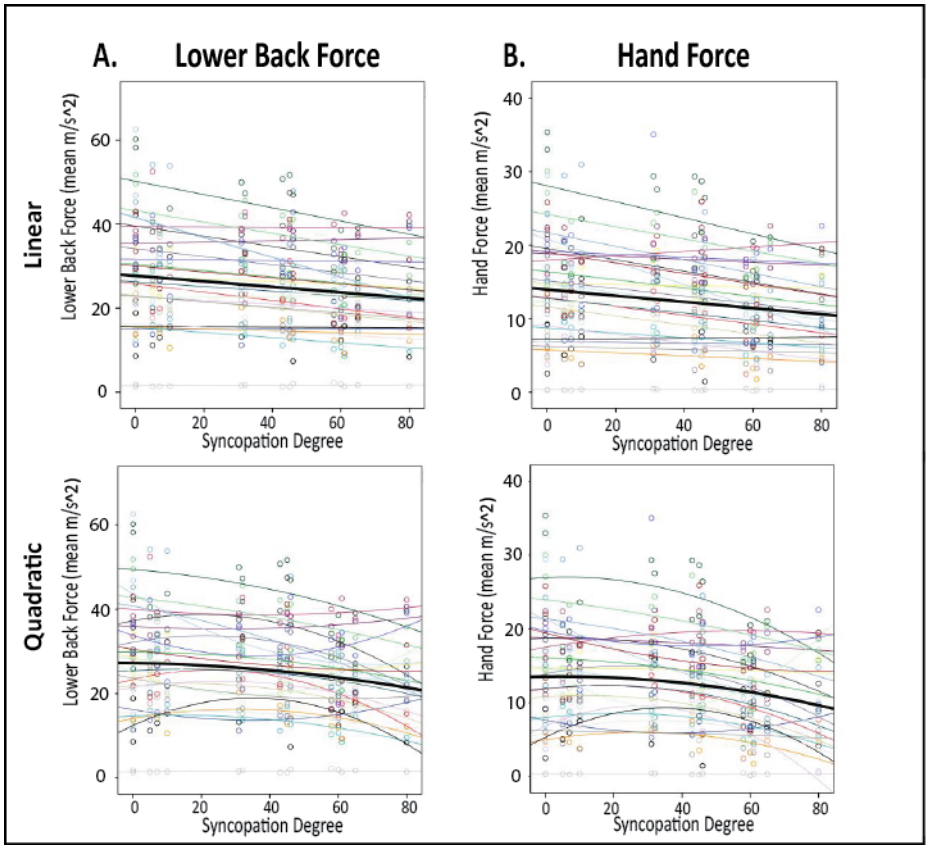


Fig. 7.2 Linear and quadratic curve-fitting for syncopation and movement force in **A.** lower back, and **B.** hand. Coloured lines represent measures of individual subjects' force; black line represents mean force.

7.3.2 Effect of Musical Background on Force

7.3.2.1 Analysis

To investigate the effect of musical background, drum-breaks were categorised into three syncopation levels (see section 6.2.2, Chapter Six), and a 5-way mixed-design ANOVA tested the effects of five variables on average force: 1) degree of syncopation (Low, Medium and High); 2) body-part (lower back and hand); 3) musical training; 4) groove familiarity; and 5) dance experience. The between-subjects factors were defined in binary categories (musician vs. non-musician, frequent groove-listener vs. infrequent groove-listener, frequent dancer vs. infrequent dancer), using set criteria for musical training and PCA for groove familiarity and dancing (see section 6.2.1, Chapter Six).

7.3.2.2 Results

There were significant effects of body-part and syncopation and a significant interaction between body-part and syncopation, but no effect of musical background (Table 7.1). Paired contrasts (Table 7.2), corrected for multiple comparisons, showed that in both lower back and hand there were significant differences between Low and High, and between Medium and High. Specifically, Low produced greater force than Medium and High. There were no significant difference between Low and Medium, for either body-part. There was more force in hand- than in lower back-movements, overall. Figure 7.3 indicates that the magnitude of the difference between High and other syncopation levels was greater in hand than in lower back force.

Main Effect	*F*	*df(error)*	*p*
Body-Part	112.94	1(19)	<.001
Syncopation	17.89	2(28)	<.001
Body-part^{x}Syncopation	8.27	2(38)	.001
Musical Training	.45	1(19)	.509
Groove Listening	.13	1(19)	.720
Dancing	.01	1(19)	.930

Table 7.1 Main effects of body-part, syncopation and musical background on movement force. $p < .05$.

Contrasts		*Mean*	*SE*	*t*	*p*
Lower Back	Low vs. Medium	-.22	.37	-.57	.576
	Low vs. High	2.86	.52	5.45	<.001*
	Medium vs. High	3.07	.53	5.82	<.001*
Hand	Low vs. Medium	.11	.67	.16	.875
	Low vs. High	4.48	.87	5.15	<.001*
	Medium vs. High	4.37	.82	5.32	<.001*
Low	Lower Back vs. Hand	-13.51	.99	-13.54	<.001*
Medium	Lower Back vs. Hand	-13.20	.94	-14.10	<.001*
High	Lower Back vs. Hand	-11.90	.83	-14.28	<.001*

Table 7.2 Paired contrasts for effect of syncopation (Low, Medium and High) and body-part (lower back and hand) on movement force. *Alpha adjusted $p < .005$, df = 25.

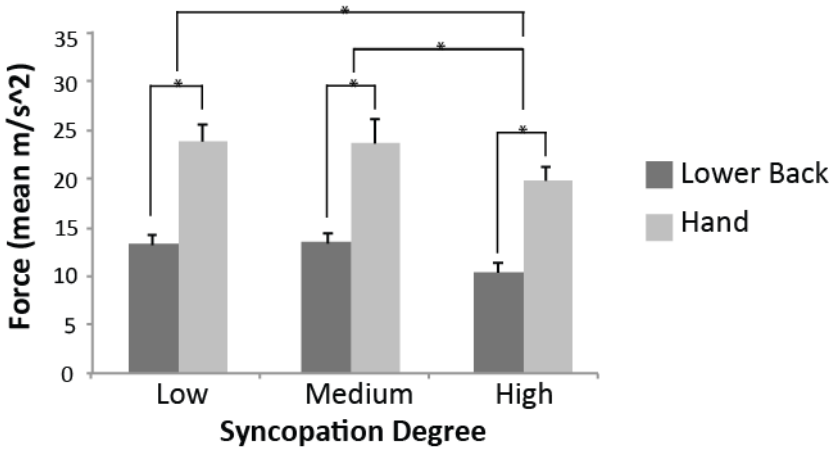


Fig. 7.3 Interaction between syncopation and body-part in movement force. *Alpha adjusted $p < .005$.

7.3.3 Individual Curve-Fitting for Synchrony

7.3.3.1 Analysis

The values representing synchrony (the coefficients produced by the cross-correlation between Hilbert-transformed movement and pulse data) were analysed in a similar way as for the rating data from the online survey and the force data described above, with a series of regressions and ANOVAs.

7.3.3.2 Results

Figure 7.4 plots each subject's degree of synchrony in lower back and hand with the drum-breaks' degrees of syncopation, with both linear and quadratic models. At first glance, the quadratic model seems a somewhat better fit than the linear, for both body-parts. The ANOVA performed on each subject's adjusted R^2s showed a main effect of model ($F(1,25) = 6.40$, $p = .018$), in which the quadratic model (Mean = .19, SE = .04) produced higher adjusted R^2s than the linear model (Mean = .13, SE = .04). There was no effect of body-part ($F(1,25) = .20$, $p = .655$), and no significant interaction between model and body-part ($F(1,25) = .85$, $p = .366$).

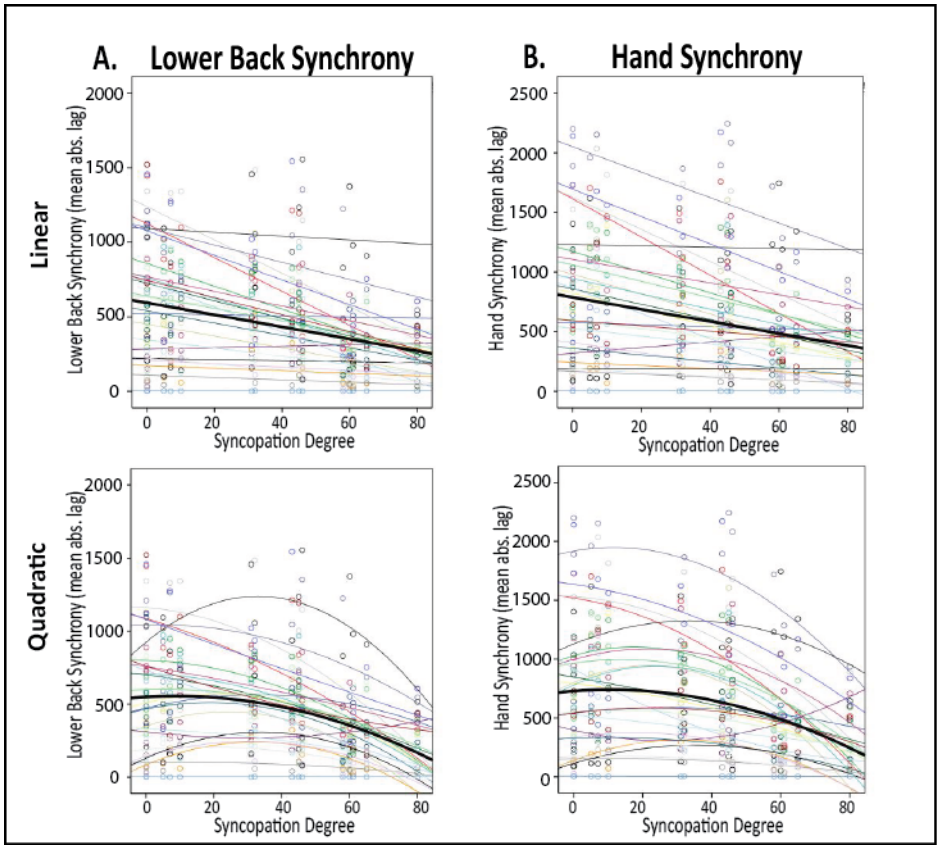


Fig. 7.4 Linear and quadratic curve-fitting for syncopation and movement synchrony in **A.** lower back, and **B.** hand. Coloured lines represent individual subjects' synchrony measures; black line represents mean synchrony.

7.3.4 Effect of Musical Background on Synchrony

7.3.4.1 Analysis

To investigate effects of between-subjects differences in musical background, a 5-way mixed ANOVA was performed with the drum-breaks re-categorised into three levels of syncopation, as in the force analysis above.

7.3.4.2 Results

As shown in Table 7.3, there were main effects of body-part and syncopation, and significant interactions both between body-part and syncopation, and between syncopation and musical training. There were no significant between-subjects main effects. The

interactions were further investigated with paired contrasts, corrected for multiple comparisons, as reported in Tables 7.4 and 7.5. Figure 7.5 indicates that synchrony was lower for High syncopation compared to Low and Medium, for both lower back and hand. Synchrony was greater in the hand than in the lower back at all syncopation levels, but the magnitude of the difference was smaller at High compared to Low and Medium levels. Figure 7.6 indicates that there were only differences in synchrony for non-musicians, and not for musicians. High syncopation elicited lower synchrony than Low and Medium syncopation. There were no differences between musicians and non-musicians within each level.

Main Effect	*F*	*df(error)*	*p*
Body-Part	8.91	1(18)	.008
Syncopation	27.45	1.18(21.17)	<.001
Body-Part^{x}Syncopation	3.84	1.58(28.36)	.043
Syncopation^{x}Musical Training	4.16	1.58(28.36)	.048
Musical Training	2.38	1(18)	.141
Groove Listening	.23	1(18)	.637
Dancing	1.28	1(18)	.272

Table 7.3 Main effects of body-part, syncopation and musical background on movement synchrony. $p < .05$. Greenhouse-Geisser corrected df.

Contrasts		*Mean*	*S.E.*	*t*	*p*
Lower Back	Low vs. Medium	19.73	23.50	.84	.409
	Low vs. High	271.78	45.30	6.00	<.001*
	Medium vs. High	252.05	33.84	7.45	<.001*
Hand	Low vs. Medium	35.12	27.94	1.26	.220
	Low vs. High	345.24	64.09	5.39	<.001*
	Medium vs. High	310.13	56.62	5.48	<.001*
Low	Lower Back vs. Hand	-187.10	46.66	-4.01	<.001*
Medium	Lower Back vs. Hand	-171.71	51.14	-3.36	.003*
High	Lower Back vs. Hand	-113.63	27.19	-4.18	<.001*

Table 7.4 Paired contrasts for interaction of syncopation (Low, Medium and High) and body-part (lower back and hand) on movement synchrony. *Alpha adjusted $p < .005$, df = 25.

Contrasts		*Mean*	*S.E.*	*t*	*p*
Musician	Low vs. Medium	4.90	25.33	.19	.850
	Low vs. High	232.53	77.69	2.99	.012
	Medium vs. High	227.62	68.12	3.34	.007
Non-Musician	Low vs. Medium	46.73	36.37	1.28	.221
	Low vs. High	373.64	72.15	5.18	<.001*
	Medium vs. High	326.91	54.83	5.96	<.001*
Low	Musician vs. Non-Musician	-217.27	158.89	-1.37	.184
Medium	Musician vs. Non-Musician	-175.45	147.31	-1.19	.245
High	Musician vs. Non-Musician	-76.16	101.85	-.75	.462

Table 7.5 Paired contrasts for interaction of syncopation (Low, Medium and High) and musical training on movement synchrony. *Alpha adjusted $p < .005$. Musicians: N(df) = 12(11), non-musicians: N(df) = 14(13).

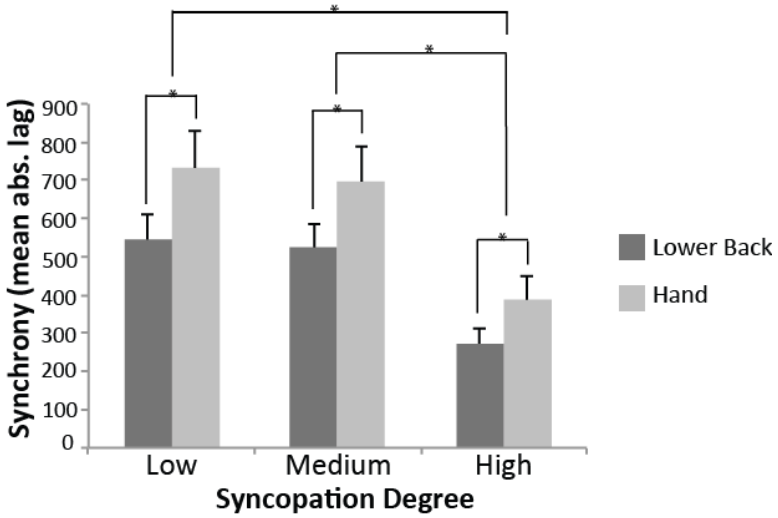


Fig. 7.5 Effect of syncopation (Low, Medium and High) and body-part (lower back and hand) on movement synchrony. Error bars = standard error. *Alpha adjusted $p < .005$.

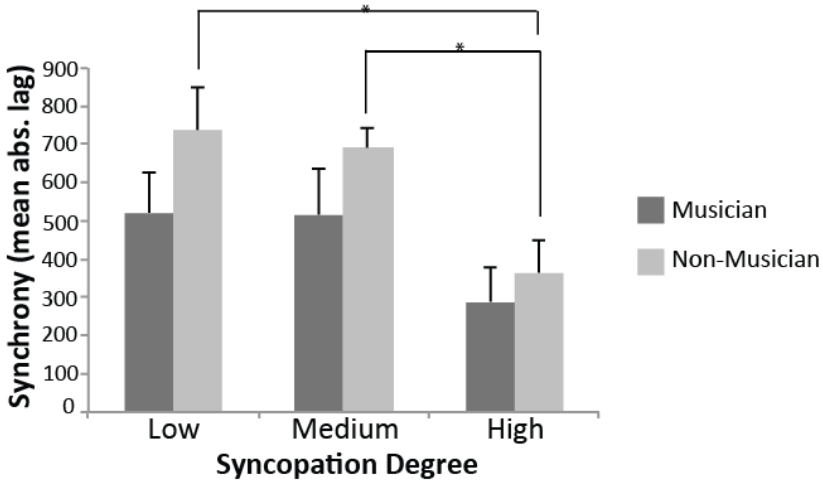


Fig. 7.6 Effect of syncopation (Low, Medium and High) and musical training on movement synchrony. Error bars = standard error. *Alpha adjusted $p < .005$.

7.3.5 Periodicities

7.3.5.1 Analysis

A nonparametric Kernel Density Estimation function was used to compute the distribution of all periodicities for each level of syncopation, as performed in previous motion-capture research (Toiviainen et al., 2010). The data for these analyses (percentage and density calculations across subjects, as opposed to individual subject data), do not allow the effects of musical background on periodicities to be addressed in a systematic way.

7.3.5.2 Results

Percentages of periodicities at metric and non-metric levels, and instances of no periodicities, are given in Table 7.6 and Figure 7.7. For lower back, 3.33% of movements were non-metric, while hand movements were non-metric 4.49 % of the time. Around 5% of movements in both body-parts showed no periodicity. Overall, approximately 90% of movements corresponded to some metric level of the drum-breaks. It was found that in both lower back and hand, the most common periodicities corresponded to the main pulse (crotchet or 0.5 sec), the minim (1 sec) and the quaver (0.25 sec), respectively. However, the difference between the most prominent period at the main pulse and the other metric periods was greater in the lower back than in the hand. There were also some periodicities, albeit weak, at the bar level (semibreve or 2 sec), and a very small percentage at the metrically complex level of the dotted minim (1.5 sec). The metrically complex periods suggest the possibility that some very few movements may have been synchronised to the drum-breaks in a 3:2 relationship.

	% Periodicities (seconds)							
	0.25	0.5	1	1.5	2	No Period	Non-Metric	Sum Metric
Lower Back	21.28	48.08	16.15	2.31	3.21	5.64	3.33	91.03
Hand	17.69	34.62	27.44	6.41	3.59	5.77	4.49	89.74

Table 7.6 Percentages of instances of no period, metric and non-metric periods (in seconds) in movements of lower back and hand.

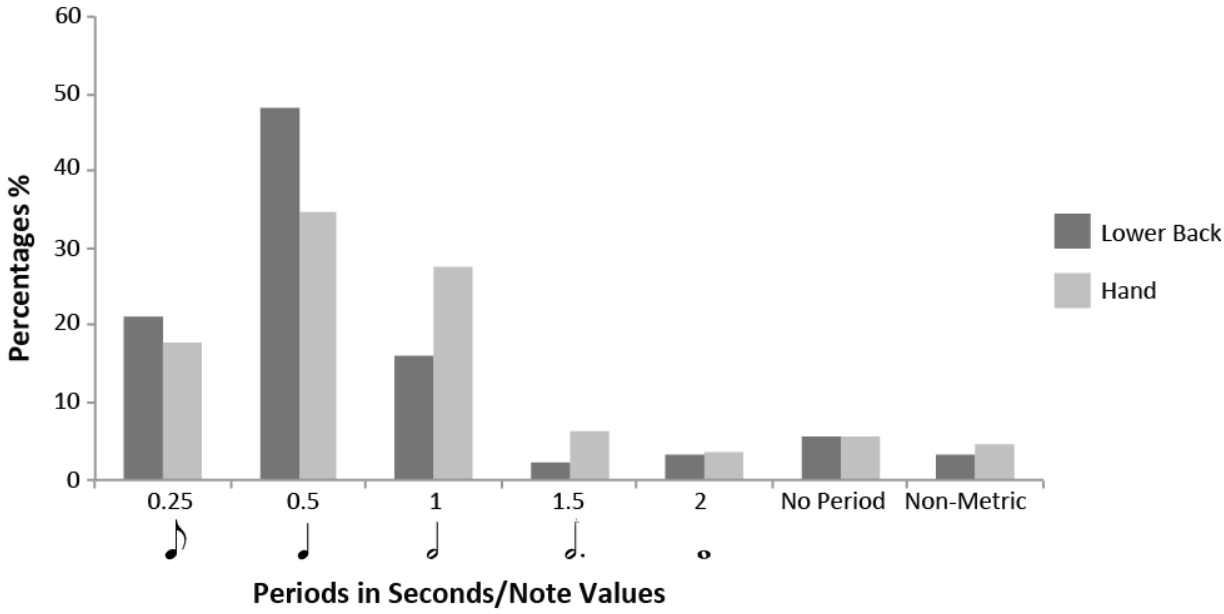


Fig. 7.7 Percentages of instances of no period, metric and non-metric periods (in seconds and note values) in movements of lower back and hand.

Densities of periodicity probabilities in lower back and hand are plotted in Figure 7.8. The most prominent periodicities in the lower back at the main pulse (crotchet) was during drum-breaks with Medium syncopation, followed by Low and High, respectively. Minim and quaver periods were more prominent during Low and Medium syncopation. Bar-level (semibreve) periods were most prominent during drum-breaks with Medium syncopation. The metrically complex period of the dotted minim was equally prominent for all drum-breaks in absolute terms, but when considering High syncopation relatively within its own context, it was indistinguishable from non-metric periods. Overall, metric

periods were less common during High syncopation compared to Low and Medium, as can be observed from the lower amplitude and broader focus of metric 'peaks' during drum-breaks with High syncopation.

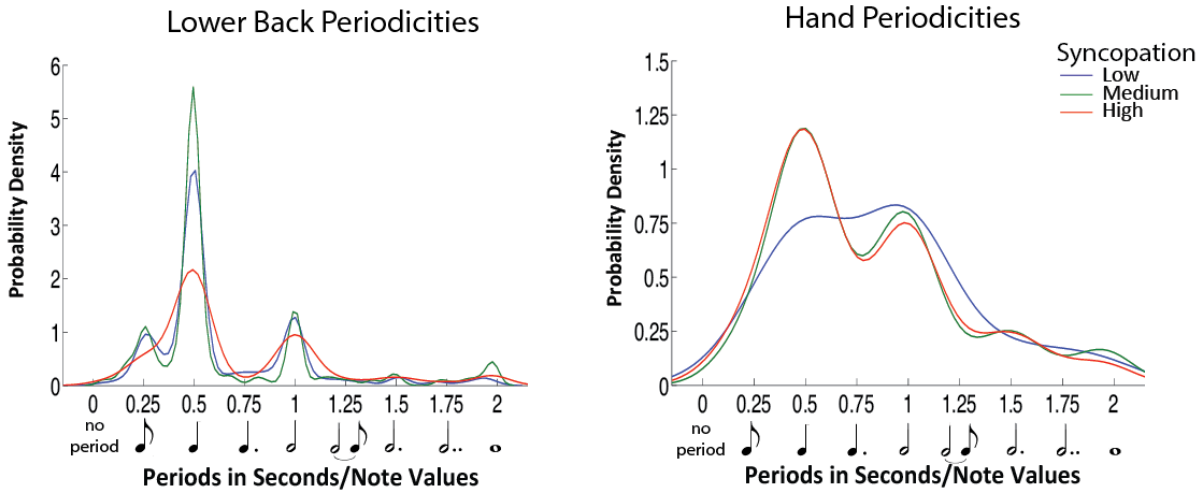


Fig. 7.8 Probability distribution of periods in movements of the lower back and hand during drum-breaks of low, medium and high syncopation.

Movements in the hand were overall less periodic, as can be observed from the lower values of probability density, compared to the lower back. The main pulse was the most prominent during Medium and High syncopation. Conversely, the minim period was the most common during Low syncopation, although the difference between the drum-breaks was small at this metric level. Furthermore, for Low syncopation drum-breaks, minim periods were marginally more prevalent than main-pulse (crotchet) periods. The metrically complex period of the dotted minim was equally prevalent during all drum-breaks, but rare overall compared to other periods, and for Low syncopation this period was no more prominent than the neighbouring non-metric periodicities. The bar-level (semibreve) period was equally common during all drum-breaks, in absolute terms, but only relatively more common than other surrounding non-metric periods during drum-breaks with Medium syncopation – though these differences were all very small. In

contrast to what was found in the lower back, periodicities were the least metric during Low, as opposed to High syncopation.

To summarise, movements were more periodic in the lower back, compared to the hand. The most common period across drum-breaks, participants and body-parts was the main pulse (crotchet), followed by the minim and the quaver, in that order. Overall, around 90% of movements were metrically periodic. The metricality of periodicities interacted with levels of syncopation in a number of ways. Movements in the lower back were the most periodic at the main pulse during drum-breaks with Medium syncopation, and least periodic during High syncopation. In the hand, movements were most periodic at the main pulse during Medium and High syncopation, and least periodic during Low syncopation. Thus, there was a broadly inverse relationship between syncopation and main pulse prevalence in the lower back compared to the hand. There were some metrically complex periods, suggesting that some movements were related to the metre of the drum-breaks in a 3:2 relationship. However, in relative terms, these periods were very rare and only distinguishable from other surrounding non-metric periodicities during drum-breaks with Low and Medium syncopation in the lower back, and Medium and High syncopation in the hand.

7.4 DISCUSSION

This study has shown that drum-breaks' degree of syncopation and dancers' musical training affect movements of the lower back and hand during spontaneous dance. The results show that syncopation affects the force and synchrony of movement in similar ways, for both lower back and hand. This suggests that increasing synchronisation accuracy requires an increase in movement force. The correlation indicates that force and synchrony were greater during low compared to high syncopation, and during medium

compared to high syncopation, but that there was no difference between low and medium. This result broadly supports previous research showing that the clearer the pulse, the more people move to the music (Burger et al., 2010). Thus, it seems that although drum-breaks with a medium degree of syncopation are rated as eliciting the most *desire* to move, these drum-breaks do not actually *make* people move any more than drum-breaks with low syncopation. However, the difference between medium and high syncopation was the same for rated movement desire and enacted movement force. In other words, the first hypothesis predicting an inverted U-shape between syncopation and movement force is only partially supported.

The second hypothesis stated that changes in syncopation in drum-breaks would affect synchronisation accuracy in body-movements. This hypothesis was confirmed. It was found that synchronisation was more accurate during low compared to high syncopation. Thus, there is broadly a negative linear relationship between sensorimotor synchronisation in dance and syncopation in groove. However, as was found for force, there was no significant difference in synchronisation accuracy between low and medium syncopation. Thus, although low syncopation fosters more accurate synchronisation than high syncopation, an intermediate degree of syncopation enables better synchrony than high syncopation, but makes no difference compared to low syncopation. It is possible that the paradox considered in the introduction, regarding the detrimental effect of syncopation on sensorimotor synchronisation *accuracy* generally, and the amplifying effect of medium syncopation on the *desire* to synchronise to groove specifically, can explain why the specific relationship between syncopation and synchrony was as found in the present study. In the former effect (synchronisation accuracy) the relationship between syncopation and synchronisation is negatively linear, while in the latter (desire to move), there is an inverted U-shaped relationship between syncopation and desire to move. These

are two different mechanisms, one relating to a sensorimotor capacity, the other to a subjective evaluation of motivation towards behaviour. It could be that these two mechanisms interact while synchronising body-movements to syncopated groove in dance. To be precise, it is possible that syncopation has a generally detrimental effect on synchronisation accuracy in a negatively linear way, but that in contexts of polyphonic groove the positive drive towards body-movement improves synchrony at medium degrees of syncopation. However, this improvement might not be enough to produce a full-blown U-shaped effect, causing synchronisation with medium syncopated drum-breaks to be the same as, rather than greater than, those with low syncopation. Alternatively, there could be some unknown factor, such as an aspect of the personality and/or background of the participants, which was not recorded in the present study.

In this regard, it should be noted that groove familiarity and dance experience did not affect the relationship between syncopation and synchrony. Thus, although dancers report that syncopated grooves make them want to move more than non-dancers, they do not dance any more forcefully than non-dancers, or at least not in a laboratory context. It should be kept in mind that, in the motion-capture study, dancing experience was not categorised in the same way as in the online rating survey, and that this inconsistency might explain this lack of effect on overt body-movements. However, an interaction was found between musical training, syncopation and synchrony. Specifically, the characteristic pattern described above was found for non-musicians only: a high degree of syncopation was associated with poorer synchrony compared to low and medium, but non-musicians synchronised to the main pulse of drum-breaks with low and medium syncopation equally well.

Although previous studies have shown that non-musicians are worse at synchronising to rhythm than musicians (Ladinig et al., 2009; Palmer & Krumhansl, 1990),

there was no overall difference in synchrony between musicians and non-musicians in the present study. However, the relationship between degree of synchronisation accuracy and musical training suggests that non-musicians are more *sensitive* to changes in syncopation degree than musicians when it comes to sensorimotor synchronisation in dance. Furthermore, the fMRI study showed that activity in the putamen, which has been suggested to be involved in the regulation of metre perception (Grahn & Rowe, 2012), was only modulated for musicians and not for non-musicians. Thus, it seems the neural structure believed to underpin perception of metric events is affected by syncopation only in musicians, while embodied synchronisation in dance is affected by syncopation only in non-musicians. It could be that the basal ganglia ensure the perception of metric events for musicians, enabling accurate body synchronisation regardless of syncopation degree during dance; while for non-musicians, the lack of support from the basal ganglia in perceiving metric events results in a change in synchronisation accuracy based on changing degrees of syncopation. However, these possibilities are speculative, and more detailed and focused empirical studies would be needed to draw firm conclusions.

It was also found that, overall, movements were more forceful and better synchronised to the pulse of the drum-breaks in the hand compared to the lower back. This could be explained by the greater spatial and temporal degrees of freedom for movement in the hand, due to its smaller size and weight, and greater mobility at the end of a limb. Furthermore, the hands are more generally involved in fine motor timing, compared to the lower back and torso, such as in everyday gesturing, writing/typing, playing instruments and sport.[3] As noted by Toiviainen et al., (2010), the torso has a higher moment of inertia than the arm, due to its greater mass, which causes greater difficulty in fine motor timing.

[3] Playing sport can also require controlled movements of the torso, such as in ski-jumping and sport dance, but overall, fine movements are more often required in hands than torso in sport.

Thus, simple biomechanical properties of the body might explain why movements in the hand were more forceful and better synchronised than in the lower back.

Toiviainen et al (2010) use these biomechanical properties to explain different periodicity patterns found in the hand compared to the torso, proposing that body-parts with greater inertia necessarily have longer periodicities in movement. The effects of syncopation on periodicities in the present study, however, were not consistent with this finding. Overall, movements were more periodic in the lower back than in the hand, and despite the lower back having naturally greater inertia, movements were more periodic in the lower back than in the hand at faster metric levels, specifically the quaver level. However, it was not the case that the hand was more periodic at slower periodicities. Rather, the lower back was found to move more periodically than the hand, overall. Furthermore, periodicities in the lower back were closer to the metric levels of the drum-breaks, i.e. better matched in period. Thus, it seems that factors other than biomechanics affected movement periodicities to syncopated drum-breaks, and the results indicate that changing degrees of syncopation contribute to this effect.

Across drum-breaks and body-parts, the strongest period corresponded to the main pulse of the drum-breaks, followed by the minim and quaver, in that order. As mentioned, a previous study (Toiviainen et al., 2010) found that the minim was the periodicity most strongly entrained to, but the authors suspected that this was a result of the measurements being based on marker locations rather than acceleration, the latter being the measure that is used in the present study. Overall, 90% of movements recorded in the present study were periodic, in ways that corresponded with metric levels of the drum-breaks. However, the periodicity data interacted with syncopation in a number of ways, suggesting that people entrain to different metric levels of music in response to different levels of syncopation. Main-pulse periods were the most prominent during drum-breaks with medium

syncopation in the lower back, and during medium and high syncopation in the hand. Similarly, the least prevalent and most variable periods occurred during high syncopation in the lower back, and during low syncopation in the hand. This suggests an approximately linear relationship between period prevalence and syncopation, but the direction of the correlation was inverted in the hand compared to the lower back. In other words, the linear relationship was negative in the lower back, while it was positive in the hand. This implies that as syncopation increased, the relative embodiment of metric levels decreased in the lower back, but increased in the hand. When syncopation decreased, this relationship was reversed. It could be that the prominence of metric periods in one body-part attenuated their prominence in the other body-part, a possibility that would indicate that the relationship between beat clarity and temporal regularity in body-movement is more complex than previously indicated (Burger, Thompson, et al., 2012).

It should be noted, however, that the effect of medium syncopation was not clear within this linear relationship. Specifically, medium syncopation in the lower back was associated with more prominent main-pulse periods compared to low and high. This might be explained by the interaction between lower-level synchronisation abilities and subjective desire to move. However, the relationship between syncopation and periodicities in the two body-parts studied was inverted compared to the relationship between syncopation and synchrony: while period prominence was greater for the lower back compared to the hand, synchronisation accuracy was greater in the hand compared to the lower back. To understand how these findings can be reconciled, the nature of periodicity and synchrony should be made clear. The former describes recurring temporal oscillations of events with the same period, but has no bearing on the relationship between these events and other external events. In the present study, periodicity was calculated as autocorrelation, that is, an oscillation's self-synchrony, or the consistency of an

oscillation's period. The latter, synchrony, describes the phase relationship between the oscillation of a body-part and an external oscillation (the main pulse of the drum-break), assessed by means of a cross-correlation representing the lag between the movement event and a drum-break pulse. Of course, by definition, synchrony does not have to be periodic at all, and in the context of this study, it is entirely possible that an oscillation might be completely synchronised with itself (prominent period), but poorly synchronised to an external event (weak synchrony). It might be for this reason that movements in the lower back were found to be more *periodic* than in the hand, but that *synchrony* was greater in the hand compared to the lower back. Perhaps due to the biomechanics and inherent inertial constraints of the lower back, movements in this part of the body can be well controlled in terms of their 'self-similar' (i.e. periodic) qualities, but not so well in terms of their coordination with an external signal, such as music. Equally, it might be that the greater temporal and spatial degrees of freedom in the hand allow for closer phase-locking with external time patterns, such as rhythm and groove, but that this also affords more variability in terms of self-synchrony. The only instance in which both periodicity and synchrony are strong is when a movement is both synchronised in phase and period for an extended period of time. It could be that the syncopations in the drum-breaks of the present study prevented simultaneous phase- and period-synchronisation, and thus caused different body-parts with different biomechanical constraints to synchronise in either phase or period, but rarely in both.

An important factor in the periodicity analysis, which should be kept in mind when interpreting the results, was that the percentages and probability densities of periodicities were calculated across subjects, and that any possible effects of between-subjects factors, such as musical training, groove familiarity and dance experience, on periodicities could therefore not be tested. However, since a between-subjects factor, namely musical training,

was found to interact with the effects of body-part and syncopation on synchrony, and there were indications of an inverse relationship between periodicity and synchrony in different body-parts, it is possible that musical training also had an effect on periodicities. This possibility should be addressed in future research.

Two further limitations of the study should also be noted. The first is that it only makes use of a measure of synchrony in relation to the main pulse. It could be that the complex interactions found are explained by patterns of synchronisation in relation to other metric levels, such as the minim and the quaver. The second concerns the demand characteristics and ecological validity of the laboratory setting. Despite the participants dancing on their own, with no-one else present, the rather artificial circumstances, and the knowledge that their body-movements were being recorded, may well have made them self-conscious, affecting the ease with which they synchronised to the drum-breaks. The brightly lit experimental room is very different from the darker, atmospherically lit and socially interactive environment in which dancing is normally enjoyed. Thus, future researchers might consider making the laboratory look and feel more like a dance club, or use club venues to record motion-capture data.

To conclude, there is a complex pattern of relationships between syncopation and movement force, synchrony and periodicity in the hand- and body-movements of people as they dance to groove-based drum-breaks. Force and synchronisation accuracy tend to correlate across body-parts and levels of syncopation, in a relationship that is approximately negatively linearly related to syncopation – although medium degrees of syncopation seem to attenuate this linear effect, such that the pattern approaches an inverted U-shape. The effects of syncopation on synchrony were most pronounced for non-musicians, suggesting that they are more sensitive to changes in rhythmic complexity in groove-based drum-breaks. Overall, the hand showed greater force and more accurately

synchronised movements, compared to the lower back. However, the opposite was found for periodicity data, suggesting that synchrony and periodicity are inversely related across these two body-parts. Metrically simple periods, such as the main pulse (crotchet), the minim and the quaver, were the most prominent across drum-breaks and body-parts; and an inverse relationship between lower back and hand was found for the relationship between periodicities and syncopation. The more syncopated a drum-break, the more periodic the movements in the hand, and the less periodic the movements in the lower back. Thus, pleasurable entrainment to syncopated grooves is embodied in ways that are broadly linearly related to force, synchrony and periodicity, but which depend on the degree of syncopation, musical training and body-part.

CHAPTER EIGHT

Summary and Conclusion

The empirical studies reported in this thesis have aimed to elucidate the relationship between body-movement, pleasure and groove, from a psychological perspective. The thesis set out to investigate why groove elicits the desire to move, and why it feels so good. Taking a multimethodological approach, this question has been tackled from a number of different perspectives, centring on perceptual, computational, subjective, neural and embodied aspects of the relationship between body-movement, pleasure and syncopation in groove. Embodied and ecological theories of cognition and perception have provided a backdrop to the studies, and in this final chapter, the aims of the five studies will be restated and the findings discussed in relation to each other. The main concepts of the thesis will be considered across methodologies, and possible theoretical implications of the research will be discussed. These more speculative statements are italised in the chapter, to distinguish them from conclusions drawn from the empirical results. Then, the theories of embodied and ecological perception will be used to help draw the empirical trends together to provide a broader picture of the relationship between body-movement, pleasure and groove. A theory will be proposed, in which the notion of perception of metric events will be used to connect body-movement, pleasure and syncopation together in groove. Then, the phenomenology of groove will be explored, in which previous theories of embodied cognition and the temporal nature of groove will be combined with novel suggestions about how embodied and affective dimensions are coupled. The chapter ends with a broader consideration of theoretical and methodological implications of the research, and suggestions for future study.

8.1 Summary of Study Aims and Results

Of all the types of rhythmic complexity that groove involves, the most common is syncopation: thus it was decided to model the degree of syncopation in groove in order to measure how it affects the positive drive towards body-movement. However, since groove is a multi-layered pattern of rhythmic complexity, there was a need for an index that could reflect the perceptual effect of syncopation in polyphonic contexts. The tapping and perceptual rating study reported in Chapter Three was conducted with this aim. It demonstrated that the destabilising effect of syncopated drum-kit rhythms depends on their polyphonic, instrumental and metric configurations and the musical training of the listener, suggesting that the acoustic properties and ecological associations of drum sounds in syncopation are shaped by statistical learning and exposure.

Based on these findings, an index of polyphonic syncopation was proposed in Chapter Four, according to which the degree of syncopation of drum-kit patterns could be modelled. Applicable to any model of metric salience, and thus able to account for the effects of musical training that are incorporated into certain models, the index is an improvement on previous monophonic indices, and offers a more ecologically valid estimation of degrees of syncopation. For studies involving groove, this improvement is statistically significant when modelling subjective ratings, as shown by the index comparison in Chapter Five.

The subjective ratings collected via a web-based survey in Chapter Five addressed the extent to which syncopated drum-breaks, as transcribed from funk tracks and composed by the author, elicited the desire to move and feelings of pleasure. A clear inverted U-shaped relationship was found, showing that intermediate degrees of syncopation elicit the most wanting to move and the most pleasure. A similar finding was demonstrated for the degree of beat salience of these drum-breaks, but entropy was a poor

predictor of the positive drive towards body-movement. Based on demographic data, it was found that, overall, those who enjoy dancing and often dance to music wanted to move more and experienced more pleasure with the drum-breaks.

The inverted U-shapes between ratings of wanting to move and syncopation, and pleasure and syncopation, were replicated with ratings collected in an fMRI study, reported in Chapter Six. This study was designed to investigate the relationship between syncopation and neural activity, and an inverted U-shaped relationship was found between the degree of syncopation and neural activity in the auditory cortex, which interacted with participants' dance experience. A negative linear correlation between degree of syncopation and neural activity was found in the basal ganglia, but only for musicians. A negative linear relationship was also found in the interior inferior insula, but only for listeners who listened less frequently to groove-based music. On the basis of these findings, a striato-insulo-auditory network was proposed, in which the metre perception required for syncopated drum-breaks is regulated in the basal ganglia, with input from the encoded degree of rhythmic regularity in the insula, and modulated attention in the auditory cortex, as a result of subjective wanting to move and feelings of pleasure.

In the motion-capture study reported in Chapter Seven, the effects of syncopation were tested on overt body-movements in dance. There were approximately negative linear relationships between syncopation and movement force, and syncopation and synchrony, showing that, generally, the more syncopated the drum-break, the less people move and the less accurately they synchronise to the main pulse of the drum-break. Furthermore, force and synchrony were strongest in the lower-back, overall. However, medium degrees of syncopation had no different effect compared to low syncopation, suggesting that the subjectively experienced desire to move and pleasure might interfere with lower-level spontaneous sensorimotor synchronisation in dance. Musical training interacted with

synchrony, indicating that only non-musicians responded to changes in syncopation when moving to groove. There was an inverted relationship between synchrony and periodicity in the lower back and hand, indicating that as phase synchronisation improved in the hand, period synchronisation increased in the lower back. Movements were primarily entrained in simple metric relationships with the music, most prominently to the main pulse. The extent to which the relationship between syncopation and periodicity was linear or U-shaped was ambiguous, again suggesting an interference of subjective wanting to move and feelings of pleasure. These complex interactions between musical training and the force, synchrony and periodicity of dancers' body-movements demonstrate that groove does not simply trigger body-movement, but is actively embodied in ways that depend on the groove's degree of syncopation and listeners' musical training.

8.2 Syncopation as Groove

As a form of rhythmic complexity, syncopation was found to be a good structural indicator of groove. Its destabilising effects could be successfully modelled in polyphonic contexts, with sensitivity towards the instrumental configuration of a drum-kit. In fact, whether the syncopation occurs in one, two or three streams, and whether in the bass- or snare-drum, appeared to be more easily modelled than the effect of metric location, which has been the primary focus of previous research (Fitch & Rosenfeld, 2007; Ladinig, 2009; Longuet-Higgins & Lee, 1984). Thus, the ecological validity of the computational index of syncopation has been improved, albeit presently only for drum rhythms. Furthermore, the polyphonic index of syncopation was successful in explaining how syncopation is related to the positive drive towards body-movement, the most important psychological effect of groove: more consistently than a monophonic index, it showed that medium degrees of syncopation elicit the most wanting to move and the most feelings of pleasure. Thus, it can

be proposed that, structurally, *grooves are repeated multi-layered patterns of rhythmic complexity with medium degrees of syncopation*, and subjectively, *the positive drive towards body-movement is most strongly felt during grooves with medium degrees of syncopation*.

Entropy, on the other hand, was shown to be a poor reflector of perceptual effects of rhythmic complexity in groove. This supports previous research showing that models derived solely from information theory, without considering perceptual mechanisms, inadequately describes the effect of rhythmic complexity (Thul & Toussaint, 2008). However, beat salience was equally shown to affect embodied and affective engagements with groove, at a subjective level. That is, together, syncopation and beat salience both contribute to the inverted U-shape. Nonetheless, the relationship between syncopation and beat salience is not straightforward. Intuitively, one might expect the degree of syncopation to correlate naturally with the degree of beat salience, in a negative fashion. In other words, the more syncopated a rhythm, the less salient the underlying beat, due to the momentary absence of pulse onsets caused by syncopation. This was indeed the case for the 15 drum-breaks used in the fMRI and motion-capture studies. However, in the larger pool of 50 drum-breaks used in the online survey, syncopation did not correlate with beat salience. For example, some drum-breaks with low syncopation did not have high beat salience. This can be explained by the dependence in beat salience on the number of onsets in a drum-break, and not just the instrumental and metric configurations of onsets: the beat salience of a rhythm can be low simply due to the sparseness of phenomenal events, even if those events all coincide with metric events. Thus, while beat salience and syncopation are both important structural characteristics of groove in equal measures, two drum-breaks with differing abilities to elicit wanting to move and feelings of pleasure will not necessarily have directly proportional degrees of syncopation and beat salience. In fact, the

rating survey showed that syncopation related most closely to pleasure, while beat salience was more consistently explained by the desire to move. Thus, it could be that *a groove's embodied and affective affordances depend on the relationship between syncopation and beat salience*.

At the neural level, both U-shaped and linear relationships between syncopation and brain activity were found, suggesting a network in which metre perception in the basal ganglia, rhythmic regularity in the anterior inferior insula and attention in the auditory cortex interact in the neural underpinning of the embodied and affective experience of groove. However, it is possible that this effect was due to varying number of onsets, a measure that has been found to be related to groove in previous research (Madison, et al., 2011). Aware of this uncertainty, the results could suggest that syncopation in groove does not have the exact same effect neurophysiologically and subjectively, and the relationship between these levels of consciousness is not unidirectional. That is, although subcortical areas show largely linear trends, cortical regions could be modulated by top-down evaluation. This reciprocity between neural and subjective levels is strengthened by the effect demonstrated on the brain of musical training, groove familiarity and experience of dancing to music during listening to syncopated groove. Therefore, it could be that that *the effect of syncopation in groove depends on the interaction between lower-level neural regulation of metre perception and rhythmic regularity and higher-level attentional modulation according to subjective embodied and affective responses and individual musical background.*

Syncopation in groove not only elicits the desire to move, but also affects overt body-movements in spontaneous dance. However, although the relationship between dance and syncopation was found to be broadly linear, there were some indications of possible interference from a more U-shaped trend. Thus, the relationship between syncopation and

amount of movement, synchronisation accuracy and periodicity strength of sensorimotor synchronisation might be affected by the subjectively manifested inverted U-shaped relationship between desire for movement and syncopation. The subjective evaluation could amplify movement force, synchrony and period-prevalence during grooves that most strongly elicit a positive drive towards body-movement. Thus, the linearly destabilising effect of syncopation, as demonstrated in previous tapping studies (Fitch & Rosenfeld, 2007; Ladinig, 2009), has a somewhat different effect in the context of groove. Here, it is proposed that, *when dancing, the sensorimotor disruption afforded by syncopation is attenuated by the subjectively experienced positive drive towards body-movement in groove*.

Together, the empirical findings suggest that syncopation in groove contributes to making people want to move and feel good, while the italised statements, albeit theoretical and speculative, explore the possibilities that the *way* syncopation is related to body-movement and pleasure depends on the level of experience. There does not seem to be a one-to-one relationship between syncopation and responses at perceptual, subjective, neural and motor levels. Rather, these levels appear to interact in regulating how syncopation in groove is experienced, and groove seems to be manifested in complex ways along which perception, body-movement and pleasure are reciprocally linked. The present research indicates that s*yncopation in groove is manifested perceptually, subjectively, neurally and corporeally in interacting linear and U-shaped ways*.

8.3 Body-Movement in Groove

The effect of syncopation in groove on body-movement was measured in a number of ways, representing different psychological mechanisms. Tapping error, ratings of wanting to move, activity in the brain's motor network and dance-movements were all recorded in

order to demonstrate the embodied nature of groove. It was shown that these different bodily outputs do not correlate perfectly in groove. Generally, the findings indicated that more implicit measures, such as tapping, neural activity and motor-expressive dance, were affected by more contextual and consciously considered effects. As mentioned above, the well-known effect of syncopation on sensorimotor synchronisation was less linear in the context of overt dance than has been found in previous tapping studies, suggesting that the extent to which groove elicits the desire to move and pleasure at a subjective level might affects the ways people physically entrain in full-body movement. This points to the important fact that wanting to move represents a different psychological mechanism from that of overt movement, and that when both modalities are stimulated at the same time, they might interact. The desire to move, as discussed, is intimately linked with pleasure, and denotes the incentive salience experienced towards overt action, due to some stimulation that promises a psychological reward. It is an affective effect as much as an embodied one, but is not expressed in motor expression or action tendencies.[1] Similarly, it is perfectly possible to move and synchronise body-movements to music even when there is no desire to do so, or pleasure in doing so. Thus, on a methodological note, care must be taken when choosing dependent variables in studies of embodied and affective aspects of groove, because *what makes people want to move in groove might not directly translate into what can be observed in dance*, *and lower-level abilities for sensorimotor synchronisation might be affected by subjective motivations to dance*.

Similarly, the central nervous system, as represented by activity in the brain, seems to be modulated by individual exposure and experience. Activity in the basal ganglia while listening to grooves was only found for musicians, suggesting that people with long-term

[1] It is of course possible that the desire to move might be measurable in implicit sensorimotor expression, such as smiling and upright posture, but it does not represent the same mechanisms as overt body-movements in dance.

musical training recruit subcortical motor-related areas during listening to syncopated groove more than people with little musical training. However, some have suggested that the basal ganglia do not strictly form a motor area, but a temporal area, with which the cortical motor network interacts in response to temporally structured stimuli with motor significance (Grahn & Rowe, 2012). In groove, then, it could be that the basal ganglia's regulation of metre perception depends on the listener's musical training. In this regard, it was found that only non-musicians were sensitive to syncopation in overt groove-directed dance. Thus, it is possible that musical expertise governs the ways in which syncopation in groove is processed: *musicians might recruit neural mechanisms that enable the perception of the main pulse in syncopated grooves, while non-musicians, in the absence of this neural support, might reflect the degree of syncopation in the way they move to the main pulse of syncopated grooves*. As for the broader motor network, activity in cortical motor-association areas was found to increase during listening to groove, but levels of activity were the same regardless of syncopation degree. Thus, it could be that support from secondary motor areas, such as the premotor cortex and supplementary motor area, are equally important during different kinds of grooves, and that lower-level temporal mechanisms or actual movement determine how syncopation in groove is perceived and actively engaged with.

The ways in which people move their bodies in spontaneous dance appears to be related to the syncopation of groove in a complex fashion. Although accurate synchronisation seems to require more forceful movements, there are interactions between the degree of phase-locking and period-prominence, suggesting that people's ability to synchronise to the main pulse is inversely related to their ability to self-synchronise in ways that are consistent with the metric periodicities in the groove. Furthermore, the groove was found to be embodied differently depending on the body-part: as

synchronisation increased in the hand, periodicities were stronger in the lower back. Thus, it is difficult to map the cross-modal correspondences between the musical structure of groove and the spatio-temporal movements of dance in linear ways. It does not seem as if groove directly *triggers* certain types of movements. Instead, it could be that *dancers use their bodies actively to explore groove and embody its structural complexity through different corporeal mechanisms*.

In sum, this research suggests that body-movement as subjectively desired, neurally regulated and corporeally enacted in groove depends equally on the groove's musical structure, specifically its degree of syncopation, and listeners' musical background, biophysical properties and active embodied participation.

8.4 Groove as Pleasure

The pleasure reported in the online rating survey was in response to a type of music whose rhythmic complexity is at the forefront of its structural characteristics. In many ways, the music featured in this research is simple. Its instrumentation consists of a drum-kit only, and there is no harmony or melody in these grooves. Nonetheless, it was shown that groove's rhythmic properties, specifically its syncopation and beat salience, elicit feelings of pleasure. Specifically, the findings suggest that *intermediate degrees of syncopation and beat salience elicit the most pleasure in groove*. As rhythm is rarely considered in psychological investigations of affective engagements with music, yet groove, which describes such culturally diverging musics ranging from West-African drumming to Brit Electro, clearly stimulates positive feelings, this research has the potential to make an important contribution to affective theories of music.

The effect of syncopation on expectation provides an obvious way to incorporate syncopation as a pleasure-stimulating rhythmic structure, since expectations are thought to

stimulate emotions in music (e.g. Huron, 2006; Meyer, 1956). However, care must be taken when making such inferences. The types of structures normally considered in the theory of music and expectation are often 'peak-based' and tend to have medium- to large-scale structural significance (e.g. a deceptive cadence at the end of a harmonic progression). The original theory of musical expectation (Meyer, 1956) relies on teleological notions of musical-structural development, in which pleasure is promoted by delayed and thwarted resolution. This is not how syncopation works in groove. Due to the constant repetition of the basic unit in groove, any expectations thwarted by syncopation are also constantly repeated, and any resulting tension should not just occur at isolated moments during the course of a track, but constantly permeate the whole groove as it moves forward. Since groove is not teleological, but repetitious (yet not static), the constantly recurring syncopations might themselves become expected. In fact, it could be stated that, a groove with little syncopation, due to its decreased ability to elicit the desire to move and feelings of pleasure, is simply less qualified to be defined as a groove in the first place. As mentioned in previous chapters, the distinction between schematic and veridical expectations might explain this initial paradox: syncopations may stimulate affective responses in groove by violating schematic expectations at a perceptual 'micro' level, yet still be fully expected at an attentive, contextual and veridical 'macro' level. Importantly, pleasure is not momentarily induced by delayed or thwarted expectations in groove. Rather, *in groove, it is likely that pleasure is continuously afforded by metric and instrumental tensions occurring within the fabric of the multi-layered syncopated patterns*.

Furthermore, the pleasure of groove cannot be separated from its embodied effects. By this it is not simply meant that pleasure is felt in the body, since such a statement is more broadly part of the very definition of pleasure (see section 1.8, Chapter One). Rather, it is suggested that *in groove, pleasure is the desire to move and the experience of*

movement. In this way, pleasure both motivates and results from body-movement. Thus, the correlations between pleasure and body-movement do not just relate to the intensity of the experience, but also to its temporal development. As long as the groove is moving forward, the syncopation and repetitiveness join the pleasure and the movement together. This is why the groove pleasure cycle cannot be strictly differentiated into distinct periods of wanting, liking and learning, as has been proposed for more fundamental pleasures. Since pleasure and body-movement are synchronised to the beat of the groove in ways that interact with the groove's degree of syncopation, the wanting, liking and learning are more likely to happen throughout the groove.[2]

Although groove increases activity in brain regions that are more commonly known to regulate fundamental pleasures, the reward network was not found to be modulated by the degree of syncopation in groove. However, since the inverted U-shaped relationship was reflected in activity of the primary auditory cortex, it could be that the subjective experience of a pleasurable drive towards body-movement might increase the attention directed towards groove, and thus modulates the sensory part of the brain responsible for auditory processing. It should be noted, again, that the effect on the auditory cortex could not be confidently concluded to relate to the drum-breaks' degree of syncopation, since activity in this area was also found to be modulated by the total number of onsets in the drum-breaks. Thus, for the moment, it can only be speculated that *pleasure in groove is manifested neurally, subjectively and corporeally, but pleasure as related to syncopation in groove is subjectively experienced, then amplified in the brain via increased attention*.

It could be that neurophysiological activity is simply the wrong modality in which to look for signs of physically grounded pleasure in groove. Musical 'chills', which are

[2] It is of course possible that dancers' pleasurable experience of dancing to groove may be subject to ebbs and flows in the embodied desire to move, but such fluctuations may have more to do with physical or auditory fatigue and distraction than the overstimulation of pleasure.

momentary instances of intensely pleasurable somatosensory sensations in response to large-scale, often teleologically manifested harmonic and melodic structures, are perhaps more similar to the kinds of fundamental pleasures that normally activate the reward system. Contrastingly, pleasure in groove is perhaps better measured in overt dance, as in the motion-capture study in Chapter Seven. In fact, musical stimuli that elicit overt action tendencies can be said to have more biological significance than those that simply send shivers down the spine. Since pleasure's biological function is to motivate behaviour, the dance that both results from and in turn contributes to pleasure in groove is perhaps better evidence for fundamental pleasure than physiologically measured arousal. Furthermore, it is thought that pleasurable 'chills' result from the lack of physical outlet for the energy that the affectively salient stimulus induces. The 'fight, flight, freeze' responses, which are the original evolutionary purpose of 'chills', almost all involve overt body-movement.[3] The electrodermal activity, racing heart and rapid breathing are signs that the body is ready for action. In many musical contexts, particularly those associated with the Western classical tradition, action is socially prohibited. And even outside the Western classical concert hall, the culture of classical music has continued to foster 'passive' music listening. It could be that the culturally determined listening norms associated with classical music have contributed to the development of musical 'chills'. When movement and action are inhibited during reward, the autonomic nervous system produces physiological arousal. In groove, however, body-movement and dance are socially and culturally accepted ways of engaging with the music and provide the necessary outlet for the energy aroused by the structural tension afforded by syncopation. In addition, the overt physical action can be performed at the first repetition of the basic unit, and can be sustained for as long as there is the desire to move. One might say that synchronised body-movements in groove are the

[3] The last, 'freeze', is the only one in which movement is avoided. But here, energy is used to *prevent* movement: being completely still is a physically effortful task.

equivalent of ‘chills’ in classical music. Since body-movement was inhibited during scanning, due to the technical limitations of fMRI, what is desired in groove was never actually possible to achieve. Thus, the lack of significantly modulated activity in reward areas of the brain as a function of syncopation might not be because syncopation does not affect pleasure in groove, but because an essential part of the groove pleasure cycle was prevented during scanning. The areas that *were* modulated by syncopation were related to the subjective desire to move and feelings of pleasure (increased activity in the auditory cortex), metre perception (in the basal ganglia) and objective encoding of the groove’s rhythmic regularity (in the anterior inferior insula). Had the participants been allowed to move during scanning, perhaps the more ‘fundamental’ pleasure regions (e.g. the OFC, NAc and ACC) would also have been affected by syncopation.

8.5 Musicians, Dancers and Groovers

An effect of musical background has been demonstrated in all the empirical studies of this project. However, due to the nature of the studies and the participants, the ways in which musical background was modelled differed. For example, while there was a distinction between those who often enjoy dancing to music and those who do not in the online rating survey, dancing experience was modelled with regard to relative frequency of dancing in the fMRI and motion-capture studies, since most of the participants did enjoy dancing to music to a certain extent. Despite these differences, some conclusions can be proposed based on the findings as considered across the research. Of all the between-subjects factors addressed in the present research, groove familiarity was found to affect the relationship between syncopation, body-movement and pleasure the least. The frequency of and preference for listening to groove-based music was only found to interact with the

modulation of syncopation-related degree of activity in the anterior inferior insula in the brain. More substantive evidence was found for musical training and dance experience.

Although musicians have traditionally be found to be better at sensorimotor synchronisation tasks involving syncopation than non-musicians, and this was supported in the tapping and stability-rating study in Chapter Three, musical training did not significantly affect evaluative ratings of wanting to move and feelings of pleasure in response to syncopated groove. Instead, the frequency with which people dance and extent to which people like to dance amplified ratings of wanting to move and feelings of pleasure. This effect remained the same across all levels of syncopation and beat salience. The implications are that in more ecologically valid listening contexts, in which the music is considered subjectively in terms of affective and embodied effects as opposed to more abstract notions of stability, people's past experiences of and preference for dancing are more relevant than years and intensity of formal musical training. However, despite dancers reporting that groove elicits more desire to move and feelings of pleasure than non-dancers, frequent dancers were not found to actually move any more to these grooves than infrequent dancers. This was shown in the motion-capture study reported in Chapter Seven, where force of movement did not vary according to dance experience. Again, it is important to emphasise that the desire to move is different from actual body-movement. Once movement is permitted, dancers' increased desire to move does not seem to translate to increased movement. However, as already mentioned, the non-dancers of the online survey were different from the infrequent dancers of the motion-capture study, thus the relationship between wanting to move and movement force remains to be more confidently determined.

The motion-capture study did, however, show an interaction between movement force, synchrony and musical training, which indicated that the less musical training

people have, the more affected they are by syncopation in groove when they dance. However, this does not contradict the findings of the tapping study, in which it was shown that musicians were better at synchronising to syncopated rhythms than non-musicians. The fMRI study had shown that the basal ganglia, a group of neural structures responsible for metre perception, were only significantly modulated in listeners with extensive musical training. It could be that musicians do better in synchronisation tasks involving finger-tapping, and that due to improved metre perception, they are able to synchronise equally well to grooves of various degrees of syncopation. Non-musicians, however, might be worse overall at synchronising in tapping to syncopated rhythms, and due to a reduced ability to perceive metre, syncopations affect their ability to synchronise in full-body movements to groove.

Thus, the relationship between musical training and sensorimotor synchronisation is not simple, and seems to depend on the rhythmic context, type of motor output, perceptual abilities and neural architecture of the listener. Furthermore, while groove familiarity appears to affect the neural correlates of groove only and has little significance at subjective and corporeal levels, the degree to which people like dancing and the frequency with which they dance seems also affect the overall desire to move and subjective feelings of pleasure. Therefore, it is proposed that *groove is a musical context in which both formal musical expertise in general, and informal corporeal experience in particular, interact with the ways in which syncopation affects embodied and affective engagement at subjective, neural and corporeal levels*.

8.6 Perception of Metric Events: Linking Body-Movement, Pleasure and Syncopation

Although a number of possible ways in which the embodied and affective dimensions of groove are causally linked have been considered, the empirical data only confirm that

body-movement and pleasure correlate within and across different psychological processes, such as subjective evaluation, neural activation and sensorimotor synchronisation. It seems clear that embodied and affective aspects are inseparable in groove and that syncopation affects both. But how are they linked? What is the *causal* relationship between body-movement, pleasure and groove? Pleasure both motivates and results from body-movement in groove: positive feelings are overtly expressed in sensorimotor synchronisation, but can also be experienced subjectively in the desire to move, even when overt action is inhibited. The expectancy stimulation afforded by syncopation, despite the repetitiveness of groove, could explain how rhythmic complexity elicits pleasure, and metre perception and entrainment are ways of accounting for the ability to synchronise body-movements despite momentary omissions of pulse onsets. Syncopation could thus be 'the missing link' in the relationship between body-movement and pleasure in groove. What is it about syncopation that joins the embodied and affective together in groove? Possible answer to this question will now be discussed, based on theoretical and speculative, yet ecologically plausible ideas.

As proposed earlier in this thesis, intermediate degrees of syncopation present the listener with the opportunity for perceiving metric events. The syncopation is such that a critical and finely balanced number of phenomenal events do not coincide with metric events, and the regular pulses of the groove are momentarily disturbed. Such a degree of syncopation affords perceptual tension, yet is not enough to disrupt the self-sustaining expectancies that the underlying regularity of the metre and the repetitiveness of the groove provide. Thus, the metric events highlighted by the syncopations, despite lacking what might be termed 'phenomenal presence', are still very much perceived: veridical expectations 'fill in' for the phenomenal events in their absence. Here, and earlier, it is suggested that grooves with a degree of syncopation that enables the perception of metric

events elicit the most desire to move because an opportunity arises for the body itself to *become* the phenomenal events of the groove. By synchronising with the main pulse, the body physically marks the metric events, both when those overt movements coincide with phenomenal events, and – importantly – when they do not, i.e. when the phenomenal events are shifted by syncopation. Since syncopation renders the metric events silent and the attending processes that form the veridical expectations are 'internal', the body provides a medium through which the metric event can exist phenomenally.

Here, it is suggested, that this corporeal invitation proffered by syncopation is what connects body-movement and pleasure. The metric events without phenomenal events open up spaces in the musical structure that the body feels inclined to inhabit. Syncopation in groove makes the metre acoustically 'incomplete' and, for the listener, the body is the most immediate and material instrument with which the metre can be 'completed'. However, it is not that dancers use their bodies to 'de-syncopate' the groove. Rather, the body provides a way of embodying the structural tension that the syncopation affords. In phenomenally enacting the metric events, the tension between the temporal regularity of the metric framework and the temporal irregularity of the syncopated rhythm can be not just 'heard', but 'felt'.

In this way, syncopation could be seen as providing a musical situation in which the body is presented with an opportunity to physically occupy parts of the musical structure set out by the groove. One might say that the syncopation *causes* the desire to move by virtue of this opportunity. However, the causality it not unidirectional. That is, the body would not be able to embody the metric events if it were not for the expectations afforded by the dynamic attending on which metre perception relies. Thus, while syncopations invite body-movement, the listener is attuned to the metric events. The desire to move is negotiated reciprocally between the music and the listener. In fact, the concept

of desire is an affective form of attunement, i.e. the cognitive mechanism enabling perception of environmental information according to the ecological theory of perception (Clarke, 2005; Gibson, 1979). Rather than reconstructing the metre from the syncopated rhythm as a form of information 'decoding', the attending processes and body-movements resonate with the metre, and the body is entrained to the groove. This resonance is manifested as a desire to move on the part of the listener, who, in seeking to 'tune' the relationship between organism and environment (mind and music), moves her body to synchronise with the metre of the groove.

Pleasure is experienced as a concomitant of this subjectively manifested desire (as recorded in the online rating survey), but may also be a result of the enacted sensorimotor synchronisation and embodiment of metric events in syncopated groove (as speculated above). The former can be seen as the 'wanting' part of pleasure, while the latter best corresponds to the 'liking' part. Thus, two of the distinct phases of the pleasure cycle are reflected in the affective experience of groove. The final part, 'learning', might be seen as the formation of veridical expectations due to the repetitiveness of the groove. All three parts rely on embodied expectation and ability to synchronise body-movement to achieve their positive valence. Wanting is afforded by schematic expectations and body-movements attuned to the metric framework of the groove, liking is engendered by corporeal enactment of the metric framework, and learning is facilitated by the embodied veridical expectations facilitated by the repetition. Furthermore, the wanting, liking and learning depend on each other, as a consequence of the embodied dimension. Without the anticipation of the physical pleasure of moving to metric events in syncopation, which is a consequence of the learned expectations of groove, dance would be less pleasurable. Similarly, if dance were not pleasurable, then there would be no desire to move in groove and no subsequent learning about the experience would take place. In this cyclical

relationship between wanting, liking and learning, there is no sensible way to delineate which comes first, or which causes which, particularly because the groove is repetitive and the syncopations constantly cause wanting, liking and learning. It is impossible to say whether pleasure is directly caused by, or causes, body-movement: rather, it seems more likely that pleasure and body-movement are mutually dependent in groove, and when the syncopation is such that metric events can be perceived, the pleasurable desire to move is physically enacted in sensorimotor synchronisation and dance. Such an ecological view of the experience of groove provides a convincing account of how body-movement, pleasure and syncopation might be linked.

8.7 'Filling In': Distributing Mind, Body and Music in Groove

When the body moves to groove, it follows the metre and continues to synchronise with the eternally repeating main pulse until the music stops, or until fatigue, boredom or other distractions set in. If the groove is syncopated to a medium degree, the movements can be seen as 'filling in' for the 'missing' phenomenal events at metric pulse events in ways that are motivated by and cause embodied feelings of pleasure. The body enters the music through syncopation, in ways that resonate with Danielsen's (2006) and Chernoff's (1979) descriptions of the 'open spaces' and 'internal beat' in funk and African music. The silent metric events exposed by syncopation through the unexpected 'off-beat' occurrence of phenomenal events open up temporal spaces in the groove, which the body, through entrainment and sensorimotor synchronisation, 'fills in' with its movements. This embodied substitution of phenomenal events is not just metaphorical, but directly physical. The body literally *becomes* the phenomenal events that are expected at the metric events, and thus physically enacts the expectations that the syncopation violates. According to this view, syncopation in groove is not just a musical structure consisting of rhythmic deviation

from metric expectations, but a rhythmic arrangement that affords affective and embodied experiences of structural tension. Without moving the body into the 'open spaces', the full pleasure potential of groove is not reached. The groove 'demands' the body in syncopation, and provides a musical-structural situation in which the body is compelled to contribute directly to the groove.

This participatory 'demand' by groove has been noted by others. Although referring to microtiming as opposed to syncopation, Keil and Feld (1994) coined the term 'participatory discrepancies' and proposed that when groove musicians play 'late' or 'early' in relation to a strict metre, they are not deviating from a norm but actively shaping the structural norm itself. Similarly, the discrepancy from expectations that syncopation is commonly thought to engender must be reconsidered in the context of groove. Because the body compensates for the potentially disruptive absence of phenomenal events, the rhythm constitutes the groove not by being 'deviant' but by being partial.

The literal sense in which body-movements fill in the metric events in groove makes the relationship between body-movement and musical structure not just mutual, but the definitions of music and body become difficult to maintain. If the body substitutes for some of the music's phenomenal absences, then as long as the groove lasts and the body synchronises to the beat, the body *is* music. Such a blurring of boundaries between the 'external' and 'internal' in embodied phenomena echoes Clark's (2008) Extended Mind Theory (EMT). Clark maintains that 'external' objects and processes are not just tools, but become fully a part of the mind when they are physically or conceptually used by an agent. In the experience of groove, mind and body extend out into the music, just as the music penetrates mind and body. By filling in the gaps in the groove, music, mind and body are mutually distributed: the mind extending into the music via entrainment and temporal prediction, and the body spreading into the music through sensorimotor synchronisation

and the phenomenal substitution at metric events. In a qualitative study of the emotional experience of groove, an informant described his experiences in ways that echo Clark's EMT:

> I just get immersed into it, you know, it's like, I feel like I'm almost inside it, you know, I'm inside the song, the experience, you know, it's not just the song, it becomes something that I can become a part of… and it's like, I don't know, it sounds a bit hippied out or something, but I almost feel like I'm at one with it, you know, it's like I just love it at that moment. It makes me feel like feelings of joy almost! (Witek, 2008, p. 38)

What this quote adds to our understanding of the distributed groove experience is that positive emotions, such as joy and transcendence, are part of the experience. In groove, cognitive extension has affective significance. Apart from entering the body and the mind though the ear, the music also extends into the listener as a structural concept. Of course, body movement isn't sound – although bodies can make sound, in groove the body provides (almost) as much of the *metre* of the music as does the sound of the music, and the metre is *real* and *physical.* It is not an imposed mental construct decoded from the deviating musical structure, but an equally embodied and affective, external and internal, subjective, neural and corporeal entity which links body-movement, pleasure and groove together in experience.

This distributed view of body, mind and music in groove can be further extended to include different socially interacting agents. When dancing with other people, body-movements are not only synchronised to the music, but to the movements of others' bodies; and when collectively filling the open gaps in syncopation, many bodies enter into the same space. In this space, bodies are distributed, much like a dance club in which bodies are bouncing across the room. The open spaces become portals through which people can share the same mental and physical space. Body-movements and expectations

become interpersonally synchronised and time exists collectively. Each repetition of the basic unit of the groove ensures that every dancer can affectively anticipate the gestures of the bodies of the other dancers. It is not just *you* feeling the desire to move, but the people around you who also succumb to the positive drive towards body-movement. Thus, social entrainment to groove affords shared emotions as well as shared actions, and since dancing often occurs at culturally specified places (clubs, parties, gigs), syncopation in groove provides a 'venue' in which cultural values and preferences can be transmitted.

8.8 Implications and Future Work

The phenomenological consideration presented here, of how body-movement, pleasure and syncopation in groove are related, can be viewed as a contribution to a more holistic theory of the psychology of music. Instead of considering affective and embodied effects as separate dimensions which relate to musical structure in different ways, groove provides an example of how pleasure, body-movement and musical structure are mutually dependent and distributed in the process that is music. The empirical findings support this view, by demonstrating that the ways in which syncopation joins music, body-movement and pleasure together depends on perceptual, subjective, neural and corporeal mechanisms and individual musical background. Furthermore, the proposed theory and findings contribute to perspectives on music in which active and participatory aspects come to the fore, and add to the important embodied influences on cognitive theory. Perhaps, in the not too distant future, theories that deny the body a place in the musical architecture will be seen as no less anachronistic than those behaviourist theories that denied the mind a place in psychology (Watson, 1913). Similarly, this thesis demonstrates that different methodologies, such as perceptual experiments, computational analysis, subjective report, neurophysiological recordings, motion-capture measurements and phenomenological-

theoretical considerations, are not fundamentally incompatible, but ecologically partial and mutually dependent in the study of music. Finally, on a more publicly relevant note, as so many experience the desire to move when they hear a syncopated groove, and since dance is one of the most overtly manifested expressions of musical pleasure, the contributions of this research are likely to interest anyone who has ever wondered why it is that music makes us want to move, and why it feels so good.

Nonetheless, many questions remain to be answered. For example, to what extent is the perception of metric events the mechanism that binds body-movement, pleasure and syncopation in groove? Empirical study is needed to determine if metre perception can indeed explain the relationship. And what about grooves involving more complex (and ecologically realistic) instrumentation than just the drum-kit? A perceptual study investigating the effect of syncopation in the context of a full band would undoubtedly improve future modelling of the desire to move and experience of pleasure in groove. It might also provide a better opportunity to measure activity in reward-related and associative motor areas of the brain, since it is surely the case that these fully-fledged real-world grooves have the capacity to properly engage the full pleasure and attention of a listener. Neuropsychological research of groove is in its early infancy, and future studies should consider pursuing an understanding of the neural connections between sensory-, motor and reward systems in the brain. Such studies will have implications for the understanding of human behaviour beyond music and groove. In particular, the role of dopamine in movement and pleasure seems a particularly fruitful link to pursue. Finally, it is hoped that the interdisciplinary framework of this project will be continued in the future, and that the potential of combining empirical, analytical and phenomenological approaches to music will be realised in greater measure. The question of what it is about music that

makes us want to move and why it feels good is structural, psychological and philosophical, and can only be properly addressed by conjoining disciplines.

8.9 Limitations

Despite the strength of the research's multi-methodological approach, some limitations remain. As discussed in Chapter Two, studies using subjective ratings are susceptible to strategic biases relating to demand characteristics, experimenter bias and social desirability. One cannot expect without doubt that ratings reflect participants' inner state in a one-to-one relationship. Furthermore, it cannot be assumed that rating scales are used interchangeably across participants with different cultural backgrounds. Since the online rating study reported in Chapter Five recruited participants from many different cultures, it is possible that some used the rating scale differently than others, for example by making more use of the extremes of the scale, or by completing the survey with a varying degree of conviction. However, since the ratings were largely replicated in the fMRI study, it can be suggested with some confidence that the U-shape found in both studies truthfully reflects the relationship between desire to move and experience of pleasure.

Furthermore, although body-movement was directly measured in the motion-capture study, immediately after ratings were collected in the fMRI study, ratings were not related to actual body-movement, but rather the *desire* to move. This was due to the well-known and currently insurmountable limitation of functional neuroimaging, regarding the prohibition of movement. As mentioned in the discussion of Chapter Six, this could also explain why activity in lower-level reward-related areas of the brain was not found to be significantly affected by differing degrees of syncopation in groove. Nonetheless, the desire to move is, as mentioned, a fairly well-established characteristic of the psychology

of groove, and positions the present research in line with previous work (Madison, et al., 2011; Janata, et al., 2012).

Despite these limitations, the use of such diverse methodologies as finger-tapping, ratings, fMRI and motion-capture has both shown how different functions (e.g. linear or U-shaped) reflect different levels of experience (basal ganglia activity or subjective experience), and how certain functions (U-shape) can be recognised across studies of similar approach (online survey and scanner ratings) as well as experiments targeting different levels of the psychological phenomenon (auditory cortex activity and subjective experience). Thus, despite the limitations of the research, the project has provided indications of how body-movement, pleasure and syncopation in groove are related in a number of different ways, and constitutes an advance in answering the question of why it is that we love to dance to music.

8.10 Methodological Implications

While cognitive approaches to music date as far back as some of the first writings on music (Levitin & Tirovolas, 2009), the legitimacy of scientific, as opposed to humanistic, approaches to music are still debated today. The tensions that have fostered the most disagreement occur at the intersection of 'traditional' musicological analysis, qualitative cultural critiques and experimental scientific investigations. Between music theorists and music psychologists, the disagreement is believed to result from their different approaches but similar aims, namely to explain 'how music works'. The difference broadly amounts to theorists valuing intellectual-theoretical methods of close analysis (or close 'reading'), often individually unique and highly dependent on (musical) training; while psychologists prefer empirical and scientifically rigorous methods, which aim to emphasise what is generalisable about musical experience, regardless of specific historical setting, local

musical context, or even, in some cases, training and individual background. The theorists often accuse the psychologists of being culturally naïve and 'populist', while the psychologists criticise the theorists for speculation or plain fantasy. Currently, the debate seems to centre on the relatively recent introduction of neuroimaging techniques in music research. For many music theorists, historians and ethnomusicologists, it seems difficult to imagine that a description of brain states and neural networks can offer anything to aesthetically, individually, historically, culturally and socially grounded experiences of music (Thompson, 2009). This scepticism has coincided with a more general concern among scholars in the humanities and social sciences about the growing feeling among the general population that scientific explanations, even those that are naïve and reductionist, are more 'true' than humanistic explanations, no matter how sensitive and sophisticated. Accusing scientific perspectives on cultural and aesthetic phenomena of 'biologism', Tallis argues that such perspectives reduce humans to genetically predisposed 'beasts', whose agency is equated to neural activity that stands no chance against the fatalistic forces of evolutionary history (Tallis, 2011). He is particularly protective of the arts and diagnoses recent strands of the scientific study of art as 'neuromania' – a succumbing to the seductive appeal of the latest findings about the brain as a way to 'explain' human behaviour.

However, views like these about the serious scientific study of music and other arts are mistaken. Most importantly, they misunderstand the aims of the psychology of music. Empirical investigations of music, whether using finger-tapping paradigms, computational modelling, subjective rating surveys, neuroimaging techniques or motion-capture recording, are not trying to provide exhaustive explanations of the phenomenon of music, 'superseding' other scholarly approaches. Rather, scientific approaches to music attempt to increase our understanding of some of the perceptual, cognitive and neural mechanisms that *underlie* experiences with music. The empirical studies in this thesis show how the

relationships between body-movement, pleasure and groove are manifested in perceptual, subjective, neural and corporeal processes. This does not mean that groove can be reduced to these mechanisms, but that they must be *part* of the explanation. No superiority in relation to any other kind of explanation (scientific or humanistic) is implied in the study of the psychology of music. The social, cultural and aesthetic aspects of groove are still just as valid and fascinating against the backdrop of psychological functions and processes. To assume that those elements are not also involved would be absurd.

The search for the origin of music provides a useful example. A number of researchers are currently concerned with the possibility of an evolutionary origin of music (for a review, see Cross, 2009), and the pro-social effects of sensorimotor synchronisation is seen as a possible explanation for the biological purpose of music (Bispham, 2006; Merker et al., 2009; Hove & Risen, 2009; Kirschner & Tomasello, 2010). However, the fact that music might have had a specific origin or combination of biological purposes when it first occurred of course does not mean that these functions are the only ways in which people experience music today. Since the origin of music, if there was such a moment in time, humans have developed their musical skills into rich and complex activities, which interact with history, social development, cultural specification, individual creativity and aesthetic evaluation. The ways in which a listener engages with music cannot be reduced *exclusively* to the effects music once had on the development of social skills, but must be understood in the context of the listener's world and life. However, the biological functions may still affect us in ways similar to those the functions originally produced. Scientists interested in the evolution of music are trying to find traces of music's original biological functions, but do not claim that such biological functions remain the only functions of music. As Judith Becker, whose study of trance combines ethnomusicological and neuropsychological perspectives, puts it:

> I believe that it is not necessary to make a scientific description stand in opposition to humanistic (…) explanations of what it means to be human. All perspectives are partial perspectives and the neuroscience of the brain leaves aside ultimate questions. We will always need poets, saints, philosophers, musicians, and madmen to help us see the full range of what it means to be human. What neuroscience can do is help us understand some of the underlying mechanisms of the central nervous system that contribute to, or that make possible the joy (…) of dancing to a rousing gospel hymn, or the ecstacy (…) while listening to sung poetry, or the transcendental pleasure we may experience when entranced by music (Becker, 2004, p. 9).

Similarly, by directing a scientific approach to the relationship between body-movement, pleasure and groove, the research presented in this thesis does not claim that the perceptual, subjective, neural and embodied mechanisms revealed can fully explain the nature of groove experience, and this is why theoretical and phenomenological perspectives have also played a central role in this final chapter – not to provide a quick fix for the reductive 'neuromania' of a naive empiricism, but as a way to complement the understanding of the psychology of groove from a scientific perspective with more broadly cultural and musicological views.

APPENDIX ONE

Demographics Questionnaire

Part.no:

1. Gender:

Female	
Male	

2. Are you:

Right-handed	**Left-handed**

3. Age:

4. Occupation (if you are a student, please write down the subject and year of your degree**:**

5. How many years of formal and/or informal (self-taught) instrumental learning have you had? (excluding obligatory musical lessons in primary/secondary school)

formal	**informal**

6. Have you been playing or making music regularly for the last two years? (e.g. instrument, dj'ing, composing)

7. At what age did you start playing or making music? (e.g. instrument, dj'ing, composing)

8. How many years of formal musical theoretical training have you had? (i.e. music theory courses, excluding obligatory musical lessons in primary/secondary school)

Notes. Demographics questionnaire used in the perceptual study on syncopation (Chapter Three).

APPENDIX TWO

Experiment Instructions

Part.no:

Please read the instructions *carefully* and ask if anything is unclear:

You will hear 55 rhythmic patterns, which differ from each other to a varying extent. We ask you to tap along to these patterns on a computer keyboard and rate them on a continuous scale on a computer screen in terms of how stable you find them.

Each pattern is based on a four-beat rhythm, which is repeated four times. In some of the patterns, the regularity of the rhythm will at one point be disrupted. This disruption can be described as a 'displacement', a 'violation of expectancy' or a 'syncopation'.

We ask you to tap along to the underlying beat of the rhythmic patterns, ignoring the irregular disruptions. To help you do this, each pattern is preceded by a voice counting in to four and a woodblock playing the underlying beat in a completely regular way.

Please start tapping along to the beat of the woodblock, after the voice has counted you in, on the G key on 'the one' and the J key on 'the two, 'three' and 'four' using your right index finger. The rhythmic pattern will immediately follow the woodblock. Please continue tapping in the same fashion into the rhythmic pattern, keeping a steady beat, until the pattern stops.

When the pattern is finished, a rating scale will appear on the screen. You now have 12 seconds to rate your perceived stability of the rhythmic pattern, using the Up and Down arrow keys on the keyboard. The scale is continuous. Press the arrow key once to make the bar move in the desired direction, and again to stop it.

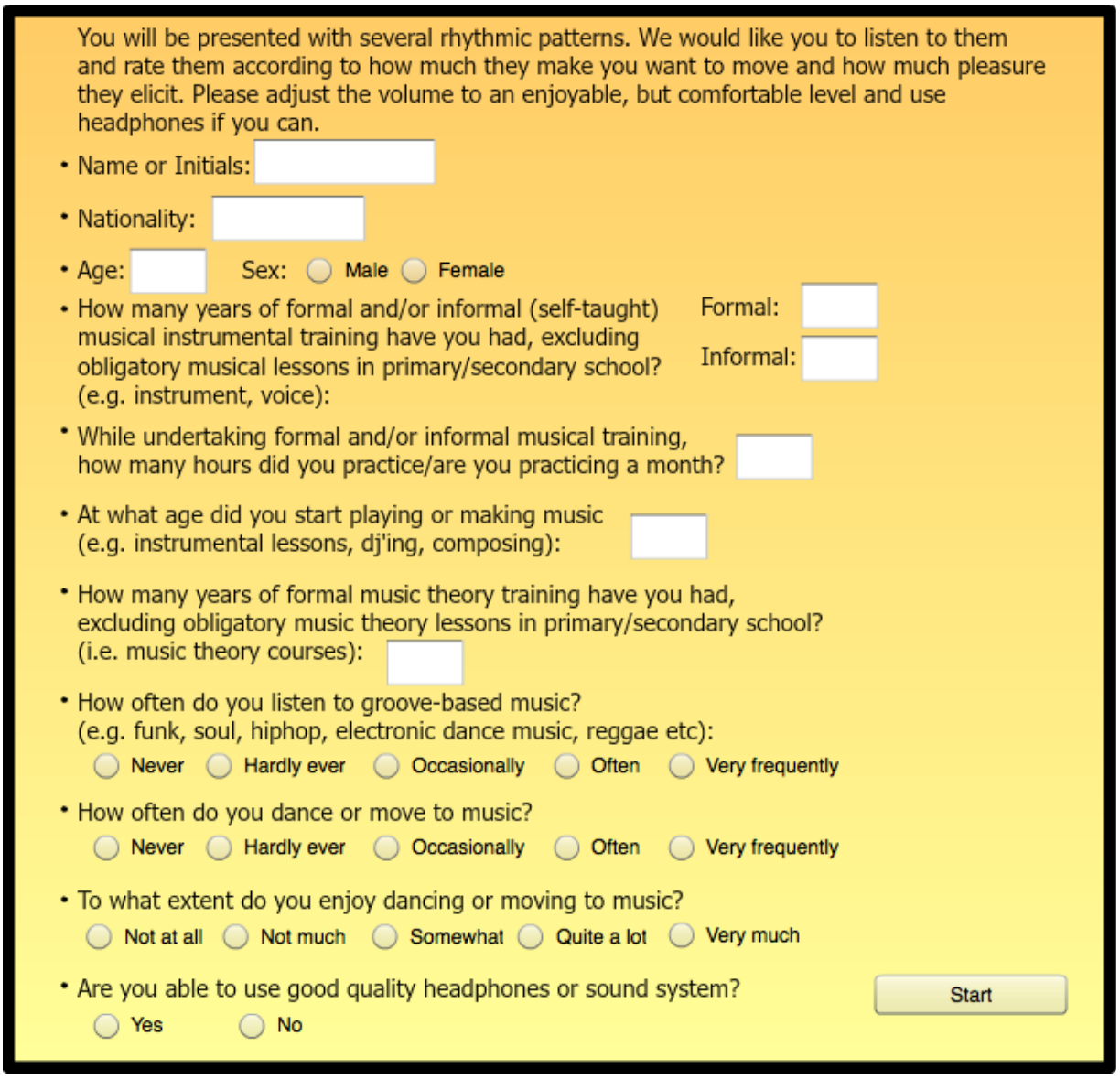
Rhythmic stability can be understood as feelings of rhythmic regularity and predictability, while rhythmic instability can be understood as feelings of rhythmic tension, violation of expectation and deviation from a regular rhythmic pattern. Please try to base your ratings on your immediate intuitive response.

Before you start the actual experiment, an experimenter will demonstrate how the task should be done, and you will get a chance to practise the task listening to rhythmic patterns which are representative of those you will hear in the experiment, but which use different sounds.

After the experiment, we will ask you to complete a questionnaire about your background. The actual experiment lasts 25 minutes. Including practice and filling out the questionnaires, the whole session should not last more than 45 minutes.

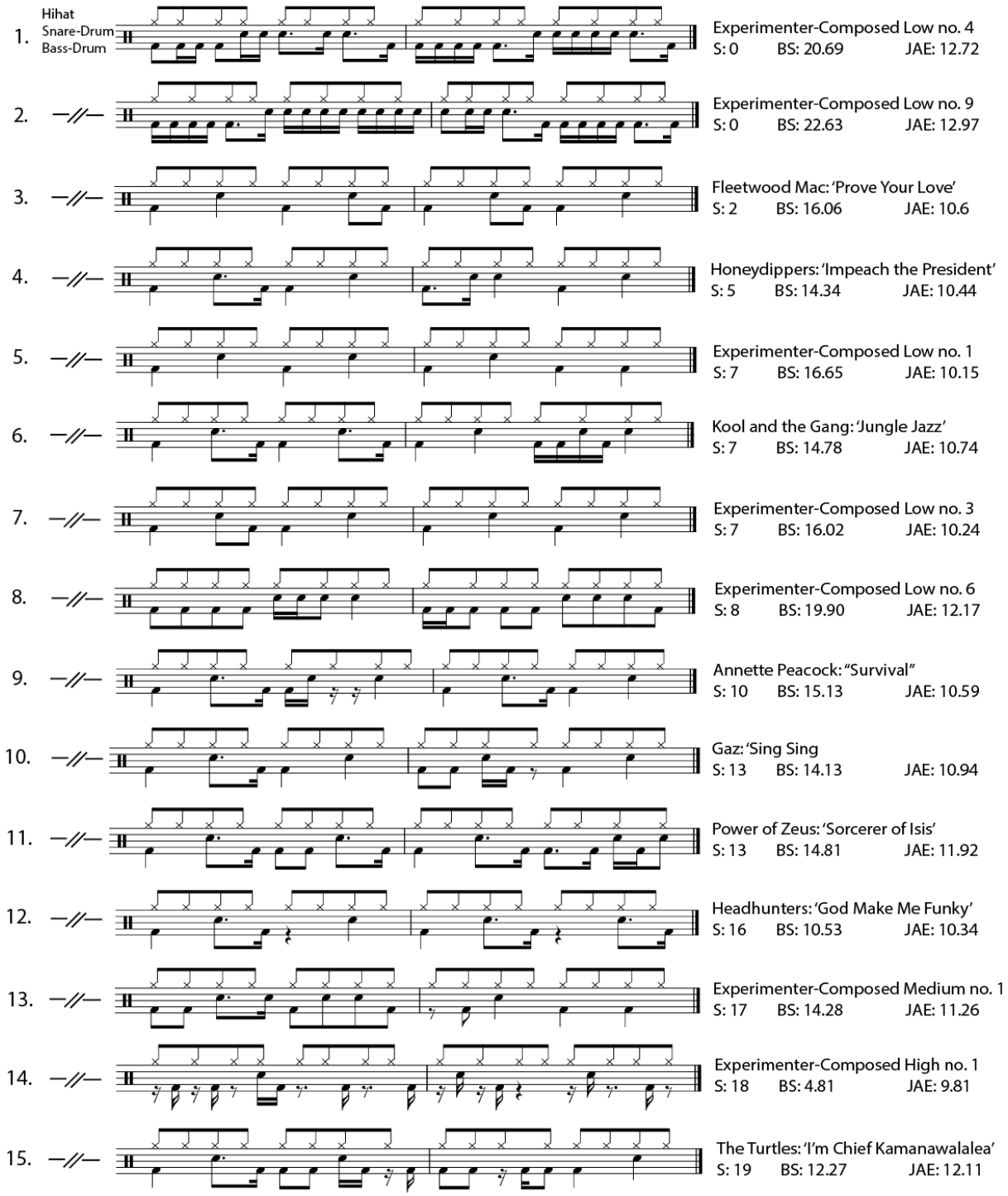
Notes. Written instructions administered before the perceptual syncopation experiment reported in Chapter Three.

APPENDIX THREE

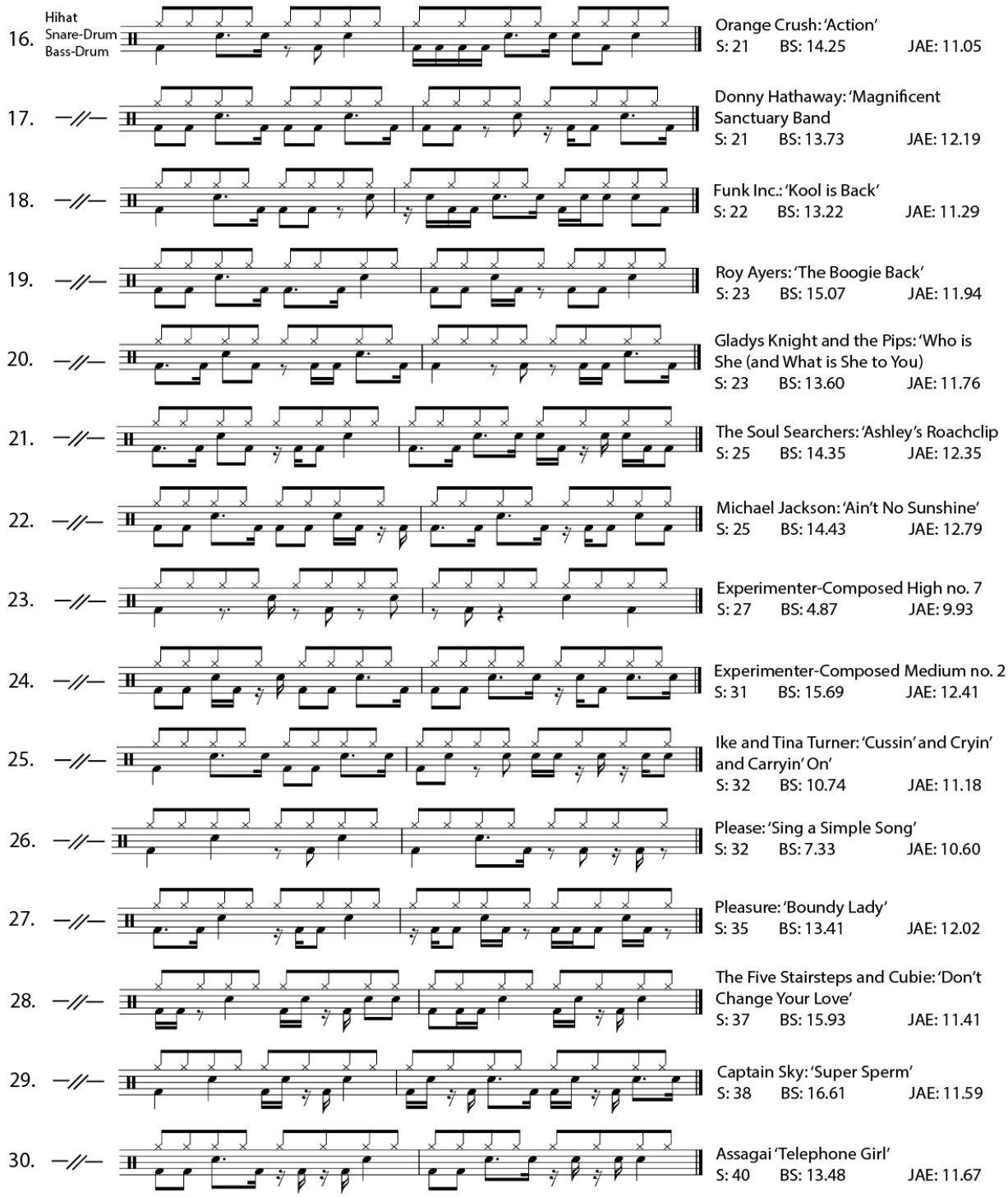


Notes. Instructions and demographics questionnaire used in web-based survey (Chapter Five).

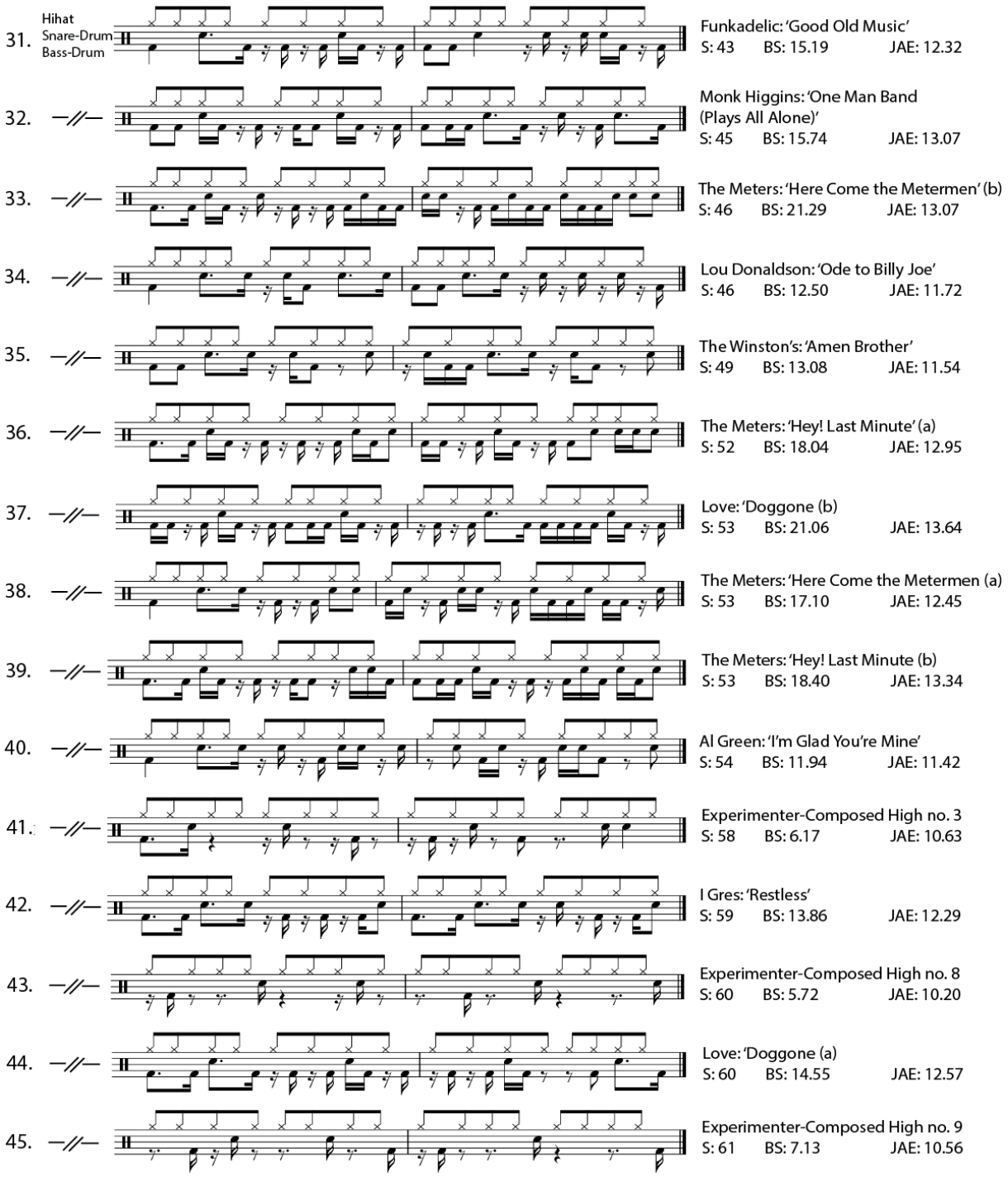
APPENDIX FOUR
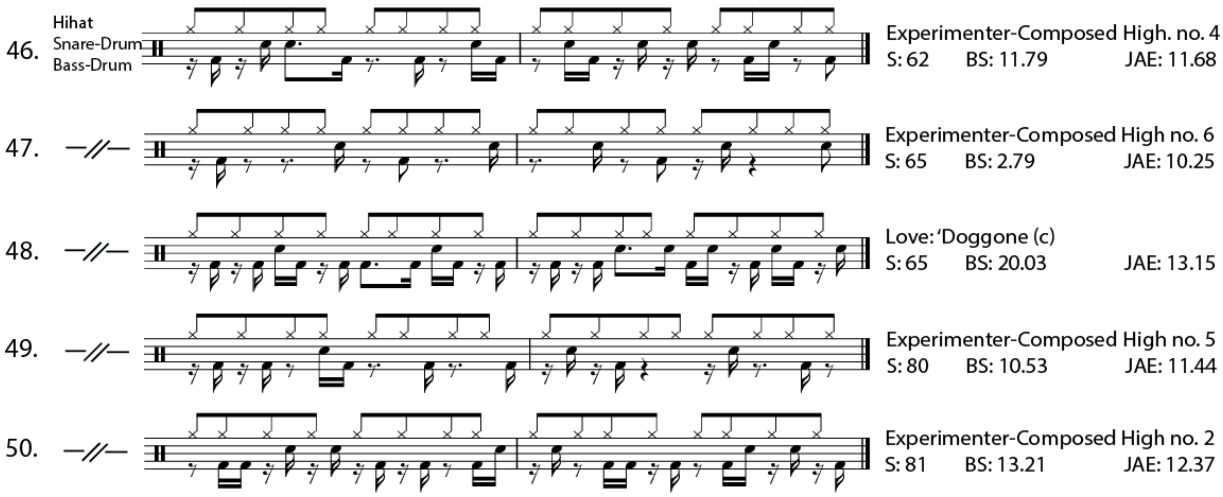


Notes. Notational transcripts and audio descriptor values of drum-breaks no. 1–15 used in the web-based survey (Chapter 5). S = Syncopation degree. BS = Beat salience degree. JAE = Joint audio entropy. Recordings provided on accompanying cd.



Notes. Notational transcripts and audio descriptor values of drum-breaks no. 16–30 used in the web-based survey (Chapter 5). S = Syncopation degree. BS = Beat salience degree. JAE = Joint audio entropy. Recordings provided on accompanying cd.

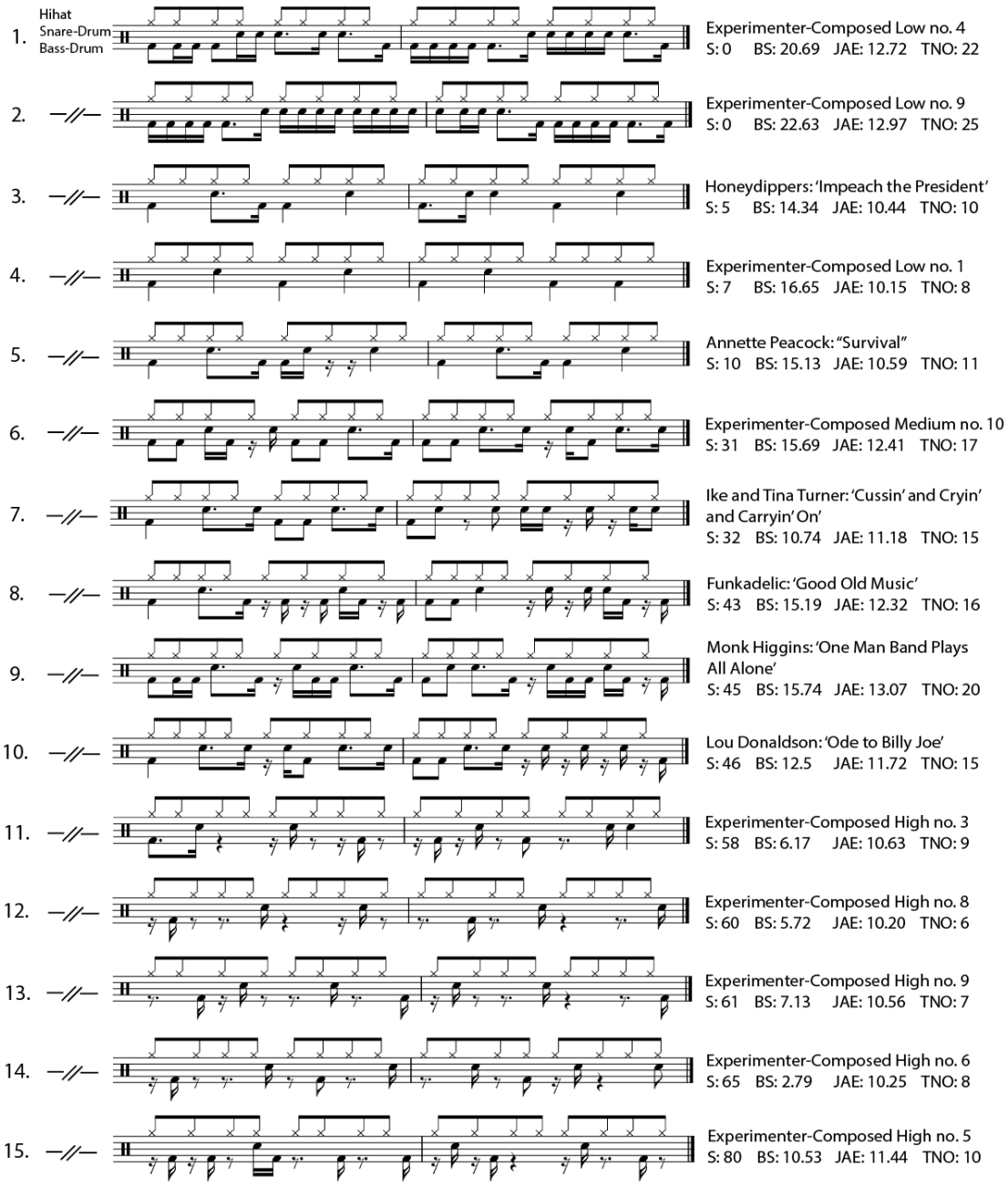


Notes. Notational transcripts and audio descriptor values of drum-breaks no. 31–45 used in the web-based survey (Chapter 5). S = Syncopation degree. BS = Beat salience degree. JAE = Joint audio entropy. Recordings provided on accompanying cd.



Notes. Notational transcripts and audio descriptor values of drum-breaks no. 46–50 used in the web-based survey (Chapter 5). S = Syncopation degree. BS = Beat salience degree. JAE = Joint audio entropy. Recordings provided on accompanying cd.

APPENDIX FIVE



Average values for 3-level categories:

Low (no. 1 - 5):	S: 4.40	BS: 17.89	JAE: 11.37	TNO: 15.20
Medium (no. 6 - 10):	S: 39.40	BS: 13.97	JAE: 12.14	TNO: 16.60
High (no. 11 - 15):	S: 64.80	BS: 6.47	JAE: 10.62	TNO: 8.00

Notes. Notational transcripts of the subset of 15 drum-breaks used in the fMRI (Chapter Six) and motion-capture (Chapter Seven) studies and audio descriptor values. S = Syncopation degree. BS = Beat salience degree. JAE = Joint audio entropy. TNO = Total number of onsets (excluding hihat). Recordings provided on accompanying cd.

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