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# "When do we get into the cultural rhythm?" A study on the effects of music-cultural perceptual narrowing

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“*Dancin in the moonlight*
*Everybody’s feelin’ warm and bright*
*It’s such a fine and natural sight*
*Everybody’s dancin in the moonlight.”*

“Dancing In the Moonlight”, King Harvest

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# *Abstract*

Rhythmic abilities are a fundamental aspect of daily life. Rhythm offers a predictable sequence of time intervals and accents that individuals can synchronize their actions to, enabling one to learn a language, communicate with others, move from one place to another, and synchronize movements to music. Syncing body movements with music, whether through dance or merely an individual response to music, is a common human behavior (Patel et al., 2005). But synchronization, though seemingly effortless, requires the complex integration of perceptual and sensorimotor skills. In moving to music, a beat must first be extracted and then a rhythmic motor response is integrated into that metrical framework (Ilari, 2014). But all over the world, metrical and rhythmic structures differ (Kalender et al., 2013). Hence, an individual's perception and processing of rhythm are shaped by the unique rhythmic characteristics of the musical culture in which they are deeply ingrained.

Studies have shown that individuals of various ages and cultural backgrounds experience a phenomenon known as music-cultural perceptual narrowing (e.g., Lynch et al., 1990; Lynch & Eilers, 1992; Hannon & Trehub, 2005a,b; Hannon & Trainor, 2007). Individuals initially exhibit sensitivity to a diverse range of perceptual structures that narrow down through exposure to the specific characteristics of their musical culture, thus leading to reduced sensitivity to less conventional structures. This study explores the effect of this phenomenon on movement-to-music synchronization, putting to question whether (i) culture-specific perceptual narrowing influences how infants spontaneously move in response to music samples with meters that are either present in their day-to-day experiences with music or absent from it, and whether these responses are (ii) modulated by daily exposure to, i.e. training with, a specific rhythmic pattern, which was either native to the infants' culture or non-native.

Italian infants aged 6 to 24 months and their parents, who were mainly exposed to music

with isochronous simple meters, were presented with songs of both simple (4/4) and complex (7/8) meters and their motor behavior as a response to these songs were analyzed. Subsequently, they were invited to participate in a month-long musical training to either a song of 4/4 or 7/8 meter. They were then asked to return to the same experimental setting and tasked to do the same thing as the first experimental session.

Preliminary analysis of infants' motor behavior during auditory stimuli exposure suggests individual differences in motor responses, potential changes in correlations between arm and leg movements, and consistent high levels of synchronization.

This thesis will first review existing literature on musicality, music processing, music-cultural perceptual narrowing, and sensorimotor synchronization (Chapter 1), then detail the research methods and materials (Chapter 2). Preliminary results will be presented (Chapter 3), and the theoretical  and educational implications of these findings for our understanding of music-motor synchrony and future research directions will be detailed (Chapter 4).

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# Introduction

Interest in music and its connection to development has significantly grown in recent years. Its use as a pedagogical tool, the enhancement of cognitive and developmental domains related to music exposure, and a variety of other applications have been topics of great interest in the field of developmental psychology (e.g., Tierney & Kraus, 2013; Khalil et al., 2019; Franco et al., 2021). Among all musical aspects of interest, rhythmic abilities warrant particular attention because they may underpin the acquisition of language, communication skills, social interaction, and, most evident of all, the human capacity to synchronize movements with music. Rhythm provides a predictable pattern of time intervals and accents to which individuals can synchronize their actions, whether in music, dance, or everyday activities.

However, though this synchronization can appear natural and effortless, it requires the complex integration of perceptual and sensorimotor skills. More specifically, synchronizing movements with music implies the ability to infer an underlying musical beat and integrate a rhythmic motor response into that metrical framework (Ilari, 2014).

Metrical structures in music are perceptually extracted from the repetition of weak (W) (i.e., shorter and/or softer) and strong (S) (i.e., longer and/or louder) beats. Interestingly, the general population may be divided into weak and strong beat perceivers, and this difference may be due to differing strategies used in perceiving beats (Fiveash et al., 2022).

Additionally, all over the world, musical cultures differ in their metrical and rhythmic patterns (Kalender et al., 2013). For instance, while Western music is mainly characterized by isochronous simple meters (i.e., duple 2/4, triple 3/4, and quadruple 4/4 meters), other kinds of music, such as those of the Balkans, India, Turkey, and Africa, present many non-isochronous complex meters (e.g., 5/8, 7/8, 9/8, etc.). Thus, the perception and processing of rhythm are also influenced by the distinct rhythmic features of the musical culture in which an individual is immersed.

Several experimental studies have demonstrated that participants of different ages and cultures undergo a process of music-cultural perceptual narrowing - they are initially sensitive to a wide variety of perceptual organizations that narrow down through exposure to the specific forms of their musical culture at the detriment of sensitivity to less common metric patterns (e.g., Lynch et al., 1990; Lynch & Eilers, 1992; Hannon & Trehub, 2005a,b).

The integration, then, of a rhythmic motor response into that cultural metrical framework enables movement-to-music synchronization. Like with beat perception, there are two qualitatively distinct groups: high and low synchronizers. This distinction was attributed to differences found between the two groups in behavior, neurophysiology, and anatomical connectivity (Assaneo et al., 2019).

Synchronization has been observed to be robust at around the age of 3 (e.g., Provasi & Bobin-Bègue, 2003; Kirschner & Tomasello, 2009 ). However, recent evidence suggests that even very young infants respond to music with different motor behavior that, although not yet fully mature, appear to underpin the ability to synchronize with music (e.g., Zentner & Eerola, 2007; Fujii, et al., 2014). Although at present, there is still little evidence regarding the earliest age at which infants start synchronizing to musical beats. Even more importantly, questions of whether culture-specific exposure to music influences their movement-to-sound responses and the manner in which it possibly does are still little explored.

To address these issues, the general objective of this project is to provide new experimental evidence on the effect of music-cultural perceptual narrowing on movement-to-music synchronization. More specifically, we aim to explore whether (i) culture-specific perceptual narrowing influences how infants spontaneously move in response to music samples with meters that are either present in their day-to-day experiences with music or absent from it and whether these responses are (ii) correlated to their age, (iii) modulated by daily exposure to, i.e., training with, a specific rhythmic pattern, which was either native to the infants' culture or non-native and (iv) correlated with the synchronization abilities of infants' caregivers in the same tasks.

To answer these questions, we performed an experimental study with infants from 6 to 24 months and their parents. Parents and infants were Italian and thus exposed mainly to music with isochronous simple meters such as duple or quadruple meter. During Session 1, spontaneous motor-rhythmic behavior was recorded with accelerometers while participants listened to songs of both simple (4/4) and complex (7/8) meters. Young participants were comfortably placed in a modified Jolly Jumper®, which allowed us to level out, at least to some extent, differences in motor development throughout the infant group. After infant testing, caregivers' synchronization ability was also assessed by instructing them to clap along to the same musical stimuli as those used with infants while their movements were recorded using accelerometers.

Subsequently, families were invited to partake in a month-long musical training at home for the purpose of examining the impact of exposure to songs of specific meter (4/4 or 7/4 songs) on both adults' and infants' movement-to-music synchronization ability. After this training, participants were re-invited to the laboratory (Session 2) and tested with stimuli and procedures identical to Session 1.

The examination of the infants' pure motor behavior while exposed to the musical stimuli served as the starting point for the data analysis. We explored possible individual differences in the amount of movement and whether they changed between sessions, the correlation between motor behavior and age, and the degree of synchronization between limbs. For this purpose, this work presents the results of this preliminary analysis. Data collection is still ongoing.

We assessed the limbs' overall movement by estimating the level of fluctuations and performing a standard deviation analysis, determined the statistical relationship between the right ankle and right wrist time series through a correlation analysis, and examined the degree to which the two limbs synchronize through a mean phase coherence coefficient analysis. The preliminary results we obtained suggest that there are differences in motor behavior across infants and that there may be a decrease in correlations between the arm and leg movements between the two sessions. By contrast, high levels of synchronization were observed for all infants in both sessions.

This thesis is organized as follows. Chapter 1 will review the existing literature on musicality, music processing, music-cultural perceptual narrowing, and sensorimotor synchronization, as well as the benefits of music training to motivate the study's aims and objectives. Subsequently, Chapter 2 details the methods and materials used. Chapter 3 presents the results gathered so far. To conclude, Chapter 4 will discuss the theoretical and educational implications of the preliminary results for our understanding of music-motor synchrony and outline future directions.

# *Chapter 1*
# *Theoretical Background*

## 1.1. Music as a universal feature of mankind

Music, though notoriously difficult to define concretely, is most simply explained by Henry et al. (2019: p. 1) as "sound and silence in time." It has often been assumed to be a human universal. Indeed, Mehr and colleagues (2019) conducted a systematic analysis of the features of vocal music found worldwide, and their ethnographic corpus showed that music exists in every society and is produced worldwide in various behavioral contexts. These contexts range from dance, play, work, and celebration, to lullabies, entertainment, and mourning.

Complicating matters further, the structure, cultural interpretation, and place of music vary in different cultures around the world. In fact, the term *music* is not present in all languages. Most North American Indian and some African languages, like the Basonhye of the Democratic Republic of the Congo or the Tiv of Nigeria have names for distinct genres but do not have a nomenclature that encompasses all the musical genres (Trehub et al., 2015).

As a system of communication, music-making is passed on through ongoing transgenerational transmission. It is shared between individuals and between societies and is often performed in front of an audience or at least with an audience in mind (Trehub et al., 2015). Another commonality of music across cultures is the incorporation of non-musical elements, which can involve dance and speech.

Some studies have analyzed music across the globe and distinguished general and specific features across different musical systems. In a study by Savage et al. (2015), a diverse collection of 304 music recordings was examined, utilizing Brown & Jordania's (2013) 70-item list of statistical universals that encapsulated cross-cultural trends in music organization and acoustic classification schemes. They identified 18 statistical universals, such as the presence of a regular pulse with subdivisions, metrical hierarchies, and a limited set of rhythmic patterns. Notably, the study highlighted the significance of simple, repetitive rhythms as a key mechanism for entrainment, facilitating synchronization in singing, dancing, and playing. Through musicality, an individual is able to tap into these rhythms, which are the fundamental pulse of music, and engage with music as a listener or performer.

## 1.2. Music & Musicality

Recent evolutionary proposals distinguish the social, cognitive, and biological relevance of music and their respective functions in human evolution. Within this view, *musicality* is defined as "a natural, spontaneously developing set of traits based on and constrained by our cognitive and biological system" (Honing et al., 2015; p. 2). Music, by contrast, is a social and cultural construct based on that musicality. It serves as a designation for the various cultural products that are created by and for music-making like dances, songs, and instruments. Consequently, musicality is a universal that has biological foundations, whereas music is extremely diverse, dependent on specific cultures, and learned through experience (Kim & Schachner, 2023).

### *1.2.1 The development of musicality*

The biological origins of musicality seem to be evident even prior to birth. From the third trimester of gestation, bone conduction allows the perception of rhythmic signals in the intrauterine environment (Sohmer et al., 2001), and between 25-29 weeks of gestational age, the auditory system becomes active (Graven & Brown, 2008) and its functionality begins to be shaped by the auditory environment in utero (Ullal-Gupta et al., 2013). These multisensory experiences might be the foundation of the musical experience and can constitute the skeleton of the developmental trajectory of musicality and rhythmic abilities after birth.

Supporting this theoretical view, compelling developmental studies offer evidence on the impact of prenatal exposure on later postnatal perception of music, therefore pointing towards a biological predisposition for experiencing music.

Provasi and colleagues (2014) show that newborns are capable of a primitive form of sensorimotor synchronization. They modify their behaviors, such as stepping (in the air) and crying in response to auditory or audio-visual stimulation. Further evidence is provided by Kisilevsky et al. (2004) who demonstrated that higher-order auditory perception initiates even before birth. By measuring movements and heart rate, they showed that there is a maturation of music perception over the last trimester of pregnancy. Body movements of near-term fetuses appear to increase, and there is cardiac response (that differs with gestational age) when presented with music stimuli (Brahms' lullaby, in this case).

After birth, newborns exposed to a particular tune during pregnancy displayed changes in movements, heart rate, and behavior when presented with the same tune after birth (Hepper, 1991). These findings were attributed to prenatal exposure to the specific tune alone and not to any postnatal experience or genetic factors. Relevantly, Masataka (1999) found that 2-day-old-hearing infants of deaf parents prefer infant-directed singing rather than singing directed to adults, showing an intuitive preference for prosodic exaggeration. Ullal-Gupta et al. (2013) also suggested that the auditory environment in the womb, characterized by the regular maternal heartbeat and filtered linguistic and musical input, potentially shapes the perception and preference for musical patterns during infancy and impacts subsequent development.

Furthermore, Trehub (2001) proposed that receptive musical skills appear early in development, well before they could be useful in producing music. As a result, she suggested that these skills can be considered predispositions. Infants possess a natural inclination towards consonant patterns, encompassing melodic, harmonic, and metric rhythms. They are predisposed to pay attention to the melodic contour and rhythmic patterns found in sequences of sounds, whether musical or spoken.

Postnatally, the perception of periodic patterns in music is evident at a very early stage of development. 2-month-olds were found by Drake & Baruch (1997) to be capable of differentiating isochronous sequences with marginally different tempi. Hannon & Johnson (2005) found that 7-month-old infants habituated to simple rhythmic sequences of duple or triple meter subsequently showed a novelty preference when provided with rhythms that violate the meter that was established prior, even if the intervals and grouping structures were similar or identical across rhythms. Another study by Winkler et al. (2009) found that newborns can detect the beat in music as they show larger mismatch negativity event-related potentials to omissions that happen on the downbeat rather than to those that occur on the upbeat. These studies suggest that beat perception needs little prior experience or learning.

Relative pitch, tonal encoding of pitch, perception of beats, and metrical encoding of rhythm are proposed by Honing et al. (2015) to be the fundamental elements of musicality. These studies demonstrate that from very early on, these capabilities, though nascent, are present.

## 1.3. The building blocks of music

Music is made up of multiple elements that combine to form levels of pitch and temporal structure in accordance with set rules to form a multifaceted and intricate structure. The capacity to perceive, interpret, and convey the intricate workings of music serves as the bridge that unites its various components. Among the commonly described elements of music, we find rhythm and the related terms tempo and beat.

| | |
|---|---|
| **Rhythm** | The arrangement of time in music, which is typically quantified in note durations such as quarter notes or eighth notes. Regardless of the speed at which a particular song is played, the rhythmic organization of the piece remains the same (Henry et al., 2018). |
| **Tempo** | "The rate at which musical events unfold over time" (Levitin et al., 2018, p. 53). It is often associated with the beat rate or BPM (beats per minute). |
| **Beat** | "A perceived pulse that marks equally spaced points in time" (Patel et al., 2005, p.226). |

**Table 1**. Definitions of Musical Terms

Within any song is a steady or regular pulsation and this is known as the beat. It is represented using a musical note, e.g., the quarter note ( ♩), to indicate the timing and length of the beat unit. Beat notation includes various notes and rests that divide the unit into smaller durations. For instance, an eighth note (♪) is half the duration of a quarter note, while a sixteenth note ( ♬) is a quarter of the duration of a quarter note. These beats can be stressed and unstressed, creating a temporal structure that serves as the rhythmic foundation of a musical composition and a consistent reference point for performers and listeners (Levitin et al., 2018). Beats are grouped together in a measure or bar, and the arrangement of beats forms the meter (Straus, 2012).

Meter can be commonly classified into three categories: simple, compound, and complex. The division of beats within each meter category determines its specific characteristics. For example, a time signature of 3/4 indicates that each measure has 3 quarter notes. Furthermore, as illustrated in Figure 1, the time signatures 4/4, 2/4, and 3/4 are referred to as simple meters as their beats are divisible into equal groups (quarter notes or eighth notes). In contrast, we have compound meters (e.g., 6/8, 9/8, 12/8) which are divisible into three parts. Time signatures that deviate from the conventional duple or triple meter (e.g., 5/8, 7/8, 9/8, or 11/8) are often referred to as complex, asymmetric, irregular, unusual, or unconventional (London, 2001) since they are not easily subdivided into equal beats. Taking the complex meter example from Figure 1, 5/8 is divided into 3 and 2 beats(eighth notes in this case) or 2 and 3 beats.

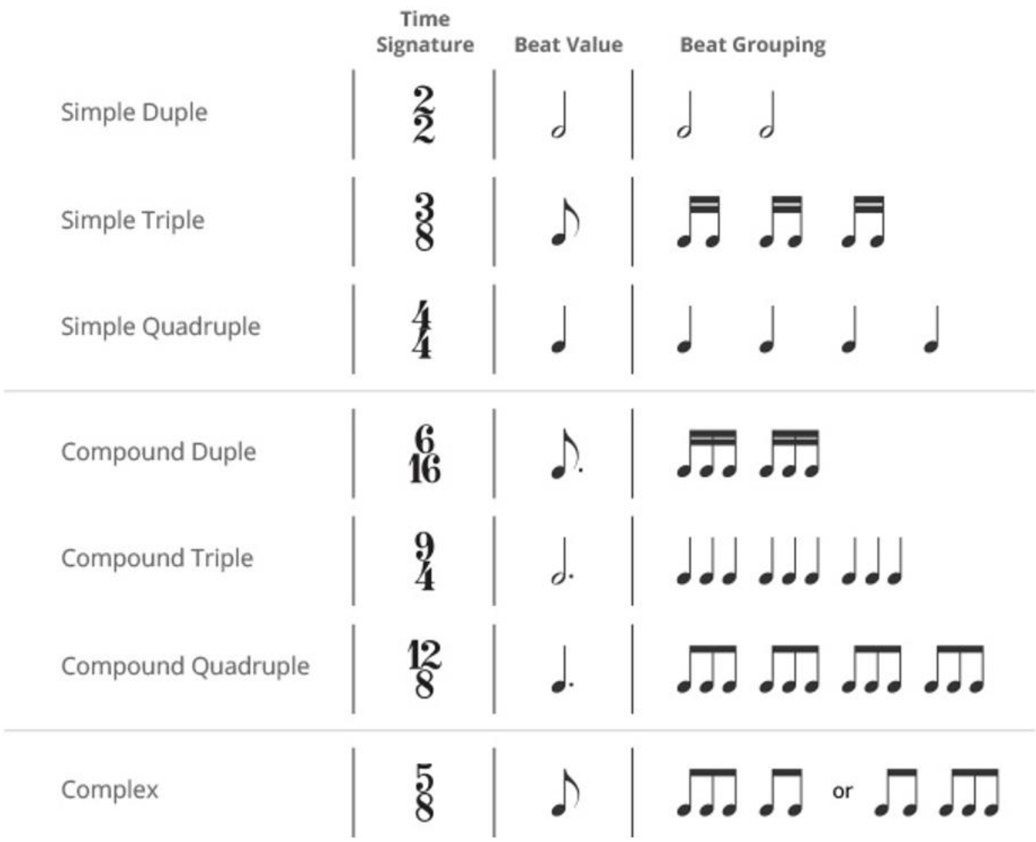


**Figure 1**. Meter classification. Adapted from "*Meter*" by Connect for Education, Inc. n.d. (https://dictionary.onmusic.org/appendix/topics/meters) Copyright 2015 by Connect for Education, Inc.

### 1.4. Cultural variation in musicality

Considering the ubiquity of music, most people develop a basic understanding of music through everyday exposure during their upbringing. Francès (1988) argues that musical knowledge can be implicit, i.e., it is mentally represented without individuals being fully aware of all the intricate rules of musical structure and is learned through experience with many examples. This implicit knowledge of music enables people to dance and move to a beat, recognize when something is off-key, remember and recreate familiar melodies and rhythms, and feel the emotions conveyed through music, regardless of whether they have received formal music training or not (Hannon & Trainor, 2007). Implicit learning, i.e., the capacity to learn without formal training, is what serves as the foundation for both children and adults to acquire musical knowledge and be musically enculturated.

Musical practice that is specific to any one culture emerges initially from the basic building blocks of music, such as pitch and duration, and the degree to which the relationships between these building blocks are deemed acceptable, desirable, or typical (Morrison & Demorest, 2009). An illustration of this is the global variety of metric structures. The 4/4 meter or time signature is often referred to as *common time* as it is used in much of Western music (Straus, 2012). However, in certain parts of the world such as Asia, Africa, and Eastern Europe, complex meters are often featured in the local music (Ka lender et al., 2013). Much of the music from these areas contains an underlying pulse of long and short durations that alternate in a 3:2 ratio, as opposed to a 2:1 or 3:1 ratio commonly found in Western music (Hannon & Trehub, 2005a).

Since musical systems vary immensely across the globe, sensitivity to one system depends greatly on experience with the specific system of exposure. Similar to language, just as how infants learn the language-specific phonemes, words, and syntactic rules of their native language, they also acquire the culture-specific scales, keys, harmonic and rhythmic structures of their music through extensive exposure (Lynch et al., 1990; Lynch & Eilers, 1992; Hannon & Trehub, 2005a,b; Hannon & Trainor, 2007; Soley & Hannon, 2010).

An illustration of this is the study on cross-cultural differences in meter perception conducted by Kalender and colleagues (2013). They found that adults who only listened to Western music, only noticed metrical changes in Turkish music when it had a simple meter. Whereas adults who had experience with both Western and Indian music (thus considered by Kalender and colleagues as bimusical) performed comparatively in detecting violations present in songs with a simple meter and songs with a complex meter. They found that bimusical individuals may have a metrical processing advantage that could be associated with implicit knowledge of two kinds of musical cultures, though the advantage was not found to be general. Moreover, incidental exposure to various meters can aid in the processing of unfamiliar metrical patterns in novel musical contexts.

## 1.5. Music-Cultural Perceptual Narrowing

Early in infancy, a general sensitivity to pitch and metric features is evident (Lynch et al., 1990; Hannon & Trehub, 2005a; Hannon & Trainor, 2007). The structures and features of musical systems that can be handled with ease are then pared down, through a process of *perceptual narrowing*. This is often characterized as a perceptual process that is experience-dependent, in which discrimination ability is maintained or even sharpened for stimuli that are frequently encountered but lost or dampened for stimuli not found in the environment (Flom, 2014). Perceptual narrowing is a general perceptual phenomenon applying to several sensory modalities and perceptual abilities. This is illustrated by infants' decreased sensitivity to non-native speech sounds, unfamiliar facial speech gestures, and the features of unfamiliar faces towards the second half of the first year of life (Maurer & Werker, 2013). There is then a resultant increase in specificity or sensitivity to those stimuli that are frequently encountered in the environment, a "narrowing" of an initial broad sensitivity when familiar, "native" stimuli are encountered.

Given the wide array of musical structures and systems present around the world, unique scales, classifications, and rules emerge within these varied musical systems. This, in turn, shapes the pitch and rhythmic structures, giving rise to music and musical experiences that are deeply rooted in specific cultures. Early in development, there is a broad, universal perceptual sensitivity to spectral and temporal structures, but after months of experiences with the infants' musical culture, a system-specific processing emerges because of "enculturation"

(Hannon & Trainor, 2007), to which we will refer in this work as "music-cultural perceptual narrowing". In other words, infants lose the ability to discern musical features that are not native to their environment and become more attuned to those features they are frequently exposed to (Morisson & Demorest, 2009).

Lynch et al. (1990) illustrated this process in a study where Western adults with varying degrees of musical skill and 6-month-old Western infants were tested to investigate whether they detected mistunings in melodies based on native Western major, native Western minor, and non-native Javanese pelog scales. Results showed that the infants were similarly capable of discerning mistunings in both native and non-native scales, but adults performed better with native than non-native scales. Thus, their findings imply that infants possess a general ability to perceive different scales at birth, and their subsequent cultural experiences play a role in shaping their perception of music. It was then found in a later study by Lynch & Eilers (1992) that by the age of 12 months, Western infants were better at discerning mistuned notes in melodies from Western scales than from Javanese scales, just like adults.

Learning culture-specific rhythm structure similarly shows perceptual narrowing in infancy. Differences in meter perception were demonstrated by Hannon & Trehub (2005b) in their study involving infants from North America. They found that they respond equally to violations of Western and Balkan rhythms at 6 months of age but fail at detecting violations in Balkan music by 12 months of age. There appears to be a perceptual narrowing in Western infants' ability to differentiate non-native, non-isochronous rhythmic patterns that occurs by the end of the first year. This is because Western listeners are accustomed to the isochronous meters of Western music, making it difficult for Western adults and 12-month-old infants to differentiate non-isochronous rhythmic patterns commonly featured in non-native Balkan music.

However, Western infants' sensitivity towards changes in culturally typical isochronous patterns does not change as shown in another study (Hannon & Trehub, 2005a). They exposed adult and infant listeners to folk melodies with varying metrical structures (simple versus complex meters) then tested them on modifications that either maintained or disrupted the initial metrical structure. It was found that North American infants aged 6-7 months could differentiate between changes that disrupted or maintained the metrical structure of musical patterns. This ability was on par with Bulgarian and Macedonian adults who had familiarity with both simple and complex meter in their own music. Interestingly, North American adults could only demonstrate this distinction in excerpts with simple meter. These findings (Hannon & Trehub, 2005a,b) imply that human listeners do begin life with flexible, broad-based processing of metrical structure, but this changes after months of exposure to the dominant metrical structure of their environment.

Relevantly, Hannon & Trehub (2005b) tested whether exposure would reverse the decline in the ability to perceive variations in non-native meters. They found that after having infants of 11-12 months of age that had no prior knowledge of Balkan music listen to recordings of non-isochronous dance music from Macedonia, Bulgaria, or Bosnia every day for two weeks, this brief at-home exposure enabled them to differentiate rhythmic patterns in non-native music. With the same exposure, adults did not imbibe the non-native structures as readily as infants did (Hannon & Trehub, 2005b).

The existence of a sensitivity window and perceptual narrowing of rhythmic structures is of direct relevance to this study. Since Hannon & Trehub (2005b) found that infants can maintain sensitivity to non-native rhythms after a brief daily exposure period, in this work we further explored whether daily experience with a non-native, complex meter influenced infants' rhythmic perception. In our study infants were Italian (i.e., natively exposed to simple meter music), they were aged between 6-24 months, i.e., a broad age range spanning early universal perception as well as the offset of the sensitive window for perceptual narrowing, and importantly, we tested not only perception, but rather the perception-motor link, i.e. the ability to synchronize movements to musical rhythm.

### 1.6. Rhythm processing & synchronization

Central to engagement with music is the processing of rhythm, as it provides a sense of time and therefore a consistent reference point for performers and listeners to entrain to. The way rhythm is processed, be it for music or for any other cognitive domain, involves several components (Kotz et al., 2018).

Periodicity, or the repetition or recurrence at regular intervals, is essential to rhythmicity. *Motor periodicity*, then, encompasses the quasi-periodic performance of repetitive actions and is found extensively in biology. This phenomenon is observed in various rhythmic activities such as walking, breathing, running, chewing, and numerous others. *Beat extraction* entails the perceptual process of deducing a pulse from a repetitive stimulus, which is often acoustic. Furthermore, most humans can synchronize their motor output to the perceived beat at will, a phenomenon which is termed by Kotz et al. as *audiomotor entrainment* (2018). Finally, *meter,* is defined by Kotz as an element that requires the organization of individual events or beats into a hierarchical structure, where certain events are emphasized or accented as "strong," while others are notated as "weak."

Moving to music or playing an instrument requires motor periodicity, beat extraction, and auditory-motor entrainment. Beat extraction is not an easy task as an isochronous beat must be inferred from a stimulus that typically contains events that are also not “on the beat” or syncopated (where strong beats become weak and vice versa). To perform this extraction, various cognitive processes come into play, including the processing of time and duration, as well as more general cognitive functions such as working memory and attention (Fiveash et al., 2022).

To effectively capture distinct underlying rhythmic abilities, Fiveash and colleagues

(2022) conducted a study putting together nine different kinds of rhythmic tasks. They found clear distinctions between perception compared to production tasks and between beat-based and sequence memory-based rhythm perception tasks. The authors proposed that accurate beat perception does not appear to be necessary for accurate synchronization and vice versa, suggesting that various rhythmic tasks may engage different rhythmic abilities within the general population.

In tasks involving beat perception, their participants were consequently divided into strong beat perceivers and weak beat perceivers. Fiveash and colleagues (2022) speculated that the difference between the two groups may be due to different strategies employed in perceiving beats. Strong beat perceivers were able  to make use of implicit beat processing mechanisms, which then resulted in improved performance, whereas weak beat perceivers made use of more explicit strategies like interval duration judgments. Furthermore, their analyses found that it is possible for the ability to tap along to a rhythm to be impaired while beat perception is spared, possibly due to a disruption in auditory-motor mapping.

Relevantly, Assaneo et al (2019) found, through a simple behavioral task that explored the spontaneous synchronization of speech (SSS test) and various related tasks, that there are two qualitatively distinct groups within the general population: high and low synchronizers. There were many differences found between the two groups in behavior, in neurophysiology, and in anatomical connectivity. Behaviorally, the high synchronizers exhibited high stability in adjusting their syllable production to that of the perceived syllables and adapted their speech output to multiple changes in the tempo of perceived speech. In their neurophysiology, they showed better brain-to-stimulus synchronization in left inferior and middle frontal gyri. While structurally, they exhibited enhanced microstructural properties in the white matter around the auditory cortex and significantly greater left lateralization. In comparison, low synchronizers were impervious to the external rhythm, thus showing no interaction between produced and perceived speech rhythms. The behavioral pattern of both groups correlated with brain features in the speech brain network, which includes production (inferior frontal gyrus), perception (early auditory cortex), and connecting white matter. More specifically, the enhanced microstructural properties in the white matter that connects auditory and motor regions could improve the synchronization between temporal and frontal areas, resulting in the improved performance of high synchronizers in Assaneo et al.'s study.

Movement also plays a key role in the perception of rhythm during development. Presenting a rhythmic pattern in two modalities, auditory and motor, as opposed to one, enhances the infant's ability to recognize and potentially respond in synchrony with the pattern. This was demonstrated by Philips-Silver & Trainor (2005) where they exposed infants to an ambiguous rhythm and bounced some of them every other beat and others every third beat. They found that babies recognized the binary or the ternary rhythm as familiar as a function of their bouncing.

It is not only in processing rhythm that movement comes into play. People often dance when engaging with music. While listening, individuals form temporal expectations by relying on the structural consistencies associated with the musical beat, which represents a recurring pulse. As a result of these regularities, people often feel compelled to engage in movements that synchronize with the rhythmic patterns of the music (van der Steen & Keller, 2013). Such behavior occurs spontaneously and is evident throughout the world (Tranchant et al., 2016). The coordination of rhythmic motion in response to an external rhythm is referred to as sensorimotor synchronization (SMS), and this encompasses activities such as clapping along to a song, tapping along to a metronome, or even engaging in musical ensemble performances like dancing or playing in a band (Repp & Su, 2013).

However, the quality of SMS can vary between individuals. As highlighted by Mills et al. (2015), research conducted on SMS has revealed that the accuracy and precision of synchronization are influenced by temporal anticipation and adaptation, and it has been observed that people vary in their capacity to both anticipate and adapt.

Adaptive timing is what allows a person to maintain synchrony even when there are intentional or unintentional timing deviations, enabling one to respond to the deviations with adjustments of one's subsequent actions (Mills et al., 2015). Governing adaptive timing are error correction mechanisms that let internal timekeepers remain coupled with a sequence of pacing events.

Two distinct error correction mechanisms, namely *phase correction* and *period correction*, have been posited as independent processes central to the reduction of *asynchrony* (Repp & Su, 2013). According to Repp and Su, asynchrony refers to the disparity between the timing of a tap (the moment when the finger contacts a solid surface) and the timing of the corresponding event in the external rhythm. Phase correction is an automatic process that continuously corrects timing inconsistencies by adjusting the timing of each movement based on the preceding asynchrony. This correction mechanism maintains the period (the time interval between successive events of the internal timekeeper) unchanged (Mills et al., 2015). By contrast, period correction involves a deliberate modification of the internal timekeeper, leading to a shift in movement tempo. This intentional error correction requires the conscious perception of a change in the tempo of the pacing sequence.

*Temporal anticipation* is what allows an individual to predict the timing of events, such as the onset of a beat or other people's body movements, along with the resulting consequences of these events on the surrounding environment. It has been proposed that this anticipation is guided by action simulation processes that are influenced by internal models. These internal models enable the pre-execution simulation of a movement, along with the potential outcome associated with that movement, prior to its actual execution (Mills et al., 2015). The authors further explain that this process requires the prior exposure of the central nervous system to the relationships between outgoing neural motor signals originating from the motor regions of the brain, incoming sensory information, and the resultant effects on both the body and the environment. Hence, it is these internal models that facilitate anticipatory error correction by adjusting planned movements for the correction of potential errors before they happen.

The mechanisms that explain the functioning of synchronization collectively fall within the realm of *entrainment* (Jones, 2018). Entrainment, as defined by Clayton (2012, p. 49) is "the process by which independent rhythmical systems interact with each other", where the systems are either aligned or one of them precedes the other by a fixed amount of time (Jones, 2018). The various types of independent rhythmic systems can possess a shared characteristic of oscillatory activity, typically displaying periodic or quasi-periodic nature. Additionally, these systems must be capable of maintaining their rhythm regardless of whether they synchronize with other rhythmic systems.

Entrainment is not confined to human behavior alone; it is a concept that encompasses a broad range of phenomena observed in various temporal and spatial scales, spanning biological and mechanical systems. It serves as an abstraction that captures a common process shared among these diverse phenomena. Pertinent to this process is the notion of *phase*, which describes where an individual rhythm or oscillation is in its cycle at any given moment (Clayton, 2012). The phase is often measured in degrees or radians and helps determine the alignment or synchronization of different rhythmic elements within a system. When two such events happen simultaneously, they are considered in phase (with a relative phase of 0°). If one event occurs exactly in the middle between the occurrences of the other event, they are said to be in anti-phase (with a relative phase of 180°), and so on.

Evidence supporting entrainment can be observed through the establishment of a stable relative phase relationship, and the subsequent restoration of this stability following a disturbance. Thus, when two rhythms are entrained, their relationship tends to stabilize and exhibit a robust nature that enables it to assert itself even in the face of disruptions - like if two pendulums swing in synchrony and one pendulum were to be stopped from swinging for a brief time, both would resynchronize.

### 1.7. Movement-to-Music synchronization

Synchronization is often studied in the context of music. In fact, music is believed to act as a stimulus that drives the internal neural activity and physical movements of the body, particularly those related to the sensorimotor system, in response to external musical cues (Levitin, et al., 2018). Adult humans can do this with nearly perfect matching to the tempo when presented with regular stimuli, but this is an ability that shows a protracted development: most children are unable to accurately synchronize to a beat until the later preschool years and they typically don't exhibit adult-level accuracy until the age of 10 or beyond (Drake et al., 2000; Provasi & Bobin-Bègue, 2003; McAuley et al., 2006).

However, early and spontaneous movements seem to occur without any prompting (Levitin et al., 2018) and there is recent evidence indicating that even very young infants can respond to music with distinct motor behavior that, though rudimentary, seems to underlie their potential to synchronize with the music. Zentner & Eerola (2010) found that 5- to 24-month-old infants do move their bodies rhythmically as a response to music, and their behavior is indicative of a predisposition for rhythmic movement when exposed to music and other metrically regular sounds.

Interestingly, though some 3-4-month-old infants moved their limbs spontaneously to music, most instead modulated their vocalizations rather than the movements (Fujii et al., 2014). The vocalizations were interpreted to be a possible precursor of singing, while the lack of spontaneous movement was theorized to be a result of music tapping into the perceptual-attentional system in the cortex, hence not triggering limb movement. Whereas the significant increases in rhythmic limb movements around the musical tempo at the individual level were interpreted by Fujii et al. as a precursor for movement-to-music synchronization.

In line with assessing infants' rhythmic behavior, de l'Etoile and colleagues (2020) conducted a study to determine the amount, tempo, and regularity of movement in infants aged 6-10 months while exposed to silence, an irregular rhythmic cue, or a regular one with tempo changes. They observed that infants tended to make spontaneous movements equally in silence as to music and they exhibited most movement in response to the rhythmic cue at 132 BPM.

In a more recent study assessing the origins of dance in infancy, Kim & Schachner (2023) surveyed 278 parents of infants aged 0-24 months on their child's current and earliest dance behavior (movements, often repetitive, in response to music that parents recognized as dancing) and motor development. Results showed that 90% of the infants displayed behavior that was recognizable as dance by 12.8 months of age, and the average age by which parents could recall their infants first instance of dancing was 9.4 months, with a standard deviation of 3.8 months, and a range of .9 to 20 months. Overall, Kim & Schachner's data show that many of the infants dance by 6 months of age, and most within the first year of life. However, it is important to note that while they found that movement to music indeed emerges early in infancy, these behaviors occurred in the home environment rather than a lab setting. Still, this study provides evidence that infants display behaviors associated with movement-to-music synchronization early in development.

Additionally, caregivers play a significant role in supporting the development of this ability by providing the infant with a foundation for their learning. Caregivers provide infants with stimuli that are temporally structured and come in various forms, such as speech, music, facial expressions, and touch. As synchronization involves the ability to anticipate when the next event will occur, the stimuli caregivers provide help lay the groundwork for the infant's entrainment abilities (Trainor & Hannon, 2013). Moreover, Kim & Schachner (2023) found that all but one of their surveyed parents reported infant-directed dance, emphasizing how common this behavior is. This, in turn, underscores the behavior as a major component of infant-parent musical interaction.

Taking into consideration that indications of musicality and perceptual skills involving music are universal and arise early in development, and evidence that infants display precursors of movement-to-music synchronization, the origins of exact and adult-like synchronization despite the immaturity of motor skill is of direct interest to the current study.

To understand infants' capacities to synchronize to external auditory stimuli, establishing their natural rate of rhythmic movement is essential. Rocha et al. (2021) examined infants' capacity to generate motor rhythms and synchronize them with external acoustic rhythms, including speech (syllable, nursery rhyme) and non-speech (drumbeat) rhythms. Their findings indicated that infants' rhythmic movement grows faster as evidenced by their *spontaneous motor tempo* (SMT), i.e., the natural rhythm or pace at which an individual does a regular, repeated movement, speeding up as they age. Their movement also grows more regular throughout development, and by 11-months, infants could move away from their SMT to better synchronize with the slower rate of nursery rhymes. As a result, the authors posited that "change from SMT to slow rhythms may provide a critical index of early sensorimotor synchronization ability (Rocha et al., 2021, p. 20)."

There is also evidence that infants are capable of *tempo-flexibility*, i.e., moving faster to faster auditory tempi and slower to slower tempi, an ability that precedes sensorimotor synchronization (Zentner & Eerola, 2010). The same authors found in their study that infants are capable of this ability, though they propose that this may have been modulated by pulse clarity. In line with this, Rocha & Mareschal (2017) conducted a study in which they tasked 10-month and 18-month-old infants, and adults with ringing a bell in synchrony with various songs of increasingly fast tempos. They found that 10-month-olds were unable to adapt their ringing to the music tempo and they were less accurate when the music was slower than their hypothesized SMT of around 400ms. On the other hand, though the 18-month-old infants were not much more accurate than the younger participants, they performed equally accurately across all presented songs, indicating that they were more capable of moving away from their natural rate of movement. However, while the older infants were closer to synchronizing to the presented songs than the younger infants, they were still not able to synchronize their movement at an adult level. Nevertheless, this change in the quality of the infants' performance across ages demonstrates a progression in their ability to synchronize their movements to music.

In general, sophisticated rhythm perception emerges during early infancy and continues to develop gradually, indicating an inherent predisposition that is further influenced by experience and continuous exposure to musical culture (de l'Etoile et al, 2020). In light of this, researchers have found positive effects of rhythm/music training on infants' music behaviors. Kindermusik training on infants of 6.7 to 8.2 months of age resulted in longer looking time towards a stimulus, demonstrating more engagement with the rhythmic sequences, presumably as a result of music exposure (Gerry et al., 2009). In a similar study by Gerry et al. (2012), they found that engaging in active musical participation from the age of 6 months onwards hastened the acquisition of culture-specific knowledge related to Western tonality compared to a similar duration of passive music exposure.

By contrast, de l'Etoile and colleagues (2020) implemented a week-long music training program on infants, with the goal of influencing infant movement parameters, but found no significant change in the infants' behaviors. As a result, they proposed that a week-long training program was insufficient and suggested a longer period of training to adequately make an impact. In line with this, a month-long musical training will be implemented in this work.

## 1.8. Musical transfer

Implementing musical training may lead to immediate benefits related to music behavior but there is also evidence for benefits outside of the music domain. While music knowledge is implicit to a certain degree, explicit instruction has been demonstrated to not only improve a person's knowledge and understanding of music but may also have a significant impact on the development of fundamental behaviors and neural processes across various domains and forms of sensory experiences (Hannon & Trainor, 2007). Since playing an instrument is a complicated activity that requires the integration of several higher-order cognitive processes, perceptual capacities, and sensorimotor skills, multiple studies have sought to determine the possible benefits of music training outside the realm of music.

In 2022, a meta-analysis was conducted by Neves et al., involving 62 longitudinal studies, with a total sample size of 3,928 participants. This review analyzed the neurobehavioral effects of music training (both instrumental and non-instrumental) on auditory and linguistic processing and found that regardless of whether the music training was instrumental or non-instrumental, there was indeed a positive effect. Furthermore, their extensive review of longitudinal data on music training and language abilities, covering studies encompassing all age groups, found that benefits are significant and similar across a range of domains such as speech discrimination, phonological awareness, verbal fluency, and general linguistic skills (Neves et al., 2022).

They also conducted a systematic synthesis of brain studies that mostly made use of EEG and to a lesser extent MRI and found convergent evidence with the behavioral data. The EEG studies reveal that music training can shape cortical auditory processing, while MRI studies have demonstrated that it can alter the morphology, connectivity of the brain’s structure, intrinsic functional connectivity, and flexibility of auditory regions in the brain, as well as affect brain responses to auditory stimuli.

Additionally, as music and language have structural similarities, the benefits gained in music training may transfer to language processing. The repetitive, comprehensive, and demanding nature of music training and its capacity to be emotionally and socially engaging, elicits a heavy demand on neural circuits. Music training improves the ability to process sound in general, which includes an improved perception of language (Khalil et al., 2019).

The results of Neves et al.'s (2022) study imply that music training can lead to both near and far transfer, indicating potential benefits in both educational and clinical settings as an intervention and development tool.

### 1.9. Aims and objectives

In light of the above, this work aims at enriching the current literature addressing these four fundamental questions:

1. Do infants spontaneously display different rhythmic movements when listening to songs with different meters?
2. Is this rhythmic behavior a function of the infants’ age (between 6 and 24 months)?
3. Does their rhythmic behavior correlate with those of their caregivers'?
4. Does daily exposure to songs that have different meters influence infants’ and their caregivers’ rhythmic movements, and enable or enhance movement-to-music synchronization?

To address these questions, we explored music-cultural perceptual narrowing and its effects on movement-to-music synchronization to both simple and complex meters.

As many of the aforementioned studies focus on adults, older children, or infants younger than 6 months, our study aims to fill the gap in the literature by studying infants between 6 to 24 months of age. The wide range in age serves to take into account both the broad-based universal and the more culture-specific perceptual stages in auditory perception as well as infant motor development since it is shown by past studies that the development of sensorimotor synchronization is highly dependent on infant motor control and the growth of their limbs (Zentner & Eerola, 2010; Rocha & Mareschal, 2017; Rocha et al., 2021).

In pursuit of this objective, the current project aims to investigate whether infants naturally exhibit distinct rhythmic movements when exposed to songs of different meters. In line with Hannon & Trehub's (2005a,b) and Kalender et al.'s (2013) studies that demonstrated cross-cultural differences in meter perception, infants and their caregivers will be presented with auditory samples of both simple (4/4) and complex meters (7/8).

During a four-minute session (Session 1), infants were video-recorded while their spontaneous movements were captured using accelerometers placed on their right wrist and their right ankle. To ensure maximum freedom of movement, they were placed in a particular type of harness, a modified Jolly Jumper®, which allowed them to safely move freely and remain upright, even if they cannot yet sit or stand stably by themselves, thus accounting for the significant differences in gross motor development within the age range tested.

As caregivers play a key role in laying the foundation for the development of SMS by providing their children with stimuli that are temporally structured and come in many different forms (Trainor & Hannon, 2013) and because infants may inherit synchronization abilities from their parents, this study intends to assess whether there is a correlation between the synchronization abilities of caregivers and their infants. We thus also measured synchronization in caregivers. The accelerometers were placed on their right and left wrists, they were seated, and they were  asked to clap along to the music stimuli. The music stimuli will be the same as those used with the infants.

Furthermore, this study also seeks to explore whether regular exposure to songs of different meters influences rhythmic movements, potentially facilitating or enhancing movement-to-music synchronization in general or specifically in the previously unfamiliar complex meter. Taking cues from the research conducted by Gerry et al. (2009; 2012) and de l'Etoile et al. (2020), a month-long musical training session was implemented. To achieve this, families participating in Session 1 were invited to partake in the longitudinal follow-up of the study. Participants were randomly assigned to one of two groups; each assigned a specific musical training condition to be conducted at home. Group A had daily exposure to a recorded version of simple duple meter songs, while Group B was exposed to complex meter songs, which are non-native to the infants' musical culture. After one month of training, infants and caregivers will be invited back to the laboratory (Session 2) and assessed using the same stimuli and procedures employed in Session 1.

As data collection is still ongoing, the current thesis focused on developing metrics and analysis methods to quantify and characterize the data derived from the accelerometers, as no standardized analysis methods exist currently in the literature for accelerometer data analysis in infants, in particular for the fine-grained analysis of the temporal dynamics of movement in brief time windows (seconds). Most accelerometer studies with infants are used to determine sleep/wake states, and thus rely on broad, mainly binary (motion present/absent) analyses of accelerometer data in long time windows (minutes/hours).

# *Chapter 2*
# *Materials and Method*

## 2.1. Participants

The current thesis reports the currently available sample of infants tested so far in the project. Data collection is not yet complete.

### *2.1.1 Inclusion criteria*

Infants and their families were recruited through various channels, such as social media platforms like the BabyLab Facebook page, the existing BabyLab database, as well as vaccination and infant healthcare centers in Padua.

The inclusion criteria for participants were as follows:

- Age range for infants participants: 6-24 months
- Absence of known health issues, including neurodevelopmental and motor disorders, repeated ear infections, and hearing loss.

Parents were asked to provide demographic information such as the child's date of birth, gender, birth term, and the height and weight at birth, as well as any relevant details regarding neurological or other developmental disorders. In addition to that, one parent was asked to join their infant's experiment session.

### *2.1.2 Sample size*

An a priori calculation was done to determine the appropriate sample size. Due to the absence of previous studies providing effect size information and the wide age range being tested (6 to 24 months), a conservative effect size of Cohen's $d$=0.5 and a power of 0.8 were assumed. To account for the division of the group into two, a minimum of 128 infants (64 per group) will be included in the final data analysis.

For the purpose of this work, the data gathered so far include *N* = 12 infants (age range: 186 days to 395 days, *M* = 277.75*, SD* = 116.17), and N = 11 parents (age range: 28 to 45 years), with 1 infant's data discarded due to fussiness. Of these, 6 infants returned for the longitudinal follow-up. Half of them, i.e. 3 participants were assigned to the 7/4 training group, the other half, i.e. 3 participants, to the 4/4 group.

Parents of all participating infants gave written informed consent prior to participation for their infant as well as for themselves. The study was approved by the Ethics Board of the University of Padua (approval obtained from the Comitato Etico della Ricerca Psicologica - area 17 - Protocollo: 5164).

## 2.2 Stimuli

### *2.2.1 Music stimuli*

The experiment involves four auditory stimuli: two segments of instrumental classical music, one with a simple (4/4) and one with a complex meter (7/8), and two only-drums segments, again one with a simple and the other with a complex meter. The segments were taken from Shostakovich's Piano Concerto No. 2 in F major, Op. 102 with bars 23-39 (I. Movement - Allegro) comprising the 4/4 excerpt, while bars 75-101 (III. Movement - Allegro) [1] maked up the 7/8 excerpt. The BPM of the original stimuli was sped up to 132 BPM with the program Audacity. We programmed the drum samples using the Garageband software with a BPM of 132. BPM was set to 132 following de l'Etoile et al. (2020)'s finding that infants showed the most movement in response to 132 BPM. Segments of the simple duple meter, and complex

[1] Shostakovich, D.D. (1974). Piano Concerto No.2, Op. 102. [Song recorded by L. Bernstein, New York Philharmonic]. *On Piano Concerto No.1, Op. 35/Piano Concerto No.2, Op. 102*. CBS. (Original work published 1950)

meter could be taken from the same musical piece, which allowed us to match the simple and complex meter stimuli in all other characteristics except for meter (same composer, same instruments, same recording, and sound quality etc.). We have chosen instrumental music with no voice, as lyrics have the potential to be a confounding variable in the setup. Drum samples were employed following the results of Zentner & Eerola (2010), where infants moved significantly more to drumbeats than to classical music.

For uniformity, each stimulus was shortened to 30 seconds to maximize potential for infant engagement, as infants have a higher chance of breaking engagement with longer samples.

The 4 samples were presented to infants in a randomized and counterbalanced order, resulting in a total of 12 lists, each consisting of one drum sample in 4/4, one drum sample in 7/8, one music excerpt in 4/4, and one music excerpt in 7/8. Each list started with 5 seconds of silence, a countdown using computer-generated cymbals and a crash, followed by 40 seconds of silence, then the samples began. Additionally, there were 5 seconds of silence in between each sample (Figure 2). Auditory stimuli were delivered through two Yamaha loudspeakers placed behind curtains to the right and left of the participant.

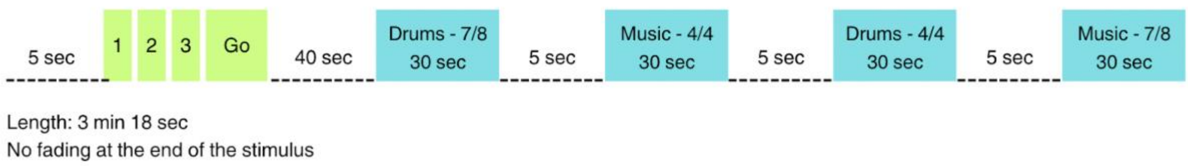


**Figure 2**. Example of a list. 1, 2, 3, and Go designate the cymbals (1-3) and crash (Go) respectively for the countdown.

### *2.2.2 Visual stimuli*

A 30-minute silent video showing slow-moving jellyfish that changed color was played on a ThinkVision screen placed in the middle of the experimental booth and 75 cm away from the participants. This was used to retain the infant's focus without interfering with the task.

## 2.3 Data Acquisition

### *2.3.1 Accelerometer*

In addition to video recording, we also registered participants' movements using accelerometers. The utilization of data derived from accelerometers provides distinct advantages in the extraction of rhythmic information from motion data. With finer spatial granularity and higher temporal resolution than video recordings, accelerometer data proves to be highly advantageous for such applications (Lee et al., 2007).

The device chosen to register movement was the GENEActive accelerometer, a lightweight, waterproof, wearable, raw data accelerometer that is able to record movement in 3-axes. Data was captured at 100 Hz per second to capture the most minute movements and configured to start recording using the on-button press function.

Accelerometers were installed on the right wrist and right ankle for infant participants and on the two wrists for adult participants.

Currently, no standardized analyses exist for accelerometer data in infants at the temporal resolution that is relevant for our research question, i.e. at the scale of seconds. Accelerometers are mainly used with infants to assess sleep /wake cycles or the overall quantity and development of gross motor skills. Such applications focus on larger time windows such as minutes or hours. This thesis will thus aim to develop novel analysis methods for infant accelerometer data.

### *2.3.2 Video recording*

A Logitech Brio video camera placed above the screen and capturing a frontal view of the participants was used to record the session. At the same time, the video camera transmitted information to the experimenters through a monitor placed outside the booth.

## 2.4 Experimental Procedure

### *2.4.1 Session 1*

*Infant participants*

Following de l'Etoile and colleagues (2020), as illustrated in Figure 3, in this study we have used a modified version of the Jolly Jumper® that suspends infants in a vertical fashion and provides them with the freedom to move while maintaining toe-touch contact with the ground. We modified the Jolly jumper by removing the suspension spring to prevent infants from bouncing and thus generating quasi-rhythmic movement not related to the task.

Infants underwent an approximately 4-minute long experimental session. One caregiver was seated within the experiment space and was visible to the infant at all times, and they were instructed not to move or make any sound. To do so, they listened to masking sounds through headphones in order to both avoid influencing the infant's response and to remain unaware of the sounds with which they will later be tested.

Infants were placed in a modified Jolly Jumper® in a testing booth. Accelerometers were then placed on the infants' right wrist and right ankle, the experimenters left the testing booth and the stimuli began. After the experimental session, infants were given a certificate and a toy or balloon as thanks for their participation.


**Figure 3.** Visualization of the setup. A baby doll is placed in the Jolly Jumper® with the suspension spring replaced with a chain.

*Adult participants*

Adults, one caregiver per infant, were tested with a procedure that differed in only a few relevant aspects. They were asked to sit in the middle of the testing booth, where they were videotaped from the neck down. The experimenter placed the accelerometers on the adult's right and left wrists and left the booth. The experiment then began once the stimuli started playing.

### *2.4.2 Musical training at home*

All participating families were invited to participate in a longitudinal follow-up study. If they agreed to participate, they were randomly assigned to one of two groups: the simple duple meter (4/4) group or the complex meter (7/4) group. Each caregiver received a 2-minute audio file containing a segment of jazz and reg-time music featuring instruments such as piano, drums, and chords. The audio file corresponded to the assigned group, either entirely in 4/4 meter or 7/4 meter. The song chosen for the 4/4 meter group was Joplin: “The Entertainer” by The New England Conservatory Ragtime Ensemble[2], while the song chosen for the 7/4 group is “Tombo in 7/4” by Airto[3]. Parents were asked to keep a log of how often they played the song for their child.

Families were instructed to incorporate the designated music into their daily routine for a duration of one month. They were encouraged to play the song at a specific moment during their baby's routine, such as during nappy changes, playtime, or any time they engage with the infant where their hands are free to clap. Moreover, the caregiver that participated in Session 1 was to engage with the infant while listening to the song. The goal of the musical training was to establish consistent exposure to the assigned musical meter.

### *2.4.3 Session 2*

After the one-month musical training period, infants and their caregivers were invited back to the laboratory for another test session following the exact same procedure as Experiment 1. They were also asked to provide the log data from the training sessions to assess their compliance.

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[2] Joplin, S. (1973). The Entertainer. [Song recorded by New England Ragtime Ensemble]. On *Scott Joplin: The Red Back Book*. Angel Records. (Original work published 1902)
[3] Airto. (1973). Tombo in 7/4 [Recorded by Airto]. On *Fingers*. CTI.

### *2.4.4 Online parental questionnaire*

All participating families were asked to fill in a parental self-report remotely. This questionnaire has been modified and adapted to Italian from the Parentalité musicale et développement: une étude à grande échelle [*Music parenting and development: a large-scale study*] questionnaire by Marino et al. (in preparation). Validation studies of this tool are ongoing and currently involve the analysis of a large-scale data set of about 200 French families with infants from 0 to 3 years (Marino et al., in preparation). *Relations between musical parenting, natural music pedagogy and familial background*). This questionnaire measures the musical environment and activities performed directly with the infants (singing, dancing, passive listening, etc.) as a function of parental musical background (i.e., musical studies, level of practice, general interest, etc.).

The shortened and modified version of the questionnaire used in this study is divided into two main sections. The first section, comprising 10 questions, investigated the caregivers' musical studies and experiences, e.g., whether caregivers have had musical training and if yes, to specify certain details about it, whether they play an instrument at home, if their profession is related to music, and their favorite musical genres and songs.

The second section, to be completed only by the parent that does the musical training with their infant at home, asks to detail musical habits that a parent has in relation to their child, like whether they listen to music together, how often, and what kind of music, and if the mother voluntarily exposed the child to music during the last trimester of pregnancy. Details about dancing or moving rhythmically to music are also given emphasis, such as whether the child dances to music even without an adult present, and if the parent moves or dances rhythmically to music in the presence or with the child. The second part then ends by asking whether the parent listens to music with a specific cultural heritage and if so, to specify two examples.

For the full questionnaire, refer to Appendix A.

# *Chapter 3*
# *Results*

As data analysis is not complete, the current thesis focuses on developing analyses and metrics to characterize infants' movement patterns descriptively and to quantify trends based on the accelerometer data. Synchronization with music and the assessment of the video recordings of the test sessions will be undertaken in subsequent phases of the study.

This work will therefore present the results of (i) an analysis establishing metrics for quantifying infant accelerometer data with second resolution, (ii) an analysis testing the correlation between the movements of the wrist and the ankle within an infant, and (iii) an analysis testing the synchronization between the movements of the wrist and the ankle within an infant. Whenever available, data from sessions 1 and 2 will be also compared.

## 3.1 Metrics for accelerometer data analysis

The accelerometer recorded the acceleration of the right ankle and right wrist along the *x, y,* and *z* axes with a sampling rate of 100Hz, for a total time of 250 seconds.

So far, the motor behaviors of 11 infants have been analyzed and each infant will henceforth be identified by a number and the initials of their names like so: {($B_1$, FM), ($B_2$, UM), ($B_3$, GT), ($B_4$, SM), ($B_5$, AMP), ($B_6$, VH), ($B_7$, CPL), ($B_8$, PG), ($B_9$, MM), ($B_{10}$, AM), ($B_{11}$, PN)}. In Figure 4 an example of a set of acceleration temporal series measured in units of gravity $1g = 9.8\ m/s^2$ along the three axes, $x$, $y$, and $z$ of $B_{10}$ (AM) 's right wrist in session 1 is visualized, along with the acceleration magnitude computed with the formula $m(t) = \sqrt{a_x(t)^2 + a_y(t)^2 + a_z(t)^2}$, regarded in this work as a reliable parameter for the overall acceleration.

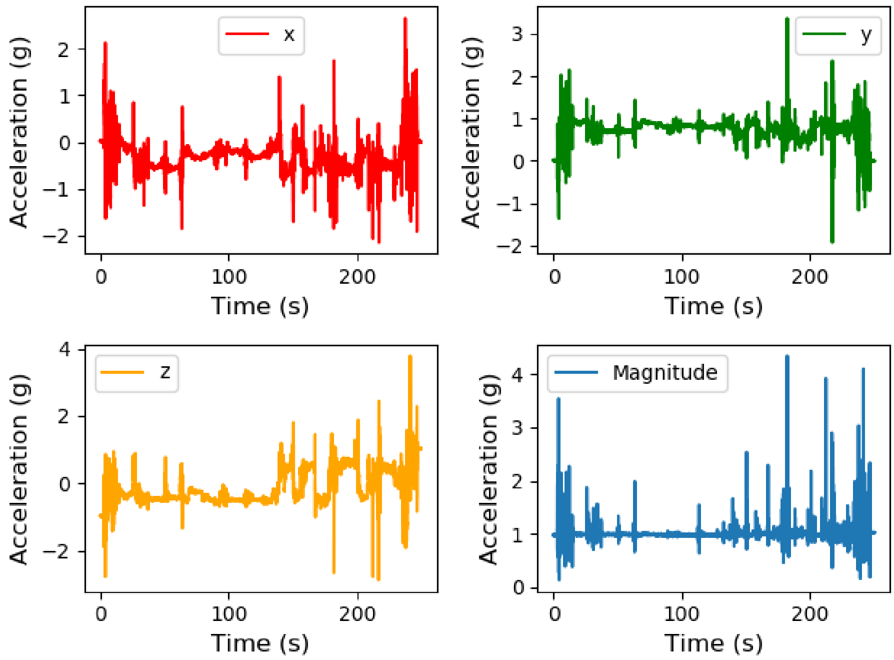



**Figure 4.** Acceleration time series along the three axes x, y, and z measured in gravitational units of $B_{10}$(AM)'s right wrist. Blue solid lines represent the acceleration magnitude which is always greater than or equal to zero.

To analyze an aspect of motor behavior, the intensity of a limb's overall movement was quantified by estimating its level of fluctuation, measured by computing its overall standard deviation $\sigma$ during the session. High fluctuations will result in a large standard deviation value, while low fluctuations will result in a small standard deviation value. To understand the following standard deviation results the specific case of $B_1$(FM) is presented. The right wrist acceleration magnitude behavior is presented on the left panels of Figure 5, in which many fluctuations appear to show. However, the histograms of acceleration values on the right panels of Figure 5 show that the occurrences of high fluctuations is small compared with static-like movements, i.e., movement with low acceleration magnitudes. Those pronounced single peaks yielding sharp histograms are a signature of low standard deviation values. For acceleration magnitudes and histograms of acceleration values of all infants, refer to appendix B.

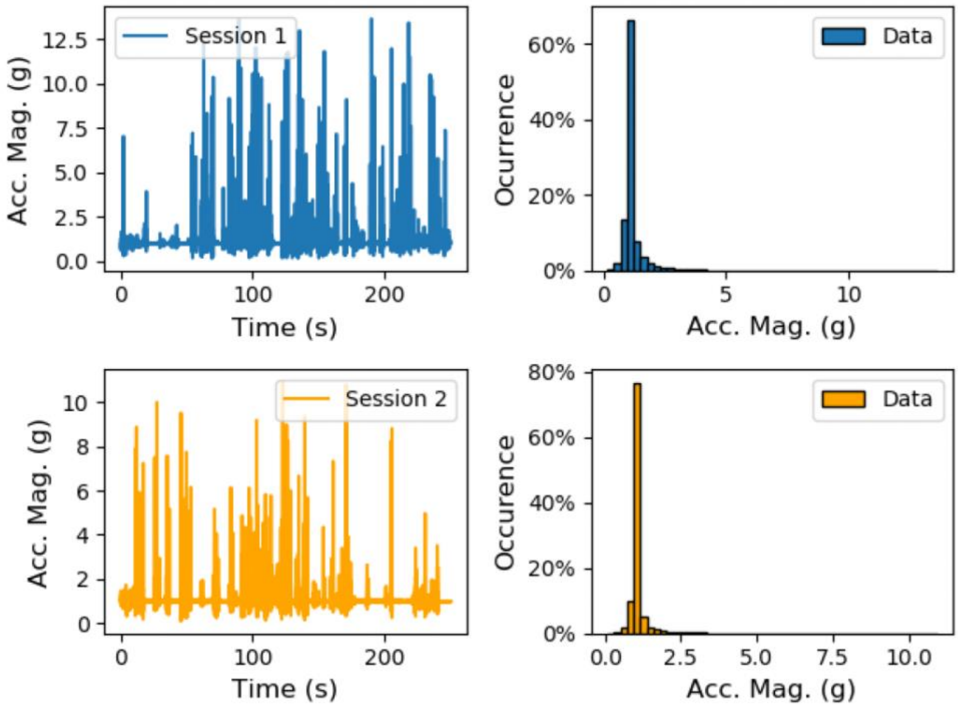
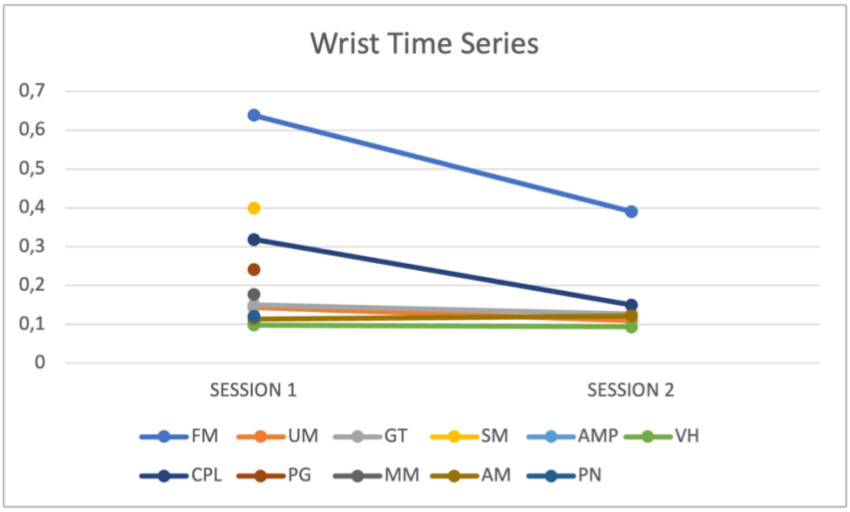



**Figure 5.** Right wrist acceleration magnitudes of $B_1$(FM). Left panels show the acceleration magnitudes of the right wrist for both sessions while right panels show the density distribution of acceleration values.

The numerical results of standard deviations for the group of babies in both sessions are summarized in Table 2 and in Figure 6. The overall fluctuation values in both ankle and wrist series fall within the range of $0 < \sigma_i^{ank}, \sigma_i^{wri} < 1$. This may indicate the presence of a persistent ground acceleration value, i.e. a set value that the accelerometer records when the limb is static. Overall, the results show a trend of decreasing standard deviation for the right wrist from session 1 to session 2. A different trend can be seen in the right ankle standard deviation values in that an equal number of infants show an increase and a decrease in their overall standard deviation from session 1 to session 2.

| Number | Baby Id | Session 1 | | Session 2 | |
|---|---|---|---|---|---|
| | | Wrist | Ankle | Wrist | Ankle |
| 1 | FM | 0.639 | 0.432 | 0.391 | 0.408 |
| 2 | UM | 0.144 | 0.094 | 0.110 | 0.130 |
| 3 | GT | 0.150 | 0.133 | 0.127 | 0.099 |
| 4 | SM | 0.399 | 0.061 | | |
| 5 | AMP | 0.104 | 0.110 | | |
| 6 | VH | 0.098 | 0.176 | 0.094 | 0.071 |
| 7 | CPL | 0.319 | 0.295 | 0.150 | 0.482 |
| 8 | PG | 0.241 | 0.258 | | |
| 9 | MM | 0.177 | 0.203 | | |
| 10 | AM | 0.114 | 0.109 | 0.122 | 0.229 |
| 11 | PN | 0.121 | 0.120 | | |

**Table 2.** Standard Deviations of acceleration values of infants' time series.



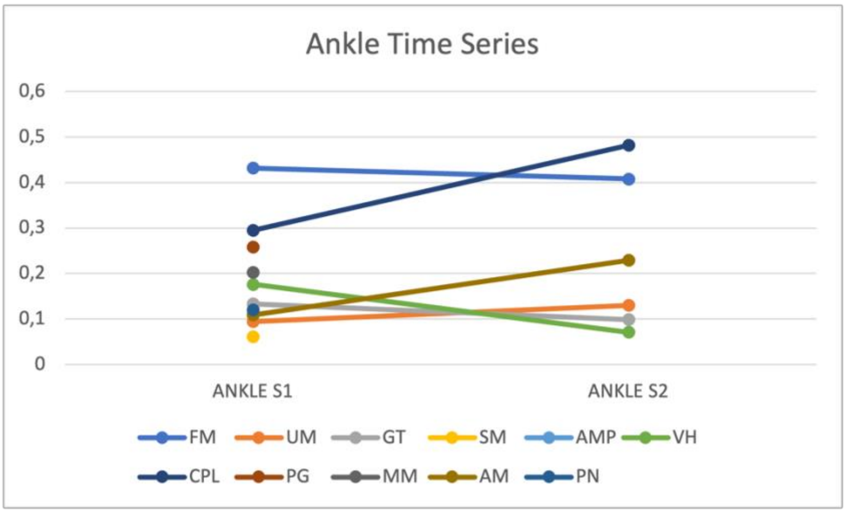




**Figure 6.** Line graphs of standard deviation values of both right ankle and right wrist of infants for both sessions.

Another interesting result, which can be seen in Table 3, is the mean values of the acceleration magnitude of all the series being very close to one. This indicates a presence of a persistent ground acceleration value, a result that is also shown in the histograms of the right panels of Figure 5. Because of this ground acceleration value, significant fluctuations may be hidden.

| Number | Baby Id | Session 1 | | Session 2 | |
|---|---|---|---|---|---|
| | | Wrist | Ankle | Wrist | Ankle |
| 1 | FM | 1.163 | 1.061 | 1.063 | 1.058 |
| 2 | UM | 1.015 | 1.023 | 1.006 | 1.023 |
| 3 | GT | 1.009 | 0.996 | 1.007 | 1.005 |
| 4 | SM | 1.079 | 0.994 | | |
| 5 | AMP | 1.010 | 1.007 | | |
| 6 | VH | 1.000 | 1.038 | | |
| 7 | CPL | 1.033 | 1.049 | 0.992 | 0.991 |
| 8 | PG | 1.059 | 1.019 | 1.011 | 1.054 |
| 9 | MM | 1.007 | 1.020 | | |
| 10 | AM | 1.003 | 1.006 | 1.001 | 1.019 |
| 11 | PN | 1.013 | 1.008 | | |

**Table 3.** Mean acceleration magnitudes of the infants' time series.

### 3.2. Correlation between the ankle and the wrist

With the above metrics in place, we first determined whether infants moved their ankles and wrists to the same extent or whether the two limbs performed movements with different amplitudes. This will be relevant later as one of the two limbs may be more suitable as a metric to be used for the assessment of movement-to-music synchronization. To determine whether there is a relationship between the amplitude of the ankle and wrist time series, a correlation analysis was run. The most common statistic used to measure the degree of linear association between two series is Pearson's correlation coefficient *r*.

Prior to computing the correlation coefficient *r*, we established the time window over which correlations between the ankle and wrist time series could be reliably computed. After an inspection of all time series samples, it was determined that the stimulus starting time of each infant belongs to the interval [30*s*, 50*s*] and the end stimulus time $t_i^f$ falls within the interval [180*s*, 200*s*]. Hence, to avoid losing data, the interval [30*s*, 200*s*] was considered for the computation of *r* in all pair ankle-wrist series. The time interval for the computation is thus visualized in Figure 7.

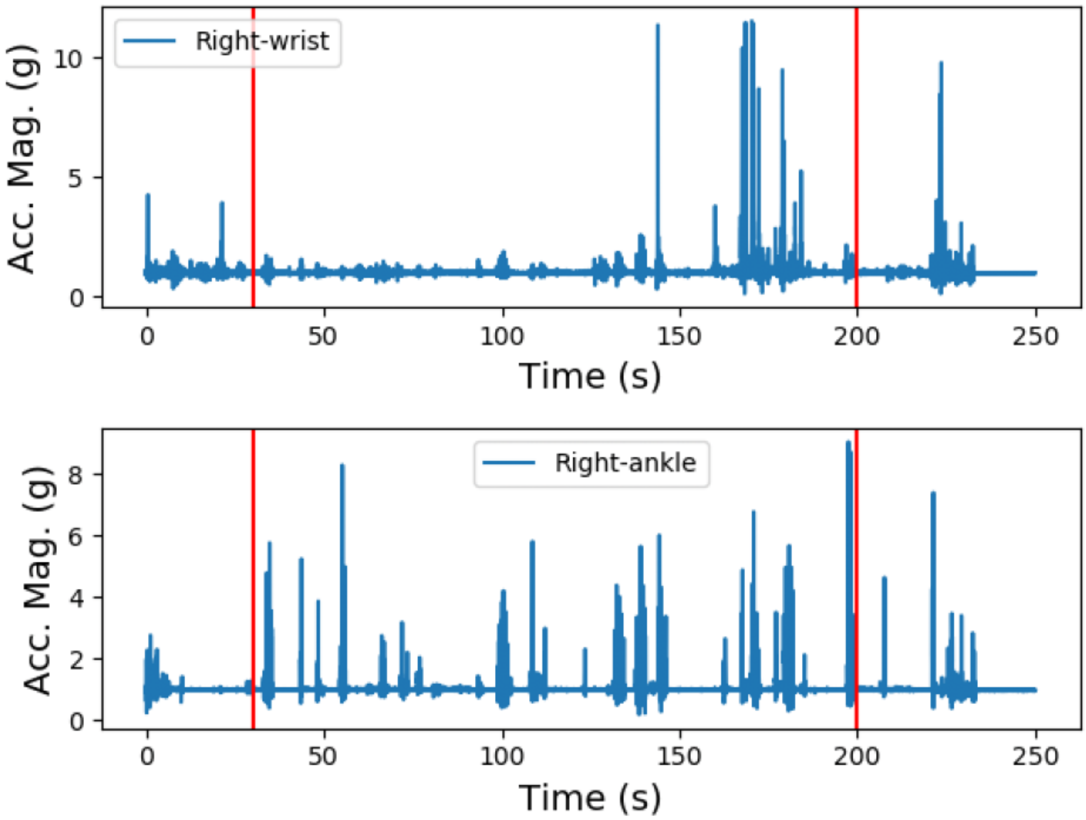



**Figure 7**. Right wrist and right ankle acceleration magnitude series for $B_7$(CPL). Solid red vertical lines denote

the interval with which the correlation coefficient r is computed. High fluctuations before and after the interval

may be due to the equipment and r

As shown in Figure 8 and Table 4, *r* values reduce from session 1 to session 2 in almost all the infants.

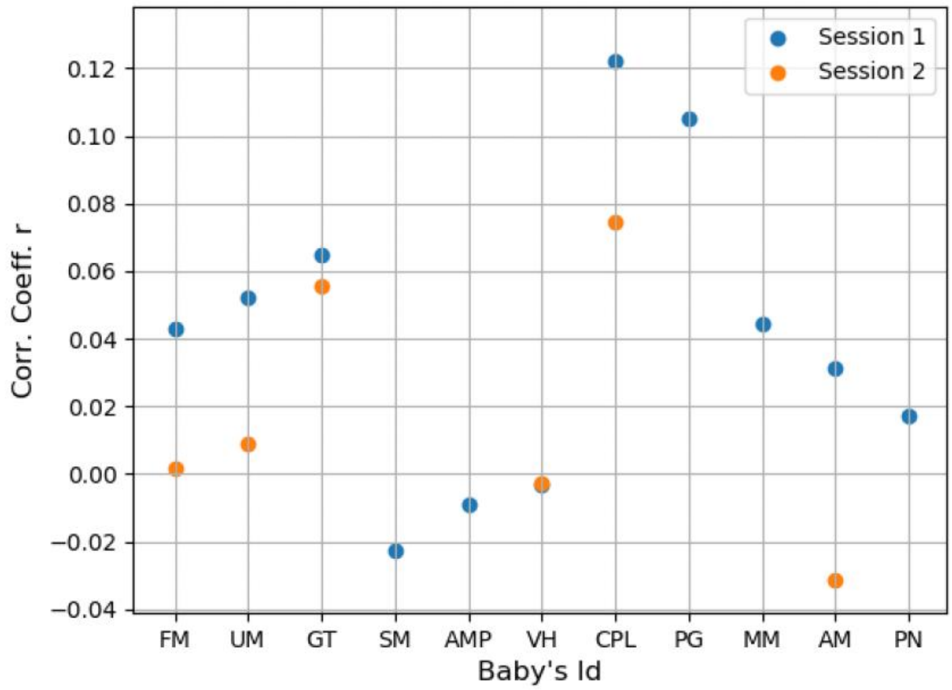



**Figure 8**. Correlation coefficient r between right wrist and right ankle series for each infant in both sessions. *r* was computed with interval [30s, 200s] in all cases.

| Number | Baby Id | Session 1 | Session 2 |
|---|---|---|---|
| | | $r$ | $r$ |
| 1 | FM | 0.043 | 0.002 |
| 2 | UM | 0.052 | 0.009 |
| 3 | GT | 0.065 | 0.056 |
| 4 | SM | -0.023 | |
| 5 | AMP | -0.009 | |
| 6 | VH | -0.003 | -0.003 |
| 7 | CPL | 0.122 | 0.074 |
| 8 | PG | 0.105 | |
| 9 | MM | 0.044 | |
| 10 | AM | 0.031 | -0.032 |
| 11 | PN | 0.017 | |

**Table 4**. Correlation coefficient results of infants.

### 3.3. Synchronization between the ankle and the wrist

Another important comparison between the two limbs is the extent to which they synchronize, i.e. move at the same time (irrespectively of their amplitude). To assess the degree to which the two limbs synchronize, *the mean phase coherence coefficient R* was used as a reliable parameter. This analysis is divided into two parts: the computation of the overall mean phase coherence coefficient in the interval [30*s*, 200*s*] and the computation of the instantaneous mean phase coherence IMPCC *R*(t).

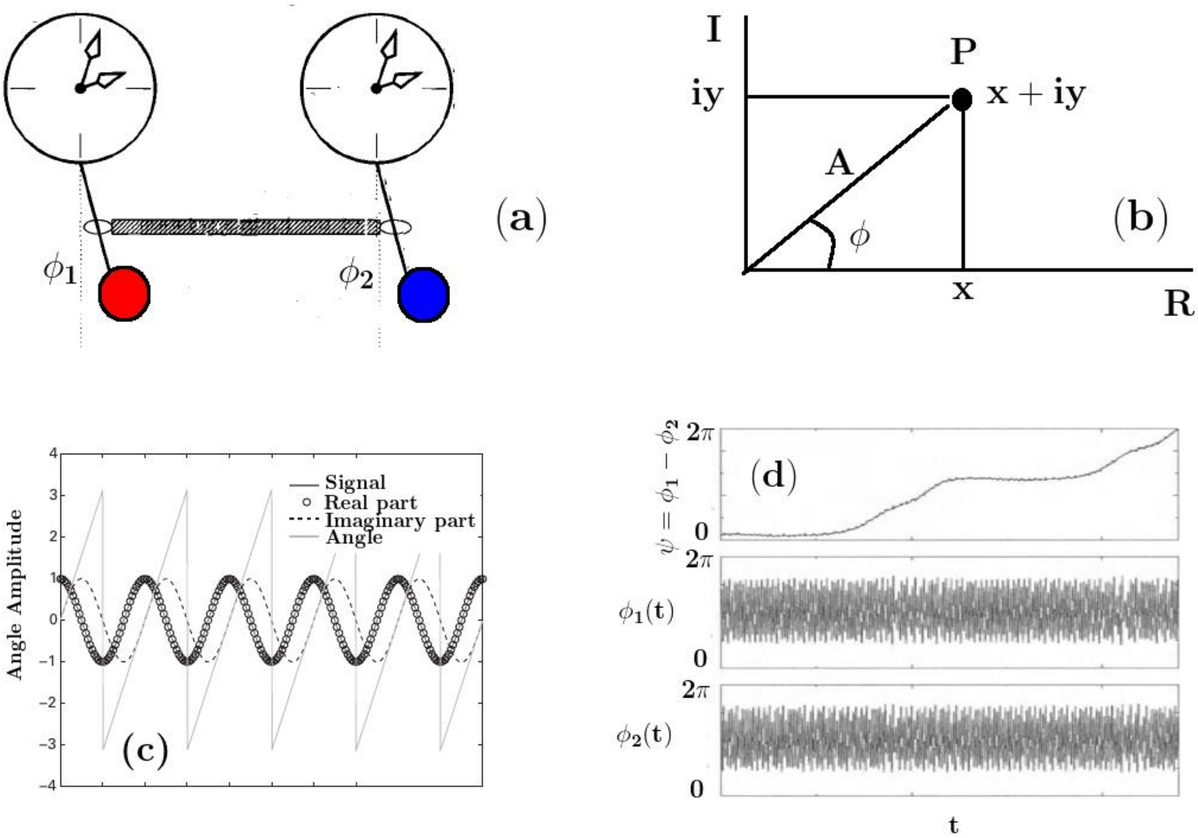



**Figure 9.** Panel (a) is a schematic representation of phase-locking of two pendulums, i.e., $\phi_1(t) = \phi_2(t), \forall t$. Panel (b) shows the complex plane where any point *P* can be expressed by a combination of a real part $x \epsilon R$ and an imaginary part $y \epsilon I$, such that $P = x + iy$, which is called the analytic form of *P*. Panel (c) shows an experimental signal (solid black line), its real part (circles), which coincides exactly with the empirical signal, its imaginary part (dashed gray line) which keeps the same structure as the real signal but has a phase displacement, and finally the instantaneous phase $\phi(t)$ (solid gray lines). Finally, illustrated in panel (d) are two instantaneous-phase time series $\{\phi_1(t)\}$ and $\{\phi_2(t)\}$ corresponding to two systems, and the instantaneous phase difference $\psi(t) = \phi_1(t) - \phi_2(t)$ which assumes values between 0 and $2\pi$.

Synchronization occurs when the rhythm of the motion of two weakly coupled, undamped harmonic oscillators adjust in terms of phase locking (Rosenblum & Kurths, 1998). In this strict sense, synchronization implies that the two angles$\phi_1$ and $\phi_2$ of the two pendulums fulfill $\phi_1(t) = \phi_2(t)$ for all t $(\forall t)$ as visualized in panel (a) of Figure 9. In order to describe synchronization between any two subsystems it is necessary to characterize their instantaneous states by instantaneous phase angles. In order to find out the instantaneous phase angles of an empirical time series $s_i(t)$ it is necessary to first construct its corresponding analytical signal $\xi(t) = s_i(t) + i\hat{s}(t)$, where $s_i(t)$ is its real part (which coincides with the empirical time series) and $\hat{s}(t)$ is its imaginary part, which is another time series keeping the same properties than $s_i(t)$ but with a phase displacement. For instance, in panel (b) we can see the analytical representation of a complex number P where x is its real part and y is its imaginary part, we can get the phase $\phi$ of the complex number P by the mathematical relation $\phi = arctan \frac{y}{x}$ where *arctan* is the inverse of the trigonometric function *tangent.* Panel (c) of Figure 9 shows a signal represented by a Cos(x) (continuous solid line) where the real part (circles) coincides exactly with the signal and its imaginary part (dashed line) is the Sin(x) which represents a single phase displacement of $\pi/2$ of the real signal. The instantaneous phases or angle amplitude are represented by a continuous gray line. The last conceptual framework can be extended to "Discrete signals", ie., time series, where the imaginary part $\hat{s}(t)$ of the analytical signal $\xi(t) = s_i(t) + i\hat{s}(t)$ can be obtained by $\hat{s}(t) = H(s(t))$ where H is a mathematical artifact called Hilbert transform. Thus, an analytic signal approach was employed to determine the instantaneous phase $\phi(t)$ of an arbitrary signal *s*(*t*).

$$\phi(t) = arctan \frac{\hat{s}(t)}{s(t)}, \quad (2)$$

where $\hat{s}(t)$ is the Hilbert transformation of the signal *s(t)*. Importantly, the instantaneous phase $\phi(t)$ as defined in Equation 2 is restricted to the interval $[0, 2\pi]$ . To measure synchronization, the mean phase coherence coefficient is defined as

$$R = \left|\frac{1}{N}\sum_{j=0}^{N-1} e^{i\psi(j\triangle t)}\right|, \tag{3}$$

where $\psi(j \triangle t) = \phi_{ank}(j \triangle t) - \phi_{wri}(j \triangle t)$is the instantaneous phase difference, as we can see in panel (d) of Figure 9, and$1/\Delta t$ is the sample rate of the series. Using Euler's formula

$$e^{i\phi} = cos(\phi) + isin(\phi) \quad , \tag{4}$$

where $i = \sqrt{-1}$ is the unit imaginary number Equation 3 can be written as

$$R = \left(\left[\frac{1}{N}\sum_{j=0}^{N-1} sin\,[\psi(j \triangle t)]\right]^2 + \left[\frac{1}{N}\sum_{j=0}^{N-1} cos\,[\psi(j \triangle t)]\right]^2\right)^2 \tag{5}$$

From Equation 5 it can be seen that $R \epsilon [0, 1]$. $R = 1$ is given if and only if the condition of strict phase locking is obeyed, whereas for a uniform distribution of phase, on average, for an unsynchronized time series, then $R = 0$.

***Overall Mean Phase Coherence Coefficient***

To measure synchronization of the two limbs, the instantaneous phases $\{\phi_{wri}(t)\}$ and $\{\phi_{ank}(t)\}\ \forall\ t$ were determined with the use of Equation 2 for right wrist and right ankle respectively. Having computed the instantaneous phases in both series, Equation 5 was applied to compute $R$, with a time step $\Delta t = 0.01s$ and a number of samples $N = 17000$ in all cases. Synchronization was assessed in both sessions in all wrist and ankle series respectively except for $B_4$(SM), who was excluded from the analysis due to a difference in the sample rates of the limbs for session 1.

Results presented in Figure 10 show high levels of synchronization in all infants in both sessions. This may be due to the persistent presence of the same ground acceleration, as seen in the histograms of the right panels of Figure 5. Another reason may be that as infants do not perform high fluctuating movements, the coefficient $R$ will consequently not be strongly influenced by high fluctuations in the series along our period of interest. It is important to note however that interpretations of these results are difficult due to the fact that no movement may also be interpreted as synchronization. The disentangling of a lack of movement from synchronized movement requires the application of a filter and further analysis with more data.

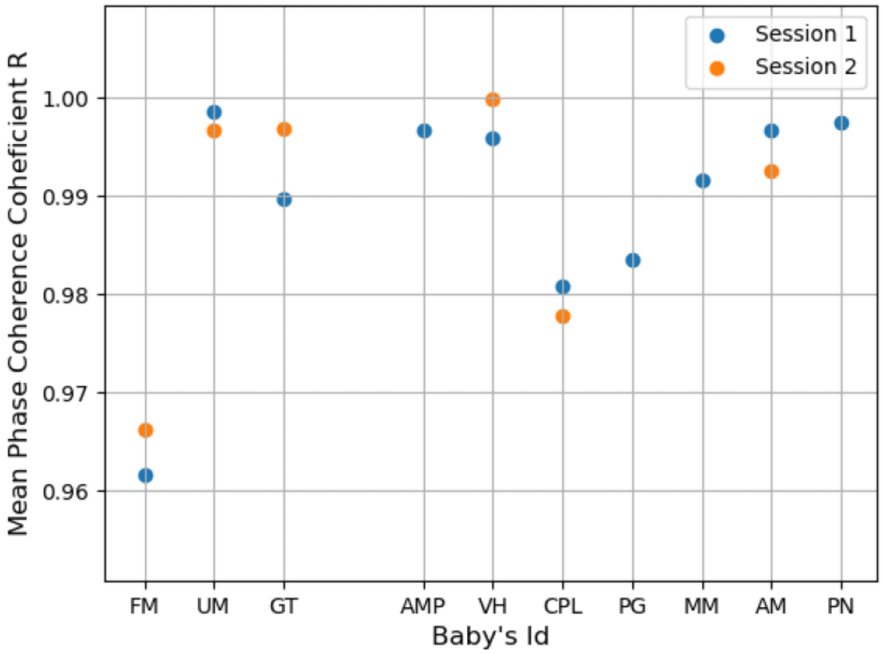



**Figure 10.** Overall results of the mean coherence coefficient R between right ankle and wrist series along the interval [30s, 200s] for both sessions. R was not computed for $B_4$(SM) as the sample rates of both limbs were different in session 1.

### *Instantaneous Mean Phase Coherence Coefficient*

To have detailed information about synchronization between infant's limbs, the instantaneous mean phase coherence coefficient *R(t)* was analyzed along the interval [30*s*, 200*s*]. For both series of instantaneous phases $\{\phi(t)\}_{wri}$ and $\{\phi(t)\}_{ank}$, for wrist and ankle respectively, a window $\omega$ with a fixed length$\Delta\omega$, i.e., a fixed number of points was defined. For a time $t_i \epsilon [30s, 200s]$, $R(t_i)$ was calculated by applying Equation 5 in the interval length of $\Delta\omega$ centered at $t_i$. First $R(t_1)$ was computed with $t_1 = \frac{\Delta\omega}{2}$ and then we continued moving forward a time step $\Delta t = 0.01s$ until the limit was reached $t_f = N - \frac{\Delta\omega}{2}$, so that $\{R(t)\}$ had a length of $N - \Delta\omega$ points. This process is visualized in Figure 11 below:

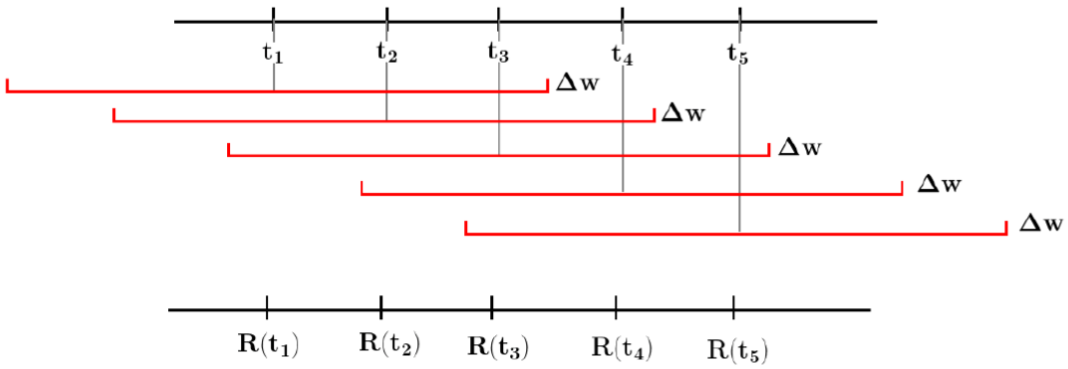



**Figure 11.** Schematic representation of computing *R(t)*. Red lines represent a window of constant length *Δω* moving along the time series.

The instantaneous mean phase coherence coefficient *R(t)* for $B_3$(GT) is shown below in Figure 12. The left panels show exactly where synchronization fluctuates and the regions of complete synchronization are marked by a continuous horizontal line at *R*(*t)* = 1. In the right panels of Figure 11, the histograms counting the occurrence of *R(t)* along the interval [30*s*, 200*s*] in five different intervals are presented, showing a distribution mostly concentrated in the interval closest to one for this particular example.

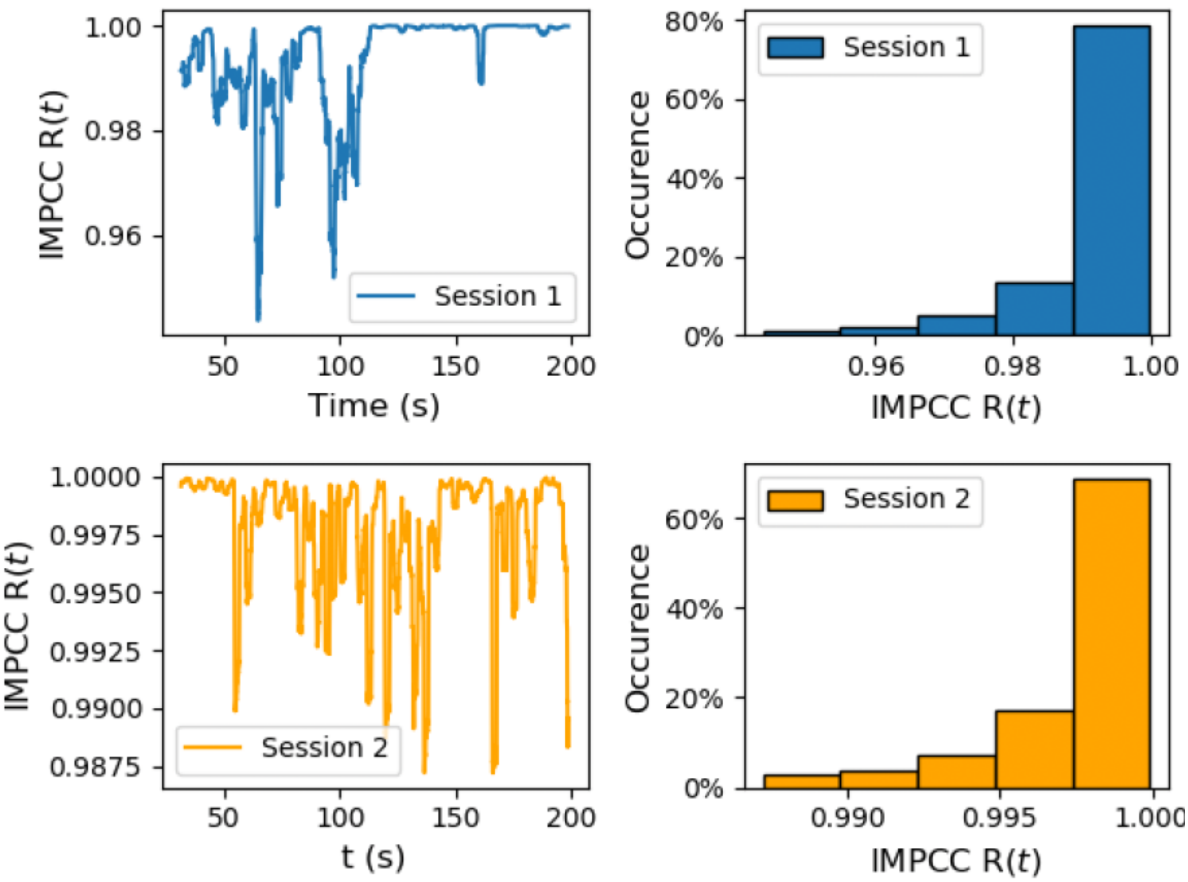



**Figure 12.** The instantaneous mean phase coherence coefficient *R(t)* for $B_3$(GT) in both sessions. Left panels show *R(t)* computed in a window size $\Delta\omega$ = 200 centered at the time *t* along the interval [30s, 200s]. Right panels show the histograms counting the occurrence percentage of *R(t)* in five intervals.

The resulting temporal series of $B_3$(GT)'s *R(t)* are in accordance with the overall results presented in Figure 10, i.e., low fluctuations and the presence of a persistent ground acceleration. The same possible reasons for the synchronization presented in Figure 10 also apply to *R(t)* presented in Figure 12. For all resulting temporal series, refer to appendix C.

# *Chapter 4*
# *Discussion*

## 4.1. Summary of results

This study explores music-cultural perceptual narrowing, investigating its potential influence on movement-to-music synchronization to both simple and complex meters. Our main objective is to understand if infants naturally exhibit distinct rhythmic movements when exposed to songs of different meters, whether their rhythmic behavior correlates with those of their caregivers, and if daily exposure to songs that have different meters influence the movements of both infants and their caregivers, potentially enabling or enhancing movement-to-music synchronization.

The first step to understanding this is to investigate infants' pure motor behavior, and, more specifically, to explore possible individual differences in the amount of movement and whether they change between sessions, the correlation between motor behavior and age, and the degree of synchronization between limbs.

For this purpose, this work presented the preliminary results of the analysis of infants' pure motor behavior while exposed to the musical stimuli. Data collection is still ongoing. The goals of this preliminary analysis were (i) to study the infants' motor behavior in terms of overall movement measured by estimating each limbs' level of fluctuations, (ii) to determine the statistical linear relationship between both the right ankle and right wrist time series, (iii) to determine the statistical linear relationship between age and each limbs' time series, (iv) and to establish the degree to which both limbs synchronize during the experimental sessions. Several interesting findings emerged, suggesting the need for further investigation with a more extensive sample of infants.

***Changes in infant motor behavior in Sessions 1 and 2***

Infant motor behavior varied among participants as evidenced by their differing standard deviation values, which are used to estimate the level of fluctuations of a limb's overall movement. High fluctuation values were not expected since the participants are infants and their range of movement is limited due to the size of their limbs, but it is interesting to see the variability in infant movement both in and between sessions.

Individual differences can be attributed to various factors, including the stage of motor development these infants have reached. It is worth noting that the timing of achieving developmental milestones varies significantly, as depicted in Figure 13, further contributing to these differences. Therefore, the movements of the infants in our study may have differed as a function of the gross motor skills they have developed. An infant that can stand with assistance may have at their disposal the capability to execute additional movements that are not available to that of an infant that has only managed to sit without support. Furthermore, the infant that can stand with assistance might feel more confident with being upright in the modified Jolly Jumper and thus feel free to move whereas an infant that is only capable of sitting without support may not have developed the postural control or leg stability and consequently may feel uncomfortable with being upright and thus will not move. These differences may be evident even in closely aged infants as the windows of achievement of these two gross motor milestones overlap.

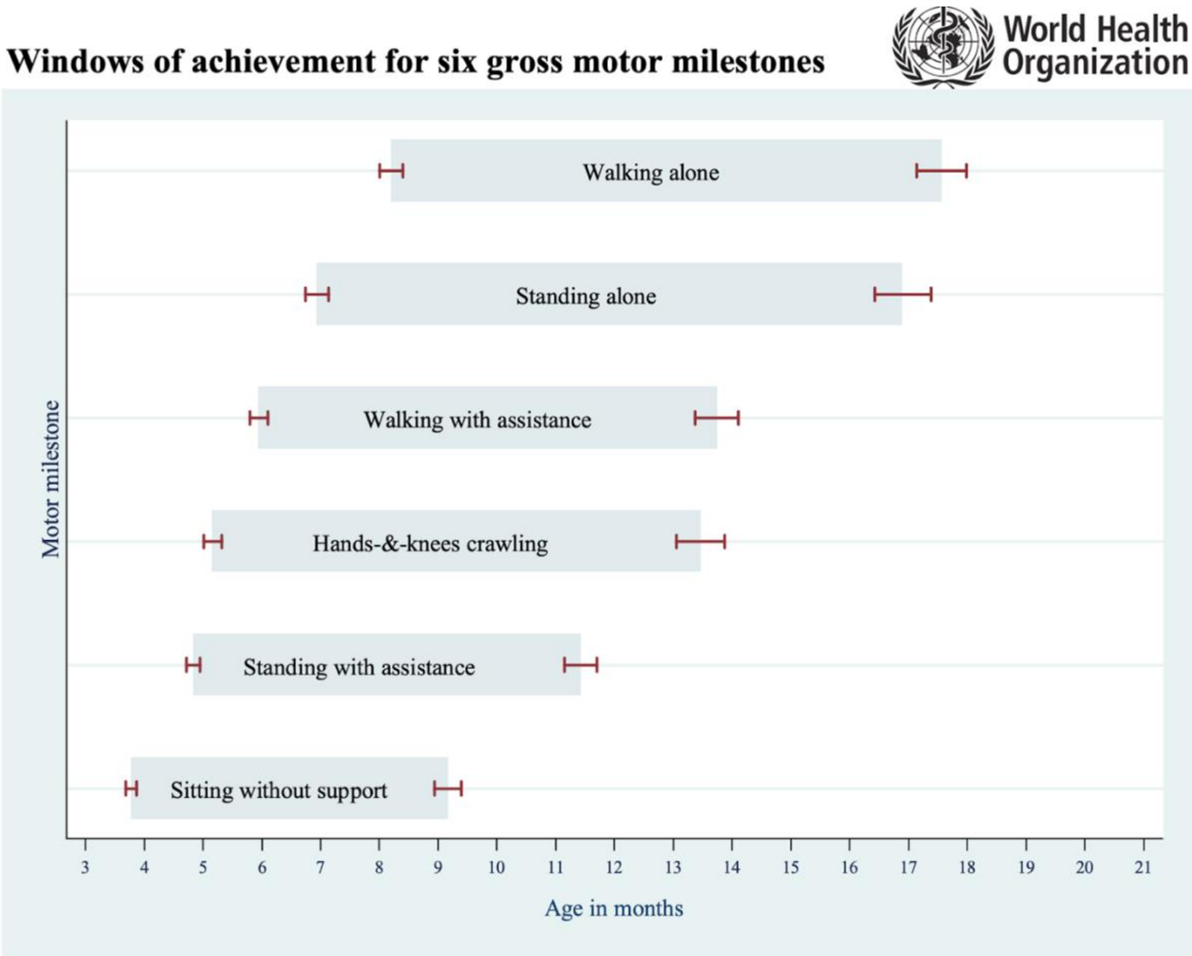



**Figure 13.** Windows of achievement for six gross motor milestones. Adapted from "*WHO Motor Development Study: Windows of achievement for six gross motor development milestones*" by World Health Organization. 2006 (https://www.who.int/tools/child-growth-standards/standards/motor-development-milestones) Copyright 2021 by World Health Organization (2021).

Another interesting result is the difference in standard deviation values from Session 1 to Session 2. We saw, and this held true for all six babies that partook in the musical training, that the overall movement of each infant changed between sessions. These differences can be attributed to several factors. One of these could be the almost daily musical training that the infants received, given that previous research has shown that musical training can influence musical behavior. Gerry et al. (2010) found, presumably as a result of music exposure, that *kindermusik* training on infants from 6.7 to 8.2 months of age resulted in more engagement with rhythmic sequences. Additionally, Hannon & Trehub (2005b), demonstrated that two weeks of at-home exposure was able to influence infants' rhythmic perception. Whereas the week-long musical training implemented by d'Etoile et al. (2020) did not result in statistically significant effects on the infants' behavior. Hence, we propose that a month-long musical training could impact the way the infants perceive meter. Consequently, this could influence their motor behavior as beat extraction is strongly linked to movement (Fiveash et al., 2022).

Moreover, the musical training implemented emphasized the involvement of their caregiver, tasking them to listen with their child and actively engage with the music. This is built upon the fact that all over the world, mothers provide a variety of musical input to their prelinguistic infants (Trehub, 2003), and infants are highly engaged by infant-directed music (Cirelli & Trehub, 2019).

A characteristic of caregiver-infant interactions is *affective entrainment*, which has to do with forming interpersonal bonds and "is related to the pleasure in moving the body to music and being in time with others" (Phillips-Silver & Keller, 2012, p.1). The practice of affective entrainment in joint action comes naturally, as infants and young children tend to have an inherent inclination to move and take delight in music within social settings. This process then supports imitation, which Phillips-Silver & Keller suggest could be mediated by *motor resonance*, i.e., the automatic, bottom-up, sensory driven stimulation of brain regions associated with movement such as the premotor and sensorimotor cortex which are activated by observing another's actions. Thus, motor resonance could promote readiness for temporally coordinated planned action in both music and dance.

Interestingly, individuals, both adults and infants, tend to exhibit more pronounced motor resonance when they are familiar with and have practiced certain actions. The ability to resonate with and simulate actions is shaped by prior experiences and perceptual processes (Phillips-Silver & Keller, 2012). Furthermore, the experience of body movement was shown to play an important role in musical rhythm perception since there is a strong multisensory connection between body movement and auditory rhythm inputs (Phillips-Silver & Keller, 2012).

In addition to the auditory and motor systems, it has been suggested that the vestibular system may have a hand in entrainment. While adults may rely on motor planning, infants often respond to passive movement cues, like being gently rocked while listening to a lullaby. Moreover, the vestibular system is known to be sensitive to sound and vibrations and it can convey a sensation of movement even without physical motion. Hence, it is plausible that vestibular information contributes, along with auditory and motor information, to different types of entrainment, including beat-based synchronization (Phillips-Silver et al., 2010).

At the same time, the social context has the potential to enhance entrainment processes. Mutual social entrainment, characterized by rhythmic responsiveness during bidirectional information exchange between two individuals, forms a reciprocal loop where each participant's rhythmic output influences the other's processing system. This interaction can lead to more coordinated physical movements and improved synchronization with a stimulus (Phillips-Silver et al., 2010). For instance, children as young as 2.5 years exhibited synchronization in drumming to an isochronous beat, but only when they engaged in this activity with a live partner in a social setting, as opposed to a machine or a recorded source (Kirschner & Tomasello, 2009).

These reasons might explain why it was found that the active participation of caregiver and infant in music listening, i.e., engaging with the music by clapping, singing, or dancing, as opposed to passive listening, i.e., simply playing music in the background, has been shown to accelerate infants' acquisition of culture-specific musical knowledge (Gerry et al., 2010). Hence, this emphasis on the active participation of the caregiver could potentially enhance the effectiveness of the musical training.

Another factor explaining why infants' movements changed from Session 1 to Session

2 could be that the encounter with the modified Jolly Jumper in Session 1 could have made them more comfortable with the harness, potentially influencing their movements in Session 2. Comfort is an element that may influence how infants behave. It has been shown that infants appear to move more in a home setting rather than the laboratory setting because they are more relaxed and comfortable in that environment (Kim & Schachner, 2023). Moreover since the infants are already familiar with the modified Jolly Jumper, they could be less inhibited.

Finally, developmental changes in motor skills and body size might result in changes in motor behavior in session 2 in comparison to session 1. Thus, keeping in mind the aforementioned factors, we predict that this trend of change between the two sessions will continue as the study progresses.

### ***Correlation between Limbs and with Age***

Considering that these motor developments that come with age could result in a change in motor behavior, a correlation coefficient analysis was performed between the limb movement and the infants' age. We found that only the correlation between wrist movements in session 2 and age was found to be statistically significant. This might suggest that older infants exhibited increased fluctuations in wrist movements, potentially indicating greater mobility or control. The resulting correlation may be due to the increase in coordination and diversification of arm movement (Abney et al., 2014). However, the limited sample set inhibits us from making conclusions.

On the other hand, leg movements tend to become more repetitive and stable with age, with a restricted range of motion (Abney et al., 2014), hinting at a potential correlation found with more data. In light of this, further data collection could potentially reveal a statistically significant correlation between age and limb movement, aligning with previous research (e.g., Kanemaru et al., 2012; Abney et al., 2014; Kim & Schachner, 2023).

Another interesting finding is the reduction of the correlation between limbs in almost all babies. A possible explanation for these results can be the functional dissociation of limbs that occurs in the first year of life. There is a change in the pattern of spontaneous movements of limbs from a general activity involving all limbs to one that involves selective interlimb coordination (Kanemaru et al., 2012). It was proposed by Kanemaru and colleagues that this may be due to the development of the spinal circuitry including central pattern generators (CPGs) and the higher structures that modulate the movement pattern generated by CPGs. Similar results were found in a case study by Abney et al. (2014) involving recording the movements of an infant from 51-days to 305-days of age. It was observed that the overall movement activity of the legs becomes more repetitive and stable with age, while the inverse pattern is observed in the arms, which could indicate the development of a functional dissociation between arms and legs. In light of the above, the decreasing trend of the correlation between arms and legs could continue as more data is collected.

### *Synchronization of Limbs*

The synchronization of limbs is of direct interest to this study as most day-to-day movements are individual and self-paced, whereas engaging with music like clapping along to a song, playing in a band, or dancing, requires synchronization (Repp & Su, 2013). While infants are not expected to show very precise movement-to-music synchronization, we are interested in the degree to which they are able to synchronize their limbs in response to a stimulus. Keeping in mind that motor development was found to significantly predict children's ability to move rhythmically in response to music (Kim & Schachner, 2023), their various stages of motor development could influence their ability to synchronize their limbs.

Figure 10 shows a high level of synchronization of limbs for all infants in both sessions. However, as mentioned previously, the persistence of a ground acceleration value, i.e. the possibility that the lack of movement may have been interpreted as synchronization, needs to be taken into account. In order to have a more complete picture of the synchronization, further analysis is, therefore, required.

## 4.2. Limitations

Our performance of a comprehensive analysis was restricted by the current sample size. While we were able to start developing metrics for quantifying movement and synchrony and examining individual differences, finding statistically significant results is highly unlikely with the sample size we have collected thus far. Additionally, we are unable to make comparisons at the group level with only 3 participants per group.

Moreover, the broad-based universal and the more culture-specific perceptual stages in auditory perception as well as infant motor development are of direct interest to this study. Because of this we intend to test infants aged 6-24 months to encompass all these dimensions. However, most of the infants' age fell within the range of 6-12 months, with the exception of $B_9$(MM) who was aged 19.56 months. The current sample size is thus not representative of all the developmental stages we aim to explore.

Another limitation is that the results that we have obtained until now regard the broadband of the data, i.e., all frequencies present in the data have contributed to the results. Frequencies with more power (generally lower frequencies) normally contribute more compared to frequencies with less power (generally higher frequencies). Since we did not perform frequency decomposition, we cannot be sure about the amount of noise that is actually present in the time series. We intend to address this by filtering the data prior to performing our analyses and running a signal analysis, specifically a power spectrum analysis, to reduce or delete noise in the time series.

Additionally, since the GENEactiv accelerometers required that we start the recordings manually by pressing on the watch faces at the same time, there were occasions where they had to be restarted once or twice during a session. To address this, notes are always taken during the sessions (e.g., how many times the watches were restarted, what time the accelerometers were triggered), so that we are able to pinpoint exactly when the accelerometers start recording.

The modified Jolly Jumper also led to one occasion where the session could not begin because the infant refused to be inserted into the harness. However, the data collected so far has resulted in a 91.67% success rate (11 out of 12 sessions were considered for the data analysis). This is a promising success rate considering that we initially assumed a 20% dropout rate.

**4.3. Future perspectives**

Data collection is still ongoing, therefore the issues of a limited sample size and it not being representative of the developmental stages that we want to explore will be addressed. As mentioned in the sample size section of this work, the intended minimum sample size to be included in data analysis is 128 participants, with 64 participants in each group. This will allow us to detect statistically significant effects and make comparisons at the group level with a power of 0.8. Moreover, we intend to ensure that each developmental stage has a representative sample so that we can explore the implications of the broad-based universal and the more culture-specific perceptual stages in auditory perception as well as infant motor development.

We will continue to analyze motor behavior by estimating the level of fluctuations of the limbs through the computation of standard deviation, perform a correlation coefficient analysis, and a mean phase coherence coefficient analysis. But prior to these analyses we will be filtering the data into separate frequency bands. This way, we will be able to interpret results in a frequency-band-specific manner, which will enable us to have more control over the characteristics of our time series. We will also be running a power spectrum analysis to reduce or delete noise in the time series. Results regarding band-pass filters and noise-reduced time series will be done in future works.

In addition to the above, we will differentiate the regions of silence and music. The data gathered so far considered the entire time series. We intend to go more in depth with our analyses by cutting out the 10 seconds of silence in between each stimulus, thus giving us more control and more specific detail on the motor behavior in response to the stimuli.

The link between the caregivers' rhythmic behavior and their infants' will also be explored. Since caregivers do lay the foundation for their infants' musical abilities, and taking into account the division of the general population to strong and weak beat perceivers (Fiveash et al., 2022) and strong and weak synchronizers (Assaneo et al., 2019), the caregivers' rhythmic ability may correlate with their infants'. Thus, a correlation coefficient analysis will also be performed between caregivers and infants' motor behavior.

To understand the effects of music-cultural perceptual narrowing and its effects on music-to-movement synchronization, an analysis of synchronization with music will be performed. Building on the results of the pure motor behavior, we will be studying the degree to which the infants are able to synchronize their movements with the music. At the same time, we will explore whether their capacity to synchronize changes as they age. Just as there could be a correlation between the movements and age, there could also be a correlation between their synchronization and age. There may be a variety of qualitative and quantitative changes in their movement behavior as they grow older, such as moving more but with no synchronization, or they move less but become more capable of movement-to-music synchronization.

Moreover, we are interested in seeing whether there is an improvement in synchronization between two sessions. Since there are two groups, one exposed to complex meter and the other exposed to simple meter, we intend to analyze whether there is a general improvement in synchronization or one that is only dependent on the meter they were trained on.

Of interest as well is the link to parental involvement. The parental questionnaire will be used to analyze their experience with music and the amount of music they expose their children to. This leads to a more comprehensive assessment of the influence of music-cultural perceptual narrowing on the rhythmic behavior of infants. Considering that this process occurs in the first years of life, our study explores the effect of daily exposure to music of certain meters right when this perceptual narrowing unfolds. There may be a sensitive period for the acquisition of rhythmic structures (Hannon & Trehub, 2005a,b). Accordingly, the timing of the musical training could be optimal for influencing the infants' rhythmic behavior and we may find that rhythmic behavior is indeed influenced by daily exposure to music. This may influence the general capacity to synchronize, or it could enhance the quality of or enable movement-to-music synchronization to a specific meter.

# *Chapter 5*
# *Conclusion*

Our study adopts a multifaceted approach to examine the impact of music-cultural perceptual narrowing. With more data, this method holds promise in offering a comprehensive insight into infants' rhythmic behavior, especially concerning their everyday interaction with music. Our analyses focus on both the quality and quantity of movement-to-music synchronization observed in infants, building upon our exploration of their motor behavior alongside that of their caregivers. Central to this is the investigation of the possible effects of brief, daily exposure to music with specific characteristics in their home environments. This collective effort has the potential to advance our understanding of how individuals get into the cultural rhythm.

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# Appendix A – Parent Questionnaire

## Questionario musicale

Gentili genitori, in questo questionario vi chiediamo di rispondere a domande su alcune delle vostre abitudini musicali. Il questionario è diviso in due parti, nella prima sezione chiediamo, se possibile, ad entrambi i genitori di rispondere personalmente. Nella seconda sezione invece, chiediamo al genitore che farà l'attività musicale a casa di rispondere, ma il contributo può venire da entrambi.

* Indica una domanda obbligatoria

1. Indicare il nome e cognome del genitore che ha accompagnato il/la bambino/a il **giorno della prima sessione** *

2. Indicare il codice del bambino (come indicato nella mail) *

3. Data di nascita del/della bambino/a *

   *Esempio: 7 gennaio 2019*

**SEZIONE 1**

**Genitore 1**

4. Età *

   *Esempio: 7 gennaio 2019*

5. Genere *

*Contrassegna solo un ovale.*

- Maschio
- Femmina
- Altro: ____________________

6. Ha conseguito studi musicali? *

*Contrassegna solo un ovale.*

- Sì
- No

7. Se sì, di che tipo? (Specificare, ad esempio: canto - danza - strumento)

____________________

8. Se sì, che genere di musica? (specificare, ad esempio musica classica, jazz, popolare, o altro da specificare)

____________________

9. Se sì, per quanti anni?

*Contrassegna solo un ovale.*

- 1 - 3 anni
- 5 - 10 anni
- più di 10 anni

10. Attualmente pratica uno strumento/il canto/la danza abitualmente **nell'ambiente casalingo?** *

*Contrassegna solo un ovale.*

- Sì
- No

11. Se sì, con che frequenza? (indicare una stima del numero di ore a settimana)

12. La sua attività professionale è legata alla sfera musicale? *

*Contrassegna solo un ovale.*

- Sì
- No

13. Se sì, quale?

14. Indicare in ordine di preferenza i suoi 3 generi musicali preferiti e che **ascolta abitualmente, e le sue 3 canzoni preferite** *

**Genitore 2**

15. Età *

_______________________________
*Esempio: 7 gennaio 2019*

16. Genere

*Contrassegna solo un ovale.*

- Maschio
- Femmina
- Altro: _______________________________

17. Ha conseguito studi musicali *

*Contrassegna solo un ovale.*

- Sì
- No

18. Se sì, di che tipo? (Specificare, ad esempio: canto - danza - strumento)

_______________________________

19. Se sì, che genere di musica? (specificare, ad esempio musica classica, jazz, popolare, o altro da specificare)

_______________________________

20. Se sì, per quanti anni?

*Contrassegna solo un ovale.*

- 1 - 3 anni
- 5 - 10 anni
- più di 10 anni

21. Attualmente pratica uno strumento/il canto/la danza abitualmente **nell'ambiente casalingo?** *

*Contrassegna solo un ovale.*

- Sì
- No

22. Se sì, con che frequenza? (indicare una stima del numero di ore a settimana)

______________________________

23. La sua attività professionale è legata alla sfera musicale? *

*Contrassegna solo un ovale.*

- Sì
- No

24. Se sì, quale?

______________________________

25. Indicare in ordine di preferenza i suoi 3 generi musicali preferiti e che **ascolta abitualmente, e le sue 3 canzoni preferite** *

______________________________
______________________________
______________________________
______________________________
______________________________

**SEZIONE 2**

**Chiediamo ad un solo genitore di rispondere alle domande di questa sezione del questionario**

26. Durante l'ultimo trimestre di gravidanza, la mamma ha esposto volontariamente il/la bambino/a a delle musiche/canzoni particolari in maniera frequente? *

27. Se sì, quali (dare un paio di esempi)?

28. Canta (con o senza musica) al suo/a bambino/a? *

*Contrassegna solo un ovale.*

- Sì
- No

29. Se sì, da quanti mesi dopo o prima della nascita ha cominciato a farlo?

30. Se sì, con che frequenza? (Indicare una stima oraria che può essere descritta in ore al giorno, a settimana o al mese. Ad esempio: 1 ora al giorno, 4 ore a settimana, ecc.)

31. Se sì, che tipo di canzoni canta? Fare almeno 3 esempi *

32. Le capita di accompagnare il canto con dei movimenti ritmici della mano *
**e/o del corpo?**

*Contrassegna solo un ovale.*

- Sempre
- Spesso
- Alcune volte
- Raramente
- Mai

33. Ascolta la musica in presenza del/la bambino/a? *

*Contrassegna solo un ovale.*

- Sì
- No

34. Se sì, con che frequenza? (Indicare una stima oraria che può essere descritta in ore al giorno, a settimana o al mese. Ad esempio: 1 ora al giorno, 4 ore a settimana, ecc.)

35. Se sì, che genere di musica/tipo di canzoni? Indicare almeno 3 esempi

36. Le capita di muoversi ritmicamente in presenza/con il/la bambino/a durante **l'ascolto musicale?** *

*Contrassegna solo un ovale.*

- Sempre
- Spesso
- Alcune volte
- Raramente
- Mai

37. Le capita di ballare in presenza/con il/la bambino/a durante l'ascolto **musicale?** *

*Contrassegna solo un ovale.*

- Sempre
- Spesso
- Alcune volte
- Raramente
- Mai

38. Il/la bambino/a balla ascoltando la musica? (anche senza il coinvolgimento **dell'adulto)** *

*Contrassegna solo un ovale.*

- Sempre
- Spesso
- Alcune volte
- Raramente
- Mai

39. Vi capita di ascoltare insieme e/o cantare canzoni/musiche che fanno parte **di una eredità culturale specifica?** *

*Contrassegna solo un ovale.*

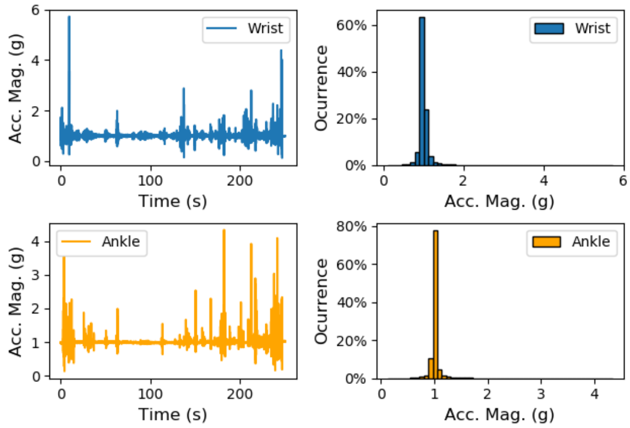
- Sì
- No

40. Se sì, quali? Fare almeno 2 esempi

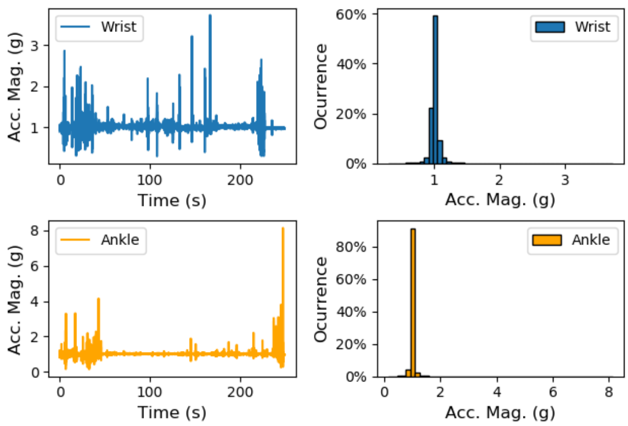
# Appendix B – Infant Acceleration Magnitudes

## Session 1

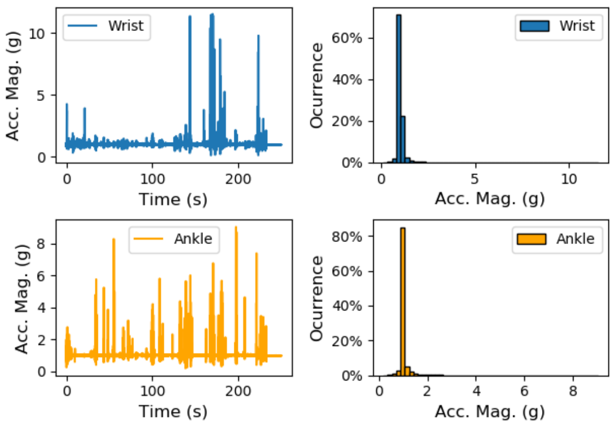
AM



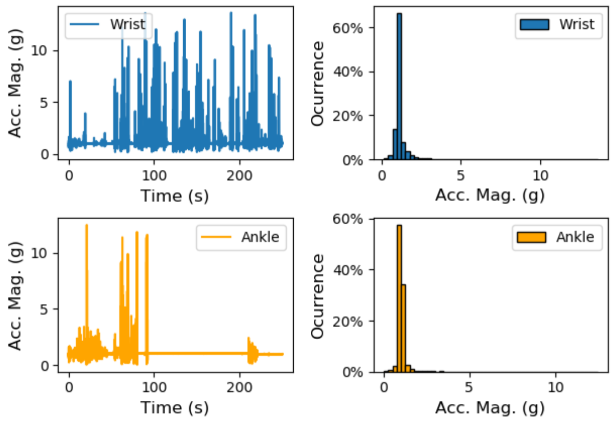

AMP



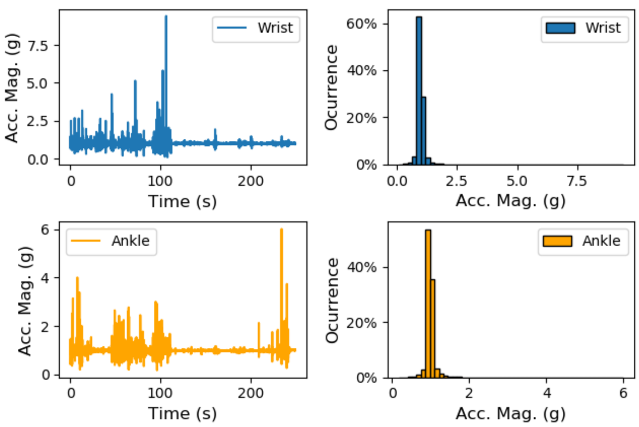

CPL



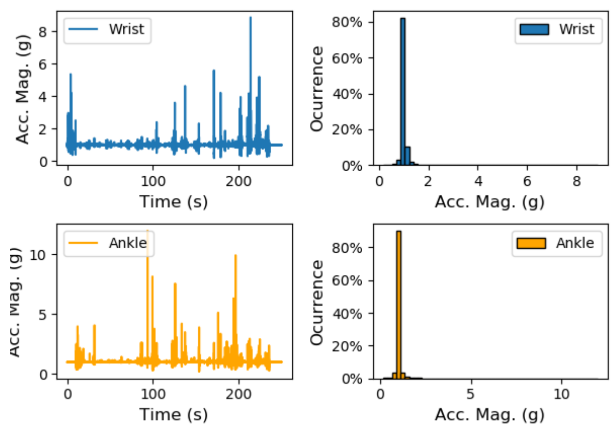

FM

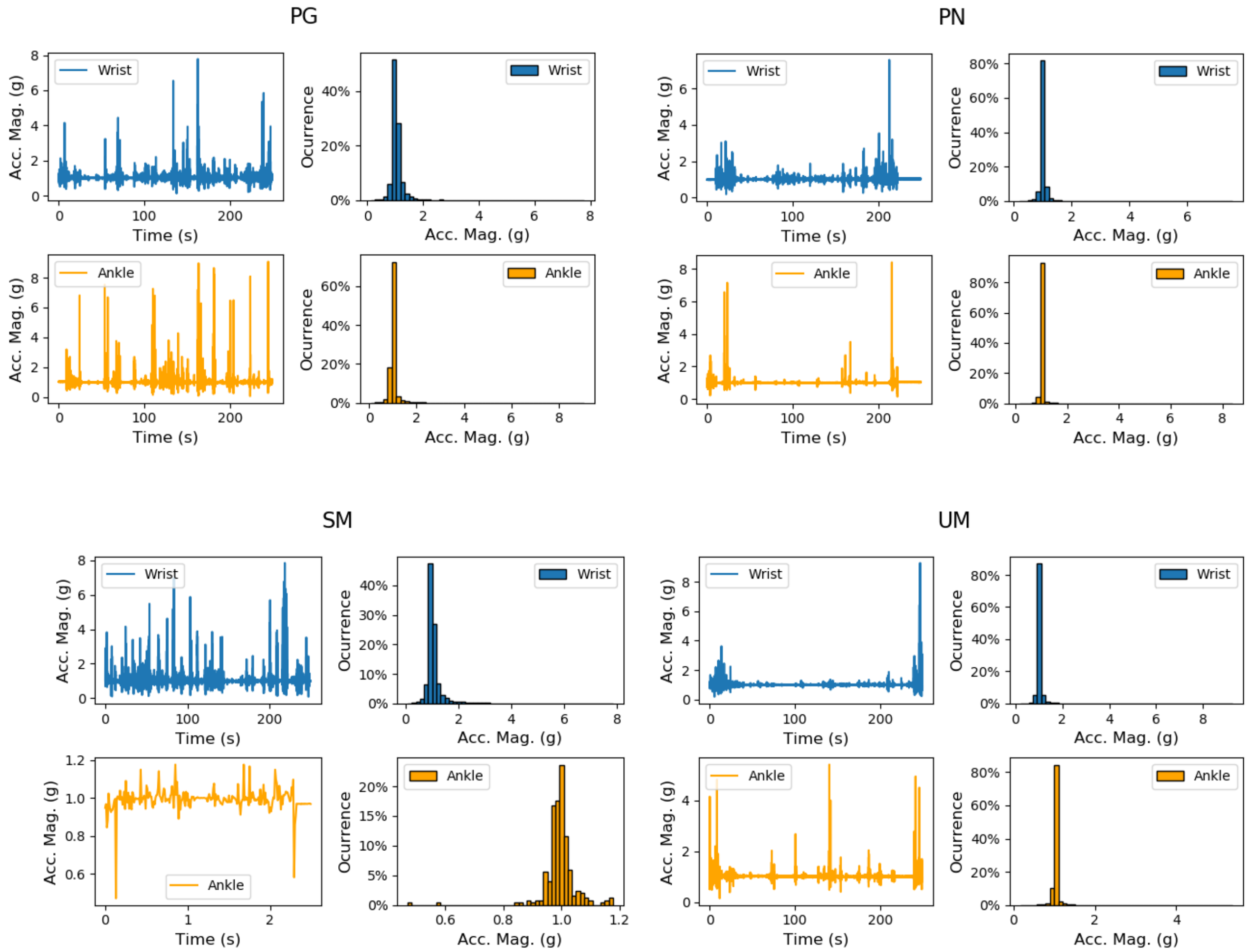



GT



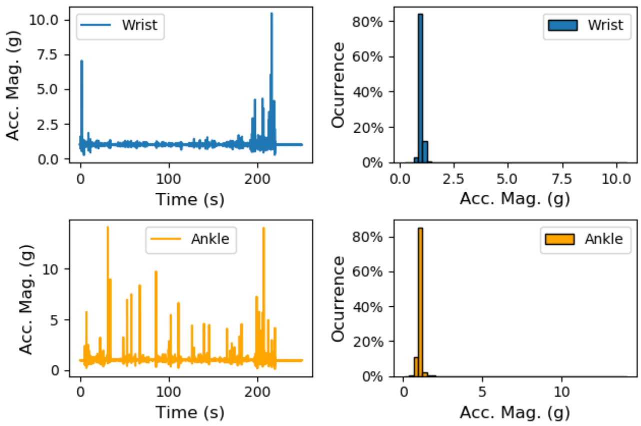

MM



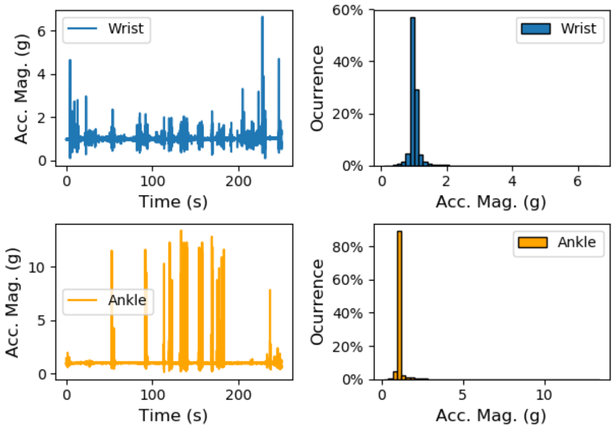

PG
PN
SM
UM
Wrist
Ankle
Acc. Mag. (g)
Ocurrence
Time (s)
Acc. Mag. (g)

# Session 2

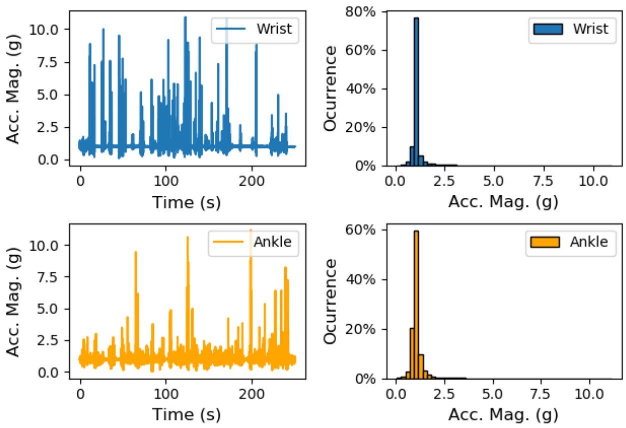
AM



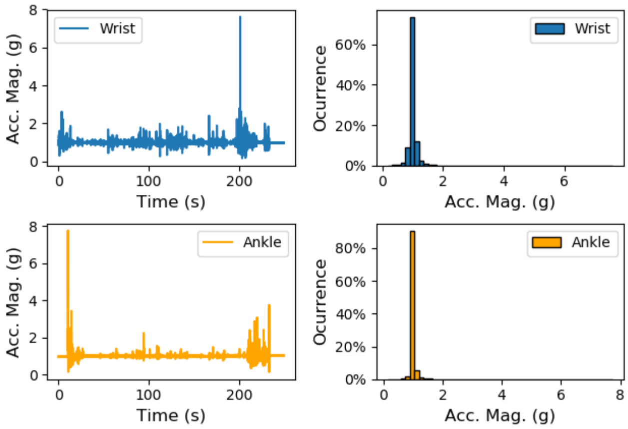

CPL



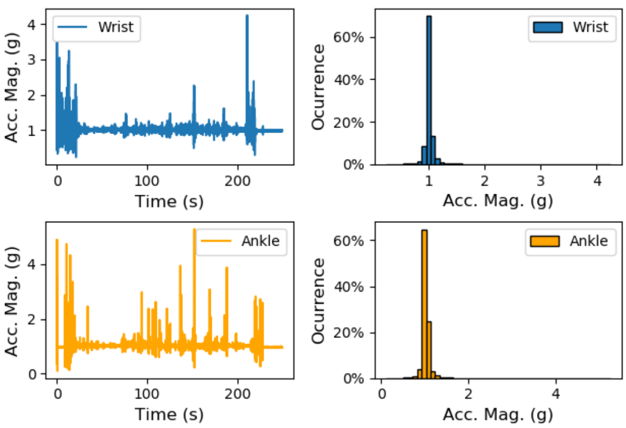

FM



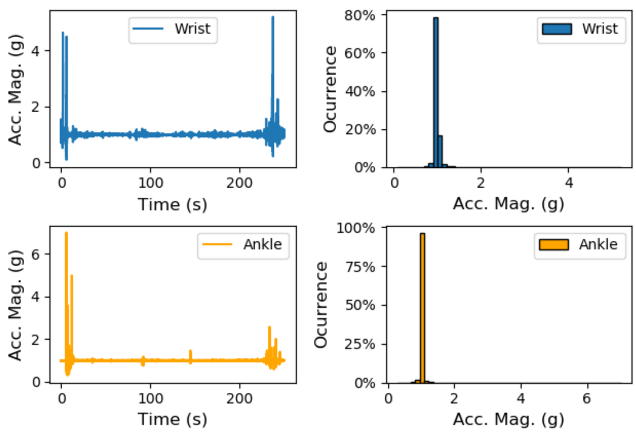

GT




UM

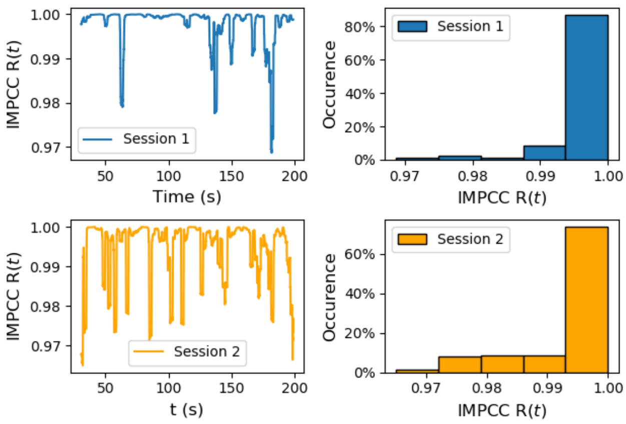



VH

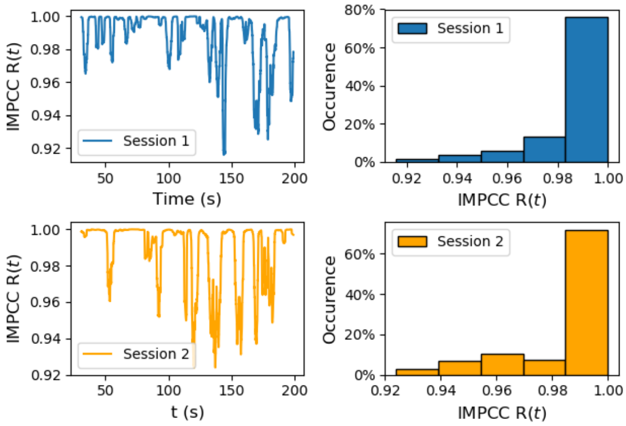


# Appendix C – IMPCC Temporal Series

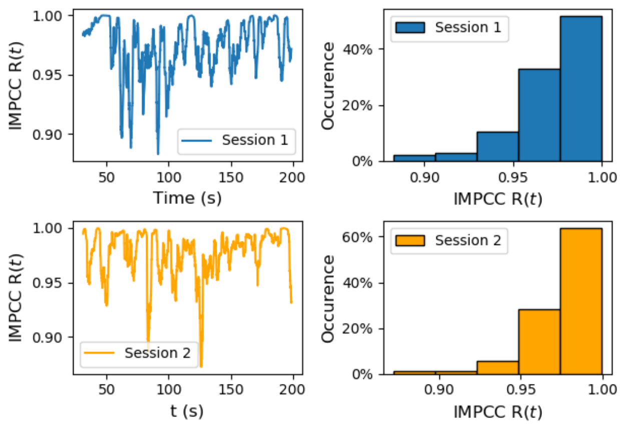
AM



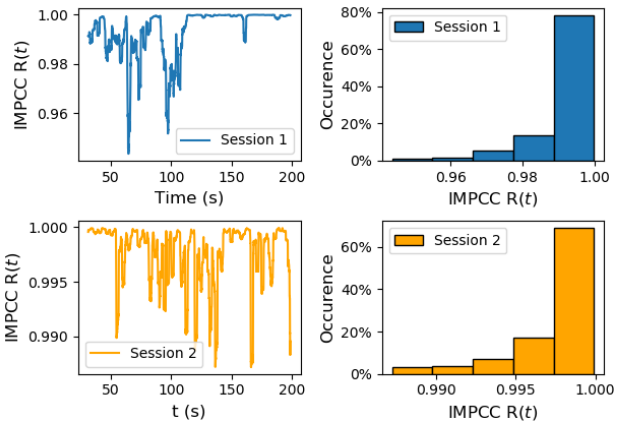

CPL



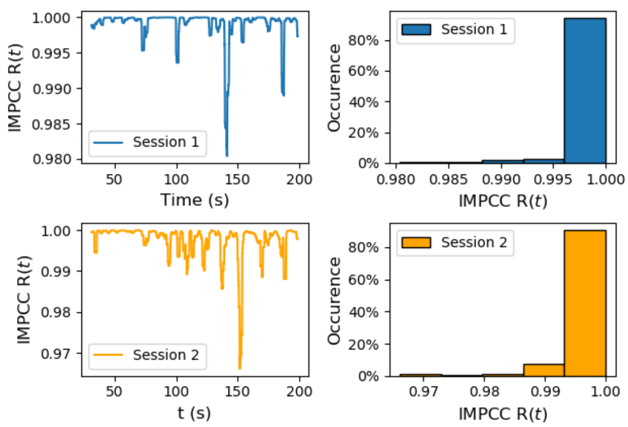

FM




GT




UM




VH