Luiz Rogério Jorgensen Carrer

SINCRONIZAÇÃO SENSÓRIO-MOTORA COM MÚSICA E METRÔNOMO EM CRIANÇAS NA IDADE ESCOLAR: RELAÇÕES COM O PERFIL SENSORIAL E O COMPORTAMENTO

Tese apresentada à Universidade Federal de São Paulo – Escola Paulista de Medicina, para obtenção do Título de Doutor em Ciências.

Orientadora: Profa. Dra. Sabine Pompéia

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Luiz Rogério Jorgensen Carrer

SENSORIMOTOR SYNCHRONIZATION WITH MUSIC AND METRONOME IN SCHOOL-AGED CHILDREN: RELATIONSHIPS WITH SENSORY PROFILE AND BEHAVIORAL MEASURES

Thesis submitted to the Department of Psychobiology, Federal University of São Paulo.
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Chefe do Departamento de Psicobiologia
Prof. Dr. José Carlos Fernandes Galduróz

Coordenador do Curso de Pós-Graduação em Psicobiologia
Prof. Dr. Carlos Eduardo Neves Girardi

Luiz Rogério Jorgensen Carrer

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Presidente da Banca:

Profa. Dra. Sabine Pompéia

Banca Examinadora:

Profa. Dra. Cléo Monteiro França Correia

Profa. Dra. Juanita Eslava Mejír

Prof. Dr. Renato Tocantins Sampaio

Profa. Dra. Rita de Cássia dos Reis Moura

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“Time is basically an illusion created by the mind to aid in our sense of temporal presence in the vast ocean of space. Without the neurons to create a virtual perception of the past and the future based on all our experiences, there is no actual existence of the past and the future. All that there is, is the present.”

Abhijit Naskar

Dedication

Este trabalho é dedicado a
Elisabetta, minha amada companheira em tantas e longas jornadas.
À minha família, em especial à minha mãe Magali, pelo amor e apoio incondicional aos meus projetos de vida.
Ao meu pai Italo (*in memorian*).

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Resumo

Objetivo: A presente pesquisa teve como objetivo analisar as habilidades de sincronização sensório-motora de crianças em idade escolar avaliadas por meio de tarefas de *Finger Tapping* (FT: tocar com os dedos), com estímulo musical e metrônomo, bem como relações do FT com aspectos internalizantes/externalizantes e do perfil sensorial (sensorial/comportamento). **Métodos:** A amostra foi composta por 305 crianças de 6 a 11 anos com desenvolvimento típico. Foram realizadas duas análises para investigar os seguintes efeitos no desempenho de FT com música e metrônomo: 1) efeito de idade e sexo na acurácia e na variabilidade do FT com tempo regular rápido (Intervalo entre estímulos= 333 ms) e lento (1000 ms); 2) efeitos de idade, sexo, comportamentos internalizantes e externalizantes obtidos por meio do *Child Behavioral Checklist* e problemas sensoriais e comportamentais do *Short Sensory Profile 2* no FT em tempos regulares rápido e lento, com mudança rápido/lento e lento/rápido, tendo música e metrônomo como dois fatores separados utilizando modelagens de equação estrutural. **Resultados:** Na primeira análise, encontramos uma melhora no desempenho (menor variabilidade, mas não na acurácia) com o aumento da idade, principalmente entre 6 e 9 anos, independentemente do tipo de estímulo e do tempo. O desempenho na música e no metrônomo mostrou diferenças na acurácia e na variabilidade do FT, independente da idade e sexo. A análise dois confirmou a melhora do FT com o aumento da idade (menor variabilidade) nos fatores música e metrônomo. A variabilidade foi mais sensível para captar os efeitos do desenvolvimento do FT em ambas as análises, enquanto a acurácia foi mais sensível para captar os aspectos comportamentais do FT na análise dois. Maiores escores em comportamentos internalizantes foram associados a uma menor acurácia no FT, mas um número maior de comportamentos externalizantes foi associado a uma maior acurácia do FT em ambos os fatores, música e metrônomo. A variabilidade do FT não foi associada a comportamentos internalizantes ou externalizantes. O perfil sensorial não foi associado a nenhum desempenho de FT. Sexo não teve efeitos significantes no FT em ambas as análises. **Conclusões:** A variabilidade do FT em crianças com desenvolvimento típico diminui a partir dos seis anos de idade, independente do tipo de estímulo e do sexo. Comportamentos internalizantes estão negativamente associados à acurácia do FT, enquanto comportamentos externalizantes estão positivamente associados à acurácia do FT, independente do tipo e tempo do estímulo, idade e sexo. Não houve associação entre as medidas do perfil sensorial e o desempenho no FT. Os fatores música e metrônomo são correlacionados, mas contribuem de forma independente e complementar na explicação da acurácia e da variabilidade no desempenho do finger tapping.

Palavras-chave: sincronização sensório-motora, *finger tapping*, música, metrônomo, desenvolvimento sensório-motor, desenvolvimento infantil

Abstract

Objective: The present research aimed to analyze the sensorimotor synchronization abilities of school-aged children assessed through finger tapping (FT) tasks to music and metronome stimuli, as well as relationships between FT performance with internalizing/externalizing behaviors and sensory profile (sensory/behavior). **Methods:** The sample consisted of 305 typically developing children aged 6 to 11 years old. Two analyses were performed, in which we investigated the following effects on FT to music and metronome: 1) effects of age and sex on FT's accuracy and variability in regular fast (Inter Stimulus Interval= 333 ms) and slow tempi (1000 ms); 2) effects of age, sex, internalizing and externalizing behaviors obtained from the Child Behavior Checklist and sensory and behavior problems from the Short Sensory Profile 2 on regular (fast and slow) and tempo change (fast/slow; slow/fast) FT tasks with music and metronome stimuli as two separate factors using structural equation modeling. **Results:** For the first analysis, overall we found an improvement in FT performance (lower variability, but not accuracy) with increasing age, particularly between 6 and 9 years, irrespective of stimulus type and tempo. Performance for music and metronome stimuli showed differences in the FT accuracy and variability, irrespective of age and sex. Analysis two confirmed the improvement of FT with increasing age (lower variability) on both metronome and music factors. Variability was more sensitive to capture FT developmental effects in both analyses, whereas accuracy was more sensitive for capturing behavioral aspects of FT in analysis two. Higher internalizing behaviors were associated with lower FT accuracy, but higher externalizing behaviors were associated with higher FT accuracy for both music and metronome factors. FT variability was not associated with internalizing or externalizing behaviors. Sensory profile was not associated with any FT measures. Sex had negligible effects on FT in both analyses. **Conclusions:** Finger tapping variability in typically developing children decreases from the age of six years, irrespective of stimulus type and sex. Internalizing behaviors are negatively associated with FT accuracy, while externalizing behaviors are positively associated with accuracy, irrespective of stimuli type and tempo, age and sex. Sensory profile measures were not associated with FT performance. Music and metronome factors were significantly correlated, but made independent and complementary contributions in explaining accuracy and variability in finger tapping performance.

Keywords: sensorimotor synchronization, finger tapping, music, metronome, sensorimotor development, child development

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List of abbreviations

BPM	Beats Per Minute
CATRS	Conner's Abbreviated Teacher Rating Scale
CBCL	Child Behavior Checklist
CFA	Confirmatory Factor Analysis
FT	Finger Tapping
GLM	General Linear Model
HSM	Histórico Sonoro Musical
ITI	Inter Tap Interval
ISI	Inter Stimulus Interval
MST	Music Sync Task
QBAI	Questionário Brasileiro de Saúde e Família
SEM	Structural Equation Model
SMS	Sensorimotor Synchronization
SP2	Sensory Profile 2
SSP2	Short Sensory Profile 2

1 INTRODUCTION

The idea behind this Thesis arose from a multidisciplinary team of researchers interested in musical cognition at the Department of Psychobiology at the Universidade Federal de São Paulo (UNIFESP), Brazil, and from investigations involving the performance of children with neurodevelopmental disorders in time perception and musical rhythmic tasks carried out at the Interdisciplinary Child Neuropsychological Care Center (NANI - UNIFESP) during a Master in Science degree published by the author (Carrer, 2014).

The studies conducted by these researchers revealed correlations between musical tests and behavioral scales, pointing to the possibility of using music in furthering research in order to gather data for the standardization of musical tests in typically developing and clinical populations of children. This stems from the link between music and cognition, as there is evidence suggesting that children who study or participate in musical activities can have better performance on tasks involving cognitive functions and academic skills, such as language learning, mathematics, reading speed and accuracy (Koelsch et al., 2005; Hyde et al., 2009; Miendlarzewska & Trost, 2014), attention, phonological awareness, working memory (Colley et al., 2018; Maróti et al., 2019) and intelligence (Silvia et al., 2016), besides inhibition and better motor planning (Abikoff et al. 1997; Degé et al., 2011; Jaschke et al., 2018).

Music skills involve Sensorimotor Synchronization (SMS), the coordination of body movements with external stimuli, involving simple movements such as clapping in synchrony with music and coordinating complex rhythmic movements also in everyday activities such as writing, dancing or performing sports activities (Repp, 2005). Although these skills are naturally developed from early childhood, the presence of motor and developmental disorders may be associated with poor performance in tasks that require motor coordination (Repp & Su, 2013). Further, dysfunctions in sensory processing are also related to motor and processing skills (White et al., 2007), and poor performance in sensorimotor skills can be associated with behaviors such as internalizing and internalizing symptoms (Maróti et al. 2019).

Finger tapping tasks (FT) as a paradigm for assessing SMS FT abilities have contributed both to the diagnosis and the treatment of motor and neurological disorders, where the training of these skills is used for the rehabilitation of sensorimotor functions (Repp & Su, 2013). These studies usually involve FT to metronomic stimuli, but there is a growing demand for more ecological/naturalistic stimuli such as music in FT experiments as they may reflect developmental changes in time perception-action coupling that might not captured in the usual laboratory tasks that use stimuli provided by metronomes (Repp, 2005). A few studies have investigated developmental and sex effects on FT performance comparing music and metronome as will be detailed below, but no study has investigated SMS FT abilities with music and metronome in childhood with possible relations with behavioral measures (scales/questionnaires) to better understand how these abilities correlate with behavior in children as they develop.

In the present study we built and applied an automated protocol for assessing SMS through FT to music and metronome stimuli in a built-in software called Music Sync Task containing four tasks for each type of stimuli: with slow regular tempo, fast regular tempo, and changing slow to fast and fast to slow tempo. These tempi were selected to be out of the spontaneous tapping at the tested age, as will be further discussed below. The software Music Sync Task automated the presentation of stimuli and registered children's FT performance to build the database for statistical analyses. To understand how FT changes with age, if this change is related to the type of stimuli (music, metronome), to the type of measure (accuracy or variability in responses) and whether these factors are associated with other types of behavior (internalizing/externalizing and sensory profiles), two analyses were carried out. Analysis 1 focused on the main effects of age and sex on accuracy and variability in FT performance comparing music and metronome stimuli in regular slow and fast tempo tasks. In Analysis 2 we used structural equation modeling to investigate the relationships between FT accuracy and variability with externalizing and internalizing and sensory and behavior measures with the FT tasks including music and metronome at slow and fast regular tempo and with tempo change, considering effects of age and sex.

We hope the results presented in this Thesis can provide useful information for researchers, clinicians and educators for the assessment of SMS abilities through FT to music and metronome in childhood, as well as the possibility to further explore these skills using the open access and easy to use software developed here (Music Sync Task).

2 LITERATURE REVIEW

"Time is of the essence" is a claim in many life and science contexts. The way time is perceived and responded to is critical for survival and for planning future goals and targets (Rubia et al., 2004; Buhusi & Meck, 2005; van Meel et al., 2005; Toplak et al., 2006; Barkley, 2014). Furthermore, our perception of time, space and sensorimotor timing are intrinsically related and can influence our thoughts, our memories and our consciousness because all humans have biological rhythmic patterns that regulate cognition, bodily functions and movements in the environment (Buhusi & Meck, 2005; Repp, 2005; Thaut, 2008; Repp & Su, 2013).

Sound in general, and more specifically musical sounds and rhythms, are auditory stimuli characterized by multiple time marks, event durations, event groupings and subdivisions which can change and modulate our subjective notion of time, with a direct impact in sensorimotor actions by creating different patterns of movements, motor responses and rhythmic habituation. These spontaneous rhythmic movements were investigated and are well described in the literature as a universal phenomenon (or skill) that developed and improved along with the evolution of bipedalism for walking and running in humans and are essential for executing coordinated body movements that are important for survival (e.g., climbing, gripping, hanging) and that are also involved in the development of human language (Mithen, 2005, p.139). Rhythm is often described as the central feature in music and recent studies show it has therapeutic properties in the treatment of disorders that show impairment in movement initiation and coordination, such as Parkinson's and developmental/motor coordination disorders (Thaut et al., 2015). This allows the listener to naturally adapt and coordinate body movements to external stimuli from the environment, such as when singing, dancing or playing music (Repp, 2005; Zatorre et al., 2007; Thaut, 2008; Overy, 2009; Paulson et al., 2013). Furthermore, Droit-Volet (2010) showed that musical sounds are perceived with different durations than non-musical sounds, even with stimuli that contain the same length of time, leading to the conclusion that there is a direct involvement of attention in musical time perception when filtering metrical accents (time marks) within a stream of complex sounds like musical rhythms; generally characterized by the beat salience (most perceptible rhythmic mark), which depends on various sound aspects such as sound attack, intensity, note durations, subdivisions and type of musical instrument used (timbre) (Zatorre et al., 2007; Danielsen et al., 2019).

The subjective notion of time and rhythm can also be altered by an individual's cultural background, motivation and affective involvement with sounds and music, besides familiarity with musical stimuli, which in turn can influence arousal and attention states, such as while listening to and/or playing musical instruments (Repp, 2005; Thaut, 2008; Repp, 2010). Additionally, it is well known that cognition operates through the engagement of several neural networks depending on the tasks at hand (e.g., thalamic-cortico-striatal circuits, also basal ganglia and cerebellum: Schlosser et al., 2006). These activations are necessary for information processing through rhythmic timed patterns that provide attention and working memory their dynamic temporal characteristics, essential for the online storage and manipulation of several types of information (e.g., simple auditory, verbal and visual) during the execution of simple and complex sensorimotor tasks (Buhusi & Meck, 2005; Schlosser et al., 2006) related to music and speech cognition, for example (Janata & Grafton, 2003; Zatorre et al., 2007; Schulze & Koelsch, 2012; Patel & Iversen, 2014).

In recent years, there have been great technological advances in the assessment of sensorimotor abilities such as perception-action coupling, rhythmic entrainment and SMS, where participants tap (usually with their fingers) on sensory platforms and/or electronic percussion instruments connected to computers, which not only automate the presentation of stimuli, but also record tapping performance (Repp & Su, 2013; Schultz & Vugt, 2016; Zanto et al., 2019; Vugt, 2020). Indeed, SMS is a wide field of research with important findings concerning the assessment of sensorimotor development, motor behavior and rhythmic entrainment (Allman & Meck, 2012; Dalla Bella & Sowinski, 2015; Dalla Bella, 2018), also important for music practice (Repp, 2005; Espinosa-Lezama & Montiel-Hernandez, 2020) and music therapy applications in the treatment and rehabilitation of neurological disorders (Thaut, 1997, 2014; Altenmuller & Schlaug, 2015; Thaut et al. 2015).

2.1 Sensorimotor synchronization and finger tapping

In a broad sense, SMS can be defined as the coordination of rhythmic bodily movements with external rhythmic cues in a predictive way (Repp, 2005), a form of referential behavior in which a motor action is temporally coordinated with a predictable external stimulus that serves as a referent (Pressing, 1999). SMS is a basic human ability that takes years to develop, starting early in childhood and reaching adult performance usually around the age of ten years when FT performance is assessed with inter stimulus intervals (ISI) close to spontaneous tapping tempo (ITI≅ 500 ms, two taps per second), as shown in classical SMS studies such as those from Smoll (1974), Thomas & Moon (1976) and more recently by Drewing et al. (2006), McAuley et al. (2006), Repp & Su (2013) and Thompsom et al. (2015).

The first publications found that used this paradigm date back to the work of Lewis T. Stevens in 1886, which involved FT in synchronism with a metronome. Since then, this paradigm has been built upon by several researchers in the field of music and neuroscience [such as Dunlap (1910), Fraisse (1966), Michon (1967), Seashore (1967)], as well as by authors in the music therapy field (Thaut, 2005, 2008, Thaut et al., 2015) and movement science (e.g., Repp & Su, 2013; Dalla Bella et al. 2015, 2017, 2018; Rose, 2021). These authors introduced new approaches and complex statistical models to further the understanding of the SMS through various modalities of behavior in real life (e.g., practice with musical instruments, singing, dancing and sports).

Finger tapping tasks usually require participants to tap with the index finger of the dominant or preferred hand on a specific surface in order to register the taps for further analysis (Dunlap, 1910; Fraisse, 1966; Repp, 2005; Repp & Su, 2013). FT can be performed following stimuli of different modalities (e.g., visual, auditory and kinesthetic), but here we will discuss FT to auditory stimuli that involves simple processing of auditory cues and the ability for coordinating a motor action in response to these stimuli. These FT tasks can also be performed either accompanying the regular beat of a metronome, or musical excerpts, where participants usually have to perceive and coordinate tapping with the main beat (rhythmic accent), the most simple periodic accent in the musical rhythm, also known as beat salience (Danielsen et al., 2019), which needs to be processed in a predictive way through feedback and feedforward processes, allowing finger movements to coordinate with the external rhythmic stimuli (Repp, 2005; Drewing et al., 2006; Thompsom et al., 2015, Tranchant et al., 2016). Finger tapping is also a common paradigm to assess SMS within clinical populations with neurodevelopmental, psychiatry, motor and neurologic disorders [e.g., autism, attention-deficit hyperactivity disorder (ADHD), stroke rehabilitation and Parkinson's disease (Allman & Meck, 2012; Repp & Su, 2013; Thaut et al., 2015).

Performance in FT tasks can be determined considering the rate limits in free tapping, spontaneous FT tempo, FT in-phase with stimuli (1:1), or with metrical subdivisions (e.g., 1:2, 1:3, 2:1), and subtle beat displacements in the rhythmic stimuli bins (Repp, 2005; Danielsen et al., 2019). In general, accuracy and variability in FT performance are the most important parameters. Measures of accuracy can include the local synchronization errors, also called asynchronies, which is the difference between tap's onset and stimulus onset time in ms, and the mean inter tap intervals (ITI) relative to the inter stimulus interval (ISI). Variability can be assessed through the standard deviation (SD) of the mean asynchronies and inter tap intervals in ms and/or the coefficient of variation (CV) (McAuley et al., 2006; Repp & Su, 2013; Thompsom et al., 2015; Monier & Droit-Volet, 2019). According to Repp (2005), variability is one of the best indicators of FT abilities. For example, musicians can perform FT with asynchrony's variability as low as 2% of the ISIs; with professional percussionists reaching nearly zero asynchronies (low synchronization errors). In these studies within typical populations, this synchronization variability can achieve high levels for up to 60% of the ISIs, with some participants performing asynchronies as large as 150 and 200 ms around the target interval, while other performing FT with asynchronies as low as 20 ms, ahead or behind the target interval (Aschersleben & Prinz, 1995; Aschersleben, 2002; Repp & Penel, 2002). For example, studies comparing musicians versus non-musicians found higher FT variability in non-musicians (Franêk et al., 1991; Repp & Dogget, 2007). Nonetheless, irrespective of the way data are analyzed, FT tasks are still a classic way of assessing SMS because FT is a simple and highly informative paradigm that permits several applications for the investigation of perception-action coupling and sensory-motor integration in multidisciplinary contexts (Repp, 2005; Repp & Su, 2013).

In general, when performing FT tasks with metronomes the taps usually precede the stimulus onset by some tens of ms, a phenomenon called *negative mean asynchrony*, in a sign of predictive (feedforward) motor action control (Repp, 2005; Guérin et al., 2021). According to Repp (2005), this phenomenon is related to a subjective synchronization where participants anticipate the taps in order to synchronize with the least possible delay in simultaneity perception. Differently, FT with music often shows a positive asynchrony, that is, a process based on the internal representation of the ISIs (Repp, 2005; Colley et al., 2018). But is worthy to note that asynchronies around 150 ms in either direction (negative/positive) can be considered an anticipation processes due to costs in information processing for the multisensory integration between auditory circuits, nerves and motor outputs in the perception-action coupling processes (Repp & Su, 2013).

Two important concepts in FT performance are the phase and period correction processes. Phase correction is a local correction of finger taps in a moment-to-moment basis in synchrony with the target ISI; it is a fast and automatic adaptation of the taps based on previous tapping information and can be assessed by measuring the mean tap's asynchrony, the difference between the tap's onset around the ISI target in ms. The second process is called period correction and can be analyzed by measuring the individual's mean inter tap intervals in ms (Michon & Van der Valk, 1967; Mates, 1994; Repp & Keller, 2004; Repp, 2005). Phase and period correction also improve with task experience, even in the same experimental session, a common process found in both musicians and non-musicians involving the tap anticipation to minimize deviations related to the perception-action coupling during periodic FT movements. If this process is disturbed, errors can accumulate and cause high distortions, disrupting performance along the task (Repp, 2005).

According to Repp (2005), when the tempo is fast (ISI lower than 500 ms), or the participant is a trained musician, phase correction is mainly based on the two preceding tap asynchronies and some kind of feedback is needed for phase correction to occur properly, more dependent on sensory memory and motor implementation, with less time for correcting the taps, thus anticipation is difficult and taps are more delayed in respect to the target ISI. Differently, longer ISIs, above 1 s, allow for a better prediction of the next stimulus onset, giving rise to the negative mean asynchrony cited above, which denotes that the participant is anticipating the taps for allowing the maintenance of an adequate motor coordination with the external stimuli. Furthermore, when tapping to the beat of music with slow tempos (ISIs ≥ 1 s), subdividing the long interval into shorter rhythmic time bins in perception can be used as a strategy for improving FT performance (Repp, 2003). Thus, depending on the ISI used as a reference and the type of feedback provided, FT performance can involve auditory-motor interactions through both feedback (correction) and feedforward (prediction) processes in order to correct and adjust the movements to coordinate with the external stimuli (Large & Palmer, 2002; Zatorre et al., 2007).

Both phase and period correction processes are at play also when tempo changes are introduced in the rhythmic sequence. It usually takes a few taps for the participant to adapt to the new pace, returning to baseline asynchronies very shortly (Fraisse, 1982; Repp, 2005; Repp, 2010). When tempo changes are large enough to be predicted and perceived consciously, phase and period correction can be enhanced by cognitive control (Repp, 2002; Repp & Keller, 2004). Sometimes, depending on the magnitude of the change, FT correction can take a longer time to stabilize (Semjem, Schulze & Vorberg, 2000; Repp & Keller, 2008; Repp, 2010). According to Repp (2002), auditory feedback from the tap's asynchronies leads to an adjusting of the coordinated movements bringing the successive tap back to the basic phase of the motor synchronization. In this study the author reported an overcorrection process in FT correction after a tempo change, concluding that overcorrection in phase correction behavior is a result of participants' adjusting the timing of their taps by a larger amount than necessary to compensate for the full asynchronies.

These are common processes, for example, when playing a musical instrument in a group or choir where musicians are continuously adapting motor responses to synchronize with rhythmic expression (micro timing deviations) of other musicians (Repp & Su, 2013). It is also a common behavior when adjusting limb movements in sports, dancing or walking according to environmental and task demands [e.g., auditory and visual cues, and/or space characteristics (Clayton et al., 2005; Burger et al., 2014; Kilchenmann & Senn, 2015)]. Some studies in the literature have also applied different and sophisticated statistical models for the analysis of FT depending on population studied, research questions and objectives (Repp, 2002; Wright et al., 2014; Mills et al., 2015; Tranchant et al., 2016; Sowinski & Dalla Bella, 2018).

When rhythmic subdivisions are well noticed (high beat salience) and clear feedback is provided (e.g., auditory, tactile, visual), FT accuracy is enhanced and taps are closer to the target interval (Aschersleben & Prinz, 1995; Repp, 2003; Repp, 2005; Madison, 2014). Further, FT accuracy is higher and variability is lower when the sequence is regular (rhythm/metric does not change) (Repp & Su, 2013; Madison, 2014), and also when clear instructions are given by the experimenter to the participant to pay attention to the task because attention is also important for FT performance (Repp, 2005; Versaci & Laje, 2021; Zhang et al., 2021). Some studies using a dual-task paradigm confirmed that there is a direct involvement of attention, working memory and executive control for both phase and period correction (Tierney & Kraus, 2013; Colley et al., 2018; Maróti et al., 2019; Marvel et al., 2019; Monier & Droit-Volet, 2019; Guérin et al., 2021). In a study by Bååth et al. (2016) using FT tasks (ISI= 600 to 3000 ms) within a dual task paradigm [FT plus working memory (visuospatial n-back task)] it was found that with slow ISI (above 1.3 s), SMS performance was significantly disrupted when compared with FT without distractors. In another study, Holm et al. (2017) also used a dual task paradigm including FT with slow and fast tempi (ISI= 524 to 1431 ms), plus a concurrent task that involved memorizing letters (3 and 7 letters), they found that executive/attentional control processes influenced sub-second repetitive motor timing. These studies are complementary in showing that attentional/executive control and/or working memory play an important role in FT performance.

One possible explanation for the SMS processing as assessed through FT lies on the dynamic attending theory model (DAT) proposed by Large & Jones (1999) where periodic auditory sequences are entrained by internal motor and cognitive neural oscillators, thus generating time expectations by detecting deviations from regularity in the produced sound sequence, while registering the asynchronies between the expected and the actual time of tap occurrence for correcting the next tap. Hence, there would be an intimate relationship between beat perception and motor functions where an increase in attentional energy at expected time of the beat occurrence leads to a focused perceptual processing at these beats in time (Patel & Iversen, 2014). Results from neuroimaging studies showed that phase (asynchrony) and period (ITI) correction involve both distinct neural circuits within dorsal pathways related to the implicit control of action and ventral processes related to the explicit perception and decision making for coordinated movements, although there are overlaps between these areas and processes (Kubovy & Valkenburg, 2001; Repp, 2005; Fedorenko et al., 2012).

Different models also postulate for the involvement of motor memory (Keele, 1968), the action-guided perception (Gibson, 1979) and the motor-guided implementation of temporal aspects of the sensory memory and cognition with the stimuli from the environment (Cassenti, 2011). Hence, when proposing a FT paradigm, care must be taken in choosing the experimental tempi (ISI), the magnitude of change with variable ISIs in the same sequence, the adequacy of all these factors for the age range of the sample, so as to maximize the possibility of obtaining reliable responses, as was done in the present research.

There are still some gaps in the literature on how FT abilities develop in school-aged children, non musicians, and research is scarce regarding comparisons between FT to music and metronome, the subject of the present study as will be detailed below. In the few studies that do investigate these abilities at this age, methods vary largely regarding stimuli type, task characteristics (e.g., inter stimulus interval, presence or absence of feedback, type of movement) and procedures (e.g., FT, foot tapping, bouncing and/or clapping hands and/or limbs), which makes it difficult to draw direct comparisons across studies. Another important issue in FT is the role of instructions given by the researcher, as seen above, which can influence the engagement of attentional resources to perform the task, besides training, intention and motivation (Repp & Su, 2013; Leow et al., 2017).

Further, to perform the tasks properly, participants must show a minimum willingness in following rules and also the intention to engage attentional resources on the task in a form of overt activity where movements are coordinated with the external stimuli (Repp & Keller, 2004; Repp, 2005; Leow et al., 2017; Guérin et al., 2021). In the specific case of music, participants also have to perceive and extract the main beat inside the rhythmic sequence (Dalla Bella et al., 2017; Danielsen et al., 2019), which is probably easier when the musical stimuli are similar to the genre they are exposed to in their daily lives since childhood (i.e., are part of their own culture).

2.2 Sensorimotor synchronization and child development

Sensorimotor synchronization abilities are a marked sign of child development since early infancy, even for rhythmic musical stimuli (Zentner & Eerola, 2010). By the age of six years, children are capable of coordinating simple body movements such as walking, bouncing, dancing, nodding to the rhythm, finger and foot tapping or simply clapping hands (Kirschner & Tomasello, 2009; Monier & Droit-Volet, 2019) with various external stimuli from the environment. For example, Greene & Williams (1993) investigated FT with ISI= 550 ms with metronome in a broad sample of children and adults (6 – 75 ys.) and found that tap variability decreased with age, mainly from 6 to 10 years old, stabilizing after this age, but FT accuracy was lower in children (6 – 10 ys.) than in adults. These authors concluded that this stabilization indicated a marked development of SMS abilities during childhood in terms of central processing systems and cognition regulating the motor responses for controlling coordinated movements with the stimuli. In a recent study by Kim et al. (2022), a strong correlation was found between *beat tapping* and working memory which was mediated by auditory digit span tasks in children aged 7 to 12 years, besides a positive effect of age on the relationship between rhythm discrimination and beat tapping.

In a study, comparing metronome to music, Drewing et al. (2006) showed that children aged 6 to 11 years old showed similar variability in responses to both types of stimuli, irrespective of inter stimulus interval. Further, McAuley et al. (2006) carried out a large study using FT tasks with 305 people aged 4 through 95 years showing that 4 to 5 year-olds performed with lower accuracy than adults in FT tasks with a metronome, but children aged 6 to 7 years showed a performance almost equal to that of adults, indicating that this skill develops quickly and consolidates throughout childhood and early adolescence from ten years old. In a broad developmental study, Thompson et al. (2015) investigated SMS with FT to the beat of snare drum sounds (ISI= 500 and 667 ms) in a sample aged 8 to 80 years and found that children's FT variability (ITI's standard deviation) was greater than that of adolescents and adults at both ISIs. Also, asynchronies were higher and more positive (delayed) in children and adolescents than in young and middle adults. Smoll (1974) and Drewing et al. (2006) also found progressive increasing of FT accuracy from 6 to 11 year-olds with metronome and similar stimuli (clicks) at different ISIs.

Furthermore, results from Monier & Droit-Volet (2019) in an FT study with *beeps* at three tempi (ISI= 500, 700 and 900 ms) in children aged 5 to 8 years old showed no age effects for the ITI's accuracy but a significant decrease in ITI's variability (ITI's coefficient of variation) with increasing age. Together, these findings showed that it is important to consider the type of rhythmic stimuli and type of measure (asynchrony/errors or variability) during development, particularly after the age of 5 years, when children begin to adapt their FT to different ISI. It is also important that studies include a wider array of ISI to better gauge the SMS changes that take place as children mature. For example, in a study of SMS with University students (18 to 34 ys.) comparing metronome to musical stimuli (e.g., pop-dance, dance-lounge, merengue, pop-rock and soul), with tempi between 116 and 132 beats per minute (ISI≈ 500 ms), Tranchant et al. (2016) found that SMS to music and metronome were similar when the music genre presented a high beat salience, such as dance-lounge and pop-rock, as judged by the participants, and SMS performance was worse with merengue and soul genres. The authors concluded that beat salience was considered a good predictor for SMS abilities with music.

According to Repp (2002), FT would be easier when performed with rhythmic musical stimuli than when performed with a simple stimulus such as the metronome, because musical structure, with its intervening rhythmic and metric events in time, exerts an involuntary influence that favors the execution of coordinated movements, a phenomenon also known as groove. Groove can be described as the spontaneous urge to move with musical rhythms in a pleasurable manner and is believed to be caused by strong rhythmic accents, event densities, varied sound intensities and different timbres in the musical stimuli (Madison, 2006; Janata et al, 2012; Stupacher et al., 2013). A recent neural (fMRI) and behavioral study by Engel et al. (2022) showed that samba music, in which there is a high level of synchrony between percussion instruments, elicited more pleasure and desire to move and dance with the beat. They also found stronger bilateral activations in brain areas related to audio-motor interactions for beat and rhythm perception (supplementary motor area, left premotor area, left middle frontal gyrus) with increased synchrony between the percussion instruments, apart from higher activation in an area involved with prosocial emotions and social bonding (subgenual cingulate cortex). The authors concluded that this motor related activity is an important factor for the perception of *feeling groove* and the urge to make rhythmic movements spontaneously to music.

Repp & Su (2013) stated that the use of music in SMS tasks can also contribute to fill a gap that still exists in the literature, with the inclusion of real-life stimuli for children and not just artificial sound stimuli generally used in the laboratory (e.g., metronome, sound bursts, *clics* and white noise). In addition, studies on SMS using music could also contribute to the assessment of these skills, expanding the possibilities of intervention in case of difficulties associated with sensorimotor skills development, because neuroscientific studies have also shown that music directly influences the sensorimotor system and cognition (Repp, 2005; Thaut, 2008; Miendlarzewska & Trost, 2014; Okada & Slevc, 2018; Moossavi & Gohari, 2019) and is also related to language development (Brandt et al., 2012; Trehub, 2013; Patel & Iversen, 2014).

There are some interesting findings regarding children's SMS development in neurosciences as investigated with neuroimaging studies, although there are some difficulties regarding children's neuroimaging data collection when performing motor tasks (e.g., setting's complexity, technical procedures and/or equipment). Children usually have difficulties in engaging in task procedures and following instructions protocols. For example, children often move body parts during the experiments inside the neuroimaging apparatus, creating noise in the data (Cheyne, 2012). Nevertheless, in a study by Wilson et al. (2010) using magneto encephalography (MEG) with children and adolescents aged 8 to 15 years old using tasks that included the coordination in flexion and extension of the limbs, only a few differences in activation between children and adolescents were found in the primary motor cortex and in the contralateral motor cortex, but there was an additional activation of the supplementary and ipsilateral motor area in the cerebellum, thus suggesting that a wider network is activated when the movements are performed by children. A more robust study with children and adolescents aged 6 to 17 years found similar results (Huo et al. 2011). The authors concluded that more studies were needed to better unravel and confirm certain neurofunctional systems and overlapping processes of sensorimotor development in childhood. In this sense, we argue that complementary methods are necessary for explaining the development of these abilities in a multidisciplinary context.

Regarding sex effects in FT, the literature is scarce and the methods and stimuli modalities (e.g., FT, limb movements, drumming with a stick, clapping and bouncing) largely vary, making it difficult to compare results. For example, Wolff & Hurwitz (1976) showed that 5 to 16 year-old girls performed more accurately and consistently (lower variability) than boys in FT to metronomes with ISIs at 500 and 1200 ms. The authors suggested that this effect could be due to developmental advantages for girls in abilities requiring serial organization in the left cortical hemisphere that are responsible for planning serial order in repetitive motor actions (e.g., speech, nonverbal auditory and visual sequences). Differently, Greene & Williams (1993) found that males had less variable responses than females in all age groups. In contrast, Smoll (1974) investigated motor responses in time with a metronome (ISI= 800, 1100 and 1400 ms) and found no sex differences in performance. Volman & Geuze (2000) also found that 7 to 11 year old girls and boys performed similarly in FT with metronomes (ISI= 900 and 1000 ms). The studies cited above showed mixed results and highlight the need for more investigation into this issue.

In the present Thesis, Analysis 1 was conducted to better understand the effects of age and sex in FT accuracy and variability of typically developing school-aged children considering metronome and music at regular slow and fast tempi. This may help in the future to characterize what is typical and atypical regarding FT in populations with neurodevelopmental disorders. Previous studies have shown that this population generally has greater variability when compared to typically developing peers in FT tasks (Repp & Su, 2013). For example, Corriveau & Goswami (2009) carried out a study with children between 7 and 11 years old showing that the group with oral language disorders showed greater variability than the typical group in the performance of a task containing two taps per second (ISI= 500 ms). Recently, studies have also shown that SMS and rhythmic timing abilities in childhood can be a predictor for language disorders (Fiveash et al., 2021).

Other studies focused on analyzing rhythmic timing and coordination of movements in children with Developmental Coordination Disorder (DCD), a condition in which there are sensorimotor dysfunctions. For example, in a study by Whitall et al. (2008) with 7 year-old children with DCD showed greater variability in performance compared to the typically developing control group in a FT task to a metronome at four different tempi (ISIs= 313 to 1250 ms). The authors suggest that children with DCD present impairment or dysfunction in auditory-motor synchronism and that these paradigms may be relevant to study the differences between processing the auditory signal and initiating coordinated motor actions, both dependent on sensory processing and motor implementation. Notwithstanding, these studies with clinical populations of children did not fully explored FT with different types of stimuli (metronome/music) or various FT performance measures such as mean asynchrony and ITI (accuracy) and asynchrony's standard deviation and ITI's CV (variability) as done here in Analysis 1. Analysis 2 went beyond, and explored how all these variables/performance measures, including changing ISI, are associated with behavioral measures (sensorimotor FT abilities, sensory, behavioral, internalizing and externalizing problems).

2.3 Sensorimotor synchronization, sensory processing and behavior

The investigation of sensorimotor skills through FT tasks is an increasingly studied and recognized field in neuroscience research (Wilson, 2010; Cheyne, 2012; Repp & Su, 2013), but its relation with behavior in children's daily and academic activities is still poorly understood. Sensorimotor skills and sensory processing are substrates for primary behaviors, related to postural mechanisms and reflex maturation, such as: muscle tone, postural control, gravitational safety and balance. They are also important for some secondary behaviors related to body perception/proprioception, such as maintenance of the level of activity, alertness and attention, motor planning, bilateral coordination and emotional stability, in addition to academic learning and related aspects (e.g., organization skills, concentration, self-esteem, self-confidence and self-control/regulation and reasoning ability (Ayres, 2005; Kilroy, 2019). According to Dunn (2017), each person has an individual threshold to perceive and respond to day-to-day sensory events, which varies for each type of sensory modality. Likewise, when considering the different sensory modalities, it should be understood that no individual presents only one sensory processing pattern, implying that a person can be both hyper responsive to one sensory modality and hypo responsive to another. Thus, Sensory Integration theory addresses how the brain processes and organizes sensory inputs to produce adaptive motor, behavioral, emotional and attentional responses through sensory processing patterns (Ayres, 2005; Dunn, 2017).

To assess these sensory processing patterns, Dunn (1999) developed an instrument called Sensory Profile, and the current version - Sensory Profile 2 (SP2), and it's short version SSP2, are available in Brazil (Dunn, 2017), where the present study took place. This instrument assesses sensory skills in an ecological way, consisting of a scale related to the sensory and behavioral responses of children in everyday social and school activities, rated by guardians and/or teachers. The answers allow the study of aspects of sensory processing and its disorders, which are also a useful tool for analyzing the perception of parents and educators about the typical or atypical behavior presented by the child in two main aspects: sensory processing patterns and behavior patterns.

For example, Little et al. (2016) studied the sensory processing patterns of children aged between 3 and 14 years in groups with typical development and neurodevelopmental disorders, such as ADHD, autistic spectrum disorder and learning disorders. The results showed that children in the groups with disorders had more sensory processing problems than those with typical development. The authors pointed out that most individuals clearly show differing thresholds and self-regulation strategies when responding to sensory experiences in the environment, and called attention for the need of more research to better understand multiple sensory subtypes in general populations regarding the relationships between sensory processing and behavior.

One important aspect of sensory processing, as assessed with the SP2 within typical population, is the presence of sensory processing deficits of about 14 to 31% in typical children, which affected their school and daily living activities, although it is difficult to draw clear conclusions due to the high variability of sensory processing measures in typical children (Pérez-Fonseca et al., 2019). In a recent study by Delgado-Lobete et al. (2020), comparing typically developing children (6 to 12 ys.) with children with DCD and ADHD, it was found that motor coordination difficulties in general were influenced by sensory processing variability. Additionally and interestingly, 25.7% from the typically developing group showed at least one atypical sensory pattern, showing that even in typical population there is some degree of sensory processing problems, although with lower levels than the clinical groups. Therefore, sensory processing is characterized by great variability and heterogeneity across the population. It is an individual characteristic that allows a person to make sense of the environment. In this sense, research has sought to understand the extent to which the type of sensory responsivity (over- and underresponding) is associated with emotional and behavioral problems (Dean et al., 2018). Emotional problems are generally known as internalizing problems, including anxiety and depression, while externalizing problems encompass hyperactivity and conduct problems (Achembach, 1991; Hannigan et al., 2016).

Furthermore, sensory processing difficulties have been associated with internalizing and externalizing behaviors, not only in clinical populations, but also in typical development (Franklin et al., 2008). Dean et al. (2018) showed that children's sensory avoiding and sensitivity patterns predicted adaptability, while sensory seeking pattern was related to depression and resiliency. Ben-Sasson et al. (2009) found that typically developing children from elementary school (7 to 11 ys.) with sensory over-responsivity towards auditory and tactile inputs showed higher cooccurring internalizing, externalizing and dysregulation problems, besides lower levels of adaptive behavior. Also, in a study by White et al. (2007) comparing typical developing and sensory processing disorder children aged 5 to 13 years old, sensory processing difficulties were related to poorer motor performance.

More recently, Mulligan et al. (2021) showed correlations between externalizing symptoms, as assessed through the Child Behavior Checklist (CBCL: Achembach, 1991), with sensory and sensorimotor aspects of sensory processing patterns, besides visual, auditory and tactile sensitivity in typical developing children, although with large variability. In a study of Blanken et al. (2017), with a large population of school-aged children (6 to 11 ys.), it was found that impairments in the sensorimotor functioning (e.g., speed-accuracy, compensatory movements) as assessed with the NEPSYII-NL scale (by Brooks et al., 2009) were significantly related to internalizing and externalizing problems as assessed with the CBCL (Achembach, 1991). Another study, by Mancini et al. (2017), with a community sample of children aged 7 to 12 years old, the authors reported significant indirect effects of motor skills on internalizing symptoms mediated by self-competence and peer problems.

Additionally, poor motor coordination is associated with internalizing problems such as depression and anxiety in children aged 6 to 12 years (Piek et al., 2010), besides social competence and anxiety symptoms in children aged 8 to 11 years (Ekornas et al., 2010). Regarding clinical populations, Cairney et al. (2013) showed that poor motor skills, as present in children with DCD, are a risk factor for the development of internalizing problems with psychosocial consequences (e.g., low self-competence and lower social support), but these implications are not limited to children with motor disorders. Other authors also pointed out that these motor coordination problems are found in children with anxiety and depression (Waszczuk et al., 2016).

In the present Thesis, in Analysis 2 we investigated the development of SMS through FT tasks in school-aged children (6 to 11 ys.), as well as effects of sex and the relationships between FT performance and sensory and behavior sub-scales from the SSP2 (Dunn, 2017) with the internalizing and externalizing sub-scales from CBCL's brazilian version (Achembach, 1991; Bordin et al., 2013), besides effects of age and sex in the same analysis comparing the use of music versus the metronome stimuli to determine if music facilitates the SMS assessed through FT performance of school-aged children, which in turn could be associated with some aspects of children's behavior in everyday activities. Music was regarded as a possible facilitator for FT because it’s intrinsic emotional and psychophysical aspects, as mentioned above in the literature review, which could possibly benefit performance.

Two separate analyses were performed:

1. Synchrony accuracy and variability in FT performance considering effects of age and sex. This allowed us to reproduce and discuss previous findings regarding children’s basic FT development with regular slow and fast tempo tasks besides comparing music versus metronome stimuli (article accepted for publication at *Psychology of Music*/SAGE – 03/2022).
2. Relationships between FT synchrony’s accuracy and variability with behavioral measures from SSP2 (sensory/behavior) and CBCL (internalizing/externalizing) with music and metronome including all music and metronome FT tasks with the following tempi: regular slow and fast; tempo change slow/fast and fast/slow, besides effects of age and sex on FT performance through structural equation modeling.

These two analyses are complementary in explaining different aspects of children’s FT to music and metronome and their relationships with sensory and behavioral measures, besides effects of age and sex. We hope our findings can lead to the development of new possibilities in the multidisciplinary application of music and metronome stimuli through automated tasks in built-in computer applications, by providing basic knowledge to facilitate future research and practice.

3 OBJECTIVES

GENERAL

To investigate the extent to which sensorimotor synchronization abilities in school-aged children with typical development (6 – 11 ys.), analyzed through finger tapping tasks, changes with age and sex, how these factors are related with sensory and behavioral measures and whether these effects differ for FT following musical or metronomic stimuli.

SPECIFIC

For Analysis 1, the objectives were:
a) To analyze effects of age and sex on FT *accuracy* to regular slow and fast tempo tasks comparing music to metronomic stimuli.
b) To analyze effects of age and sex on FT *variability* to regular slow and fast tempo tasks comparing music to metronomic stimuli.

For Analysis 2, the objectives were:
c) To analyze the structural relationships between FT *accuracy* to regular slow and fast, and to tempo change slow/fast and fast/slow measures relating music and metronome factors, besides effects of age, sex, SSP2 raw sensory and behavioral scores and raw scores from the internalizing and externalizing sub-scales from CBCL.
d) To analyze the structural relationships between FT *variability* to regular slow and fast, and to tempo change slow/fast and fast/slow measures relating music and metronome factors, besides effects of age, sex, SSP2 raw sensory and behavioral scores and raw scores from the internalizing and externalizing sub-scales from CBCL.

4 METHODS

The data used in Analysis 1 and 2 were obtained from the same sample. Therefore, we will describe the data collection process, which was common to both analyses first, and then proceed to the specific aspects of each Analysis.

4.1 Sample

We tested a convenience sample of 6 to 11 year olds with typical development of both sexes. The parameters for the sample size calculation were: a) power= 80%, b) alpha level= 5% (95% confidence intervals). Considering all variables and analyses performed [General Linear Models (GLM) repeated-measures, Confirmatory Factor Analysis (CFA) and Structural Equation Models (SEM)], a minimum sample of 270 children was necessary (G-Power: Faul et al., 2009). Eligibility criteria were having scores within the cut-offs that indicated typical development in the guardian and teacher’s ratings in the questionnaires and not having formal music education.

4.2 Instruments

4.2.1 Instruments used for determining eligibility

Eligibility criteria were having scores within the cut-offs that indicated typical development in the guardian and teacher’s ratings and not having formal music education.

a) Brazilian questionnaire on the child environment - QBAI [Questionário Brasileiro de Saúde e Família (Engel de Abreu et al. 2014)]: composed of twenty questions on child's development, socioeconomic status and clinical history. Children who presented auditory or developmental problems were not included in the research.

b) Conner’s Abbreviated Teacher Rating Scale (CATRS-10, Brazilian version: Brito, 1987): questionnaire for behavior problems such as hyperactivity and inattention, composed of 10 questions responded according to the following four categories and values: 1= none; 2= few; 3= moderate; 4= often, with scores rated by the teachers

and children who had scores above the cut-off points for ages 6 to 11 ys. (cut-off= 14 to 18) and genders were excluded (cut-off= 18 for boys and 14 for girls).
c) Music and Sound History questionnaire (Histórico Sonoro Musical – HSM: Carrer, 2014): ten questions related to previous musical experience and education besides relevant information about the child's relationship with sounds and music and musical preferences in daily activities (Appendix 7).

4.2.2 Instruments used in the analyses

4.2.2.1 Music Sync Task – Finger Tapping

The tasks and stimuli were adopted mainly from Repp (2005), Drewing et al. (2006), Carrer (2014), Thompson et al. (2015) and Tranchant et al. (2016), designed and implemented using a computer built-in software application (Music Sync Task – Figure 1) developed for the purposes of this study and used for the automated presentation of the recorded instructions and stimuli (metronome and music), as well as the registration of the taps in a dataset (.CSV format). The Music Sync Task software is a free application that runs on any computer platform to enable the replication of the present study in different contexts with the same method and procedures (see Figure 1 – QR code access to Music Sync Task and stimuli).

The metronomic stimulus and the instrumental music were produced with a MIDI controller keyboard connected to the computer using audio samples of standard musical instruments from the Logic Pro 9.1 software (Apple Inc. USA) with sounds/timbre commonly used in Western cultures: *cowbell*, *pulse bass guitar* and *studio kit drums* for the bass drum and snare drum sounds. The music's beat accent (or beat salience) was well marked in the music by the bass drum and snare drum through the Logic's MIDI rhythmic quantizing algorithm used to regularize the rhythm in a 4/4 metric based on the same time point as the ISI target for the metronome. An acoustic guitar was live recorded with two basic chords commonly found in POP genre, containing two bars in C major and two bars in B flat major in loop, with no melody or lyrics for preventing bias from language processing issues and strong familiarity with the musical stimuli. The same musical stimulus was used in a previous study (Carrer, 2014). Here, the same music was used with two main tempos, slow and fast, in four task types, as described next in detail.

The Music Sync Task software contains eight auditory tasks, four with music and four with metronome, randomized for each participant before running the tasks. There are four types of tasks with both music and metronome stimuli: 1) slow-regular [ISI= 1000 ms (60 BPM)]; 2) fast-regular [ISI= 333 ms (180 BPM)]; 3) slow to fast; and 4) fast to slow. Each task included 10 s for the participant to practice, and 20 s during which their performance was registered irrespective of task type. The tempi were chosen based on various studies (Repp, 2005), but mainly from Drewing et al. (2006) as intervals that impose mild difficulties because they are considered out of the basic spontaneous timing (ITI≅ 500 ms) found within typical populations (Repp, 2005) (Figure 1 and QR code access to Music Sync Task and stimuli).

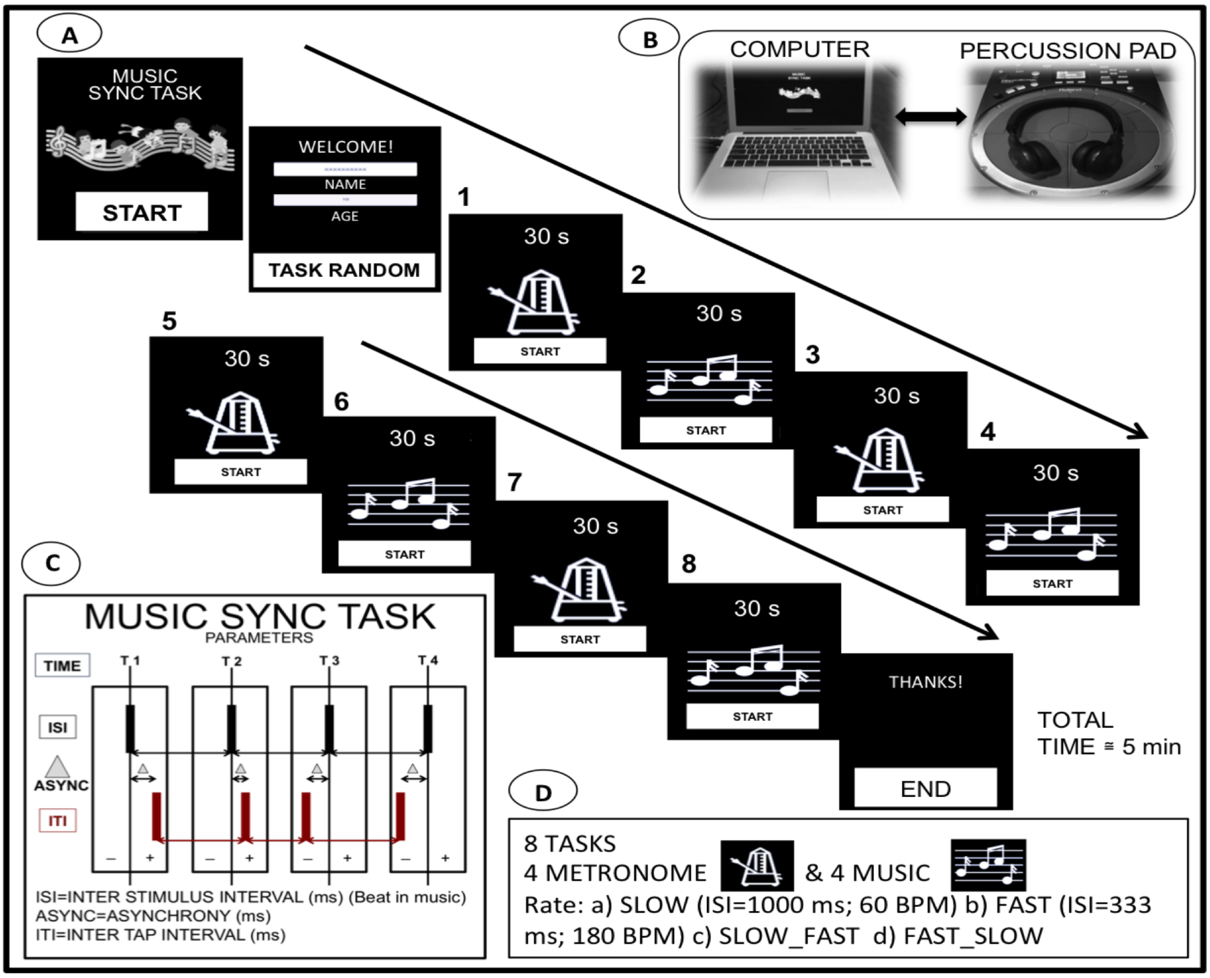

Figure 1. Music Sync Task: A) Music Sync Task software screen “START” presentation, “WELCOME” to insert information and “TASK RANDOM” randomizes the tasks for presentation. B) Equipment C) parameters/measures D) tasks and rates; (ISI= inter stimulus interval; ITI= inter tap interval; BPM= Beats Per Minute). The QR code to access the stimuli is located on the top right of the Figure.

The regular slow and fast tempo FT tasks were analyzed and discussed in Analysis 1 (accepted for publication at *Psychology of Music* – SAGE – 03/2022). For Analysis 2, all FT tasks and the following behavioral measures were considered.

4.2.2.2 Behavioral measures

a) Child Behavior Checklist (CBCL; Achenbach & Rescorla, 2001; adapted for local use by Bordin et al., 2013) - This is a questionnaire used to measure the degree of social competence, emotional and behavioral problems of a child or adolescent, in the present case, according to the perception of the children's guardians. It is composed of 113 questions that are rated according to the following three-point Likert-type scale: 0= absent; 1= occurs sometimes; 2= occurs often. In the present study we used summarized raw scores from questions related with two raw sub-scores from the scale: internalizing behaviors (anxious/depressed; withdrawn/depressed; somatic complaints) and externalizing behaviors (rule-breaking and aggressive behavior) (Achenbach & Rescorla, 2001), the higher the scores, the higher the frequency of the problems. The t-scores are used for screening clinical categories (t-scores > 70), they were not used in the analyses, but were inspected to characterize the sample.

b) Short Sensory Profile 2 (SSP2) – Portuguese version (Dunn, 2017) - This questionnaire is composed of 28 questions covering four characteristics quadrants: 1) seeking, 2) avoiding, 3) sensitivity and 4) registration. Scores vary according to the frequency of occurrence of the behaviors that are rated according to the following six point Likert-type scale: 0= does not apply; 1= almost never; 2= occasionally; 3= half the time; 4= frequently; 5= almost always. The higher the score, the higher the frequency of problems related to sensory and behavioral events. In the present study we used summarized scores from questions related with two raw sub-scores from the scale: sensory problems and behavior problems.

4.3 Procedures

The research protocol was approved by the UNIFESP Ethics Committee (CAAEE-69206517.9.0000.5505) (Attachment) and all participants and their parents provided informed assent and consent, respectively. The convenience sample was recruited from two public schools in the city of São Paulo, Brazil, between January and December of 2019 (before the COVID-19 pandemic). To this end, an invitation letter explaining all ethical aspects, methods and procedures was sent to the schools (Appendix 1). After permission from the schools (Appendix 2), and educational city board (Appendix 3) parents/guardians received an invitation letter (Appendix 4). Those who accepted taking part of the research were sent a series of documents including Consent Form for guardians (Appendix 5) and Assent Form for children (Appendix 6) to be signed, as well as health and behavioral questionnaires to be filled in to check for eligibility criteria (Brazilian Questionnaire on the Child Environment - QBAI (Engel de Abreu et al. 2014) which was returned to the researcher. Teachers were then asked to fill in the Conner's Abbreviated Teacher Rating Scale (CATRS-10, Brazilian version: Brito, 1987) to check that children were developing as expected. The QBAI, CBCL and SSP2 questionnaires are protected by copyright, so they are not included in the Appendix.

Participants were individually tested in a quiet room in their own schools. Informed assent was obtained shortly before the experiment itself. Initially, they answered the Music and Sound History questionnaire (Carrer, 2014) that was read to them and filled in by the researcher with their answers. Participants performed the FT tasks standing in front of the percussion instrument. First, the researcher presented the Roland percussion instrument (HPD-20, Roland Corp. Japan) to the participant and gave some general information about the procedures and explained what they should do. Next, each participant was asked to play a few taps freely on the percussion pad (piezoelectric touch sensor on the instrument with a rubber surface) and adjust it to a comfortable volume. Participants tapped with the index finger of the hand they preferred on the percussion pad and listened to the sound of their own taps (*cowbell* timbre), together with the reference metronome sound and music which they listened to through headphones which contained a digital system for external noise suppression (JBL-E45-BT/USA). The researcher also had a similar headphone to monitor performance (Figure 2). The same experimenter (the author of the Thesis) administered all tests. The children and schools that took part in this study were awarded with a “Science Partner” certificate (Appendix 8).

After starting the software and inserting the participant’s demographic information (name, sex, age, preferred hand), the software automatically randomized the order of the eight tasks just before data collection commenced. Each task was preceded by a pre-recorded instruction requiring participants to follow the main beat in music (most salient beat), and metronome sound. The task contains a training period of 10 s to confirm that the participant understood the instructions. After a period of 3 s of silence, the program started the presentation of stimuli and recorded the participants’ taps for 20 s in each task. The raw data was saved automatically in *.CSV* spreadsheets (Figure 2).

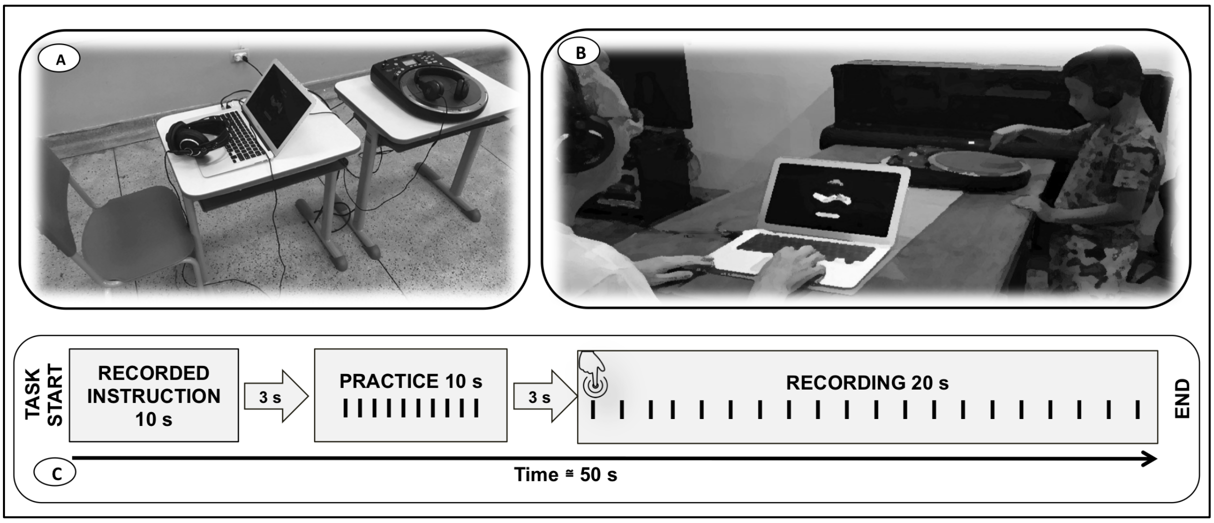

Figure 2. Experimental procedure illustration: A) school setting with equipment; B) session illustration; C) task illustration showing an example of the task’s routine.

Next we present Analysis 1, and following we provide details of Analysis 2 conducted here, their respective results and discussions, and end by providing a general discussion and conclusions.

5 RESULTS

Three hundred and thirty six children and parent dyads assented/consented in taking part in the study, but 31 were not included because they did not fulfill the eligibility criteria: not having developmental/health problems assessed using the QBAI questionnaire (N=17); signs of hyperactivity/inattention problems assessed with the instrument CATR'S-10 (N=14). Only one participant showed CBCL's t-score above 70 (clinical category) on internalizing symptoms, and thirteen participants (4.3%) on externalizing symptoms, but they were not excluded from the sample because this was not a criterion for doing so. The sample's raw scores from the SSP2 sensory and behavioral problems sub-scales were below the cut-off scores for the age range investigated here (raw scores < 50; Dunn, 2017, p. 33).

The final sample used in both Analysis 1 and 2 consisted of 305 children aged 6 to 11 years (56% female), which we considered as typically developing and who were on average from middle income families [in socioeconomic classes according to the Brazilian criteria for socioeconomic status (ABEP, 2020): 3.9 % class A; 53.1 % class B; 41 % class C and 2 % class D and E]. They had no formal music instruction, but 65% of the sample reported participation in cultural activities at school that included musical stimuli. Regarding musical preferences, more than ten genres were listed, with POP music being the most prominent (20.3%) then FUNK (16.4%) and DANCE MUSIC (10.5%), in addition, 23.6% reported no musical preference at all or dubious answers. Thus, this data did not enter our final analyses but can be further investigated in more detail. The final sample presented no complaints at school, neurological disorders or hearing problems as reported by parents and teachers.

5.1 Analysis 1 – Sensorimotor synchronization with music and metronome in school-aged children. (accepted for publication at Psychology of Music – SAGE – 03/2022)

In this analysis we only considered effects of age groups (6 – 11 ys.) and sex (male/female) on FT to music and metronome at regular slow and fast tempi because we were interested in checking basic FT abilities found in previous studies with regular FT tempo tasks, confirming the performance for sex and the age groups studied and guiding future research to broader populations with basic FT tempos and measures.

5.1.1 Statistical analyses of Analysis 1

The analyses were carried out using the SPSS software (Statistical Package for Social Science - IBM Corp. V. 20, USA). The statistical analyses were performed using data after removal of data registration errors and the first three taps from each FT measure to avoid bias in the analyses (Repp, 2005). The data was analyzed with repeated-measures General Linear Models (GLM; Field, 2013) with stimulus type as the within-subject factor with two levels (metronome and music) and two between-subject factors: age (6 levels, 6 to 11 years old) and sex (two levels, males and females). All possible interactions were considered. Four separate models were run for each measure: 1) synchronization accuracy= mean asynchrony in ms; 2) synchronization variability= mean asynchrony's standard deviation in ms (SD); 3) ITI accuracy= ITI as % of ISI; 4) ITI's variability= ITI's Coefficient of Variation in % (CV), with each tempo (fast and slow) as dependent variables, totaling eight models. The *post hoc* analyses were performed with the Dunn-Sidak procedure, which corrects for multiple comparisons, sample and normality bias, and focused on pertinent contrasts. A 95% confidence interval (alpha ≤ 0.05) was applied. Partial Eta Square (η^2_p) coefficient was used to estimate the effect sizes of each factor, where η^2_p between 0.0588 and 0.1379 were considered medium effect sizes and those ≥ 0.1380 considered as large effects (Field, 2013). The analyses considered all participants, including outliers, without missing or imputation of missing data.

5.1.2 Results of Analysis 1

Descriptive statistics of sample and continuous FT measures by age group and sex.

Table 1. Distribution of the sample by age group and sex.

AGE (years)	Mean (SD) Age years	N	%Total	%Female
6	6.47 (0.27)	39	12.8	53.8
7	7.49 (0.32)	51	16.7	54.9
8	8.49 (0.30)	45	14.8	44.4
9	9.53 (0.31)	49	16.1	69.4
10	10.54 (0.29)	75	24.5	65.3
11	11.36 (0.26)	46	15.1	43.5
	Total sample = 9.18 (1.67)	305	100.0	56.0

Next we present the descriptive statistics for all measures included in the GLM models.

Table 2. Synchronization accuracy (mean asynchrony in ms) by age group and task type.

AGE Years	TASK TYPE	Mean	SD	95% CI Lower	Upper	Mean	SD	95% CI Lower	Upper
		SLOW				FAST			
6	**Metronome**	-42.84	58.69	-60.96	-24.72	29.69	25.15	22.43	36.95
	Music	14.05	57.23	0.21	27.90	24.26	26.96	14.66	33.85
7	**Metronome**	-18.32	57.38	-34.20	-2.45	27.49	20.86	21.13	33.85
	Music	34.73	40.52	22.60	46.86	34.57	29.72	26.16	42.98
8	**Metronome**	-17.04	63.05	-33.96	-0.12	28.34	26.10	21.56	35.12
	Music	25.81	37.46	12.88	38.75	30.51	33.94	21.55	39.47
9	**Metronome**	-21.63	58.06	-39.12	-4.15	28.15	21.62	21.15	35.16
	Music	26.69	52.35	13.33	40.05	39.95	30.43	30.69	49.21
10	**Metronome**	-17.13	57.40	-30.82	-3.44	26.56	22.56	21.07	32.04
	Music	30.28	36.55	19.82	40.74	38.56	28.93	31.31	45.81
11	**Metronome**	-17.93	58.24	-34.70	-1.15	21.08	23.36	14.35	27.80
	Music	19.92	39.84	7.11	32.74	42.97	32.10	34.09	51.86

Note: Tasks: (ISI: Slow= 1000 ms; Fast= 333 ms). See text for significant effects.

Table 3. Synchronization variability (mean asynchrony standard deviation in ms) by age group and task type.

AGE Years	TASK TYPE	Mean	SD	95% CI Lower	95% CI Upper	Mean	SD	95% CI Lower	95% CI Upper
		SLOW				FAST			
6	**Metronome**	84.92	35.33	74.60	95.25	74.39	29.38	66.44	82.34
	Music	84.68	39.77	75.40	93.95	79.41	28.18	70.28	88.55
7	**Metronome**	85.73	35.26	76.68	94.78	52.94	24.55	45.97	59.90
	Music	64.85	33.22	56.72	72.98	62.07	30.23	54.06	70.07
8	**Metronome**	72.66	32.54	63.01	82.31	53.08	24.69	45.65	60.50
	Music	61.53	35.08	52.87	70.19	61.23	27.63	52.70	69.76
9	**Metronome**	66.50	29.99	56.54	76.47	54.73	27.99	47.05	62.40
	Music	54.21	27.59	45.26	63.17	60.37	27.82	51.55	69.18
10	**Metronome**	67.54	34.97	59.73	75.34	45.02	25.13	39.01	51.03
	Music	46.40	20.42	39.39	53.40	51.78	30.09	44.88	58,68
11	**Metronome**	61.32	27.34	51.76	70.89	41.65	19.93	34.29	49.01
	Music	44.40	21.59	35.81	52.99	49.63	29.63	41.17	58.09

Note: Tasks: (ISI: Slow= 1000 ms; Fast= 333 ms). See text for significant effects.

Table 4. Inter Tap Interval accuracy (ITI as % of ISI) per age group and task type.

AGE years	TASK TYPE	Mean	SD	95% CI Lower	95% CI Upper	Mean	SD	95% CI Lower	95% CI Upper
		SLOW				FAST			
6	**Metronome**	0.10	5.40	-1.84	1.83	1.17	3.41	0.39	1.91
	Music	1.57	7.13	0.21	2.80	1.25	5.00	0.21	2.25
7	**Metronome**	0.51	8.53	-1.02	2.20	1.21	3.07	0.52	1.84
	Music	0.50	5.61	-0.52	1.75	0.51	2.77	-0.47	1.31
8	**Metronome**	1.13	9.06	-0.54	2.89	0.79	2.24	0.08	1.50
	Music	1.81	4.38	0.54	2.96	0.30	1.88	-0.67	1.23
9	**Metronome**	-0.31	5.31	-2.72	0.82	0.20	1.61	-0.54	0.92
	Music	0.27	2.53	-1.03	1.46	0.19	2.33	-0.75	1.21
10	**Metronome**	-0.50	2.09	-2.02	0.75	0.49	1.97	-0.12	1.02
	Music	0.16	1.97	-0.72	1.23	0.70	3.32	0.01	1.54
11	**Metronome**	-0.36	1.44	-2.02	1.38	-0.10	1.81	-0.84	0.56
	Music	0.03	1.26	-1.20	1.20	0.17	3.40	-0.82	1.06

Note: Tasks: (ISI: Slow= 1000 ms; Fast= 333 ms). See text for significant effects.

Table 5. Inter Tap Interval variability (ITI's CV in %) by age group and task type.

AGE years	TASK TYPE	Mean	SD	95% CI Lower	95% CI Upper	Mean	SD	95% CI Lower	95% CI Upper
		SLOW				**FAST**			
6	**Metronome**	10.97	7.87	8.00	13.80	16.88	11.45	14.17	19.52
	Music	14.03	9.84	11.68	16.22	17.74	9.98	14.95	20.23
7	**Metronome**	14.13	16.22	11.63	16.71	14.30	10.53	12.12	16.80
	Music	10.88	8.58	9.04	13.02	15.69	10.63	13.36	17.98
8	**Metronome**	9.66	11.95	6.94	12.36	15.00	10.09	12.23	17.22
	Music	12.72	10.05	10.38	14.63	13.02	7.49	10.45	15.38
9	**Metronome**	7.80	5.79	4.68	10.28	12.20	8.49	8.98	14.14
	Music	7.26	5.86	4.91	9.30	13.72	9.06	11.64	16.73
10	**Metronome**	6.29	3.67	4.09	8.47	8.41	3.88	6.54	10.58
	Music	6.17	4.24	4.78	8.21	9.85	7.72	8.19	12.18
11	**Metronome**	6.08	3.13	3.55	8.92	9.71	6.52	7.30	12.25
	Music	5.95	4.30	3.75	7.96	8.34	3.43	5.93	10.82

Note: Tasks: (ISI: Slow= 1000 ms; Fast= 333 ms). See text for significant effects.

Table 6. Descriptive statistics for FT accuracy and variability measures by task type and sex.

TASK TYPE	SEX	Mean	SD	Mean	SD
		Async (ms)		**Async variability (ms)**	
Metronome Slow	**Male**	-32.84	57.55	74.07	38.42
	Female	-12.04	57.31	69.59	30.16
	Total	-21.11	58.24	71.54	34.02
Music Slow	**Male**	26.89	44.84	59.56	32.31
	Female	25.59	43.00	54.98	31.74
	Total	26.15	43.75	56.98	32.02
Metronome Fast	**Male**	22.90	23.67	54.23	28.92
	Female	31.09	22.19	49.54	25.28
	Total	27.52	23.17	51.58	26.98
Music Fast	**Male**	34.51	29.15	59.99	30.40
	Female	38.28	31.93	57.24	30.56
	Total	36.64	30.76	58.44	30.47

Note: Async= asynchrony; Slow= 1000 ms; Fast= 333 ms. See text for significant effects.

Table 6. Continuation - Descriptive statistics for FT accuracy and variability measures by task type and sex.

TASK TYPE	SEX	MEAN	SD	MEAN	SD
		ITI/ISI (%)		ITI CV (%)	
Metronome Slow	**Male**	-0.43	5.73	8.68	9.67
	Female	0.40	5.85	9.08	9.36
	Total	0.04	5.80	8.91	9.49
Music Slow	**Male**	1.00	4.37	10.16	8.65
	Female	0.36	3.90	8.23	7.01
	Total	0.64	4.12	9.07	7.82
Metronome Fast	**Male**	0.53	2.37	12.94	9.88
	Female	0.67	2.44	11.72	8.12
	Total	0.61	2.40	12.26	8.94
Music Fast	**Male**	0.47	3.48	12.92	8.16
	Female	0.55	2.98	12.52	9.35
	Total	0.52	3.20	12.70	8.84

Note: ITI= inter-tap interval; ISI: Slow= 1000 ms; Fast= 333 ms. See text for significant effects.

5.1.3 Main results and significant interactions from the GLM repeated-measures analyses.

Next, we present the significant main effect results and interactions from the GLM repeated-measures analyses.

a) Synchronization accuracy (mean asynchrony in ms)

For the slow tempo, we found an effect of stimulus type ($F_{1, 293}$= 156.12; $p <$ 0.001; η^2_p= 0.35), with negative mean asynchrony for metronome and positive mean asynchrony for musical stimuli. The stimulus type and age interaction was not significant, but stimulus type interacted with sex ($F_{1, 293}$= 9.929; $p < 0.002$; η^2_p= 0.03). Boys performed worse (higher asynchrony) in the metronome (p = 0.001), but this only reached a very low effect size. No other interactions or main effects were found ($p >$ 0.08) (Figure 3A). For the fast tempo, there was a main effect of stimulus type ($F_{1, 293}$= 17.707; $p <$ 0.001; η^2_p= 0.06), with higher positive asynchronies with musical stimuli. Stimulus type also interacted with age ($F_{5, 293}$= 3.499; p = 0.004; η^2_p= 0.06), with higher positive asynchrony only in the 9 to 11-year-olds for the music stimuli compared to the metronome at these ages (*ps* ≤ 0.02). For the younger children, there was no difference in synchronization between the music and metronome in these tasks at any age (*ps* > 0.08) (Figure 3B). Age as a main factor was not significant (*ps* > 0.06).

b) Synchronization variability (asynchrony's standard deviation in ms – SD)

Variability in synchrony had the highest effects overall regarding stimulus type. For the slow tempo, the main effect of stimulus ($F_{1, 293}$= 36.173; $p < 0.001$; η^2_p= 0.11) showed higher variability for the metronome than the music ($p < 0.001$). Stimulus type did not interact with any other factor (*ps* > 0.08). Variability also decreased with age in the slow tempo ($F_{5, 293}$= 10.910; $p < 0.001$; η^2_p= 0.16): those aged 6 showed higher variability than those aged 8 to 11-year-olds (*ps* ≤ 0.001), those aged 7 showed higher variability than those aged 9 to 11-year-olds (*ps* ≤ 0.04) and those aged 8 showed higher variability than those aged 10 and 11-year-olds (*ps* ≤ 0.03) (Figure 3C). For the fast tempo, there was a main effect of stimulus type ($F_{1, 293}$= 14.965; $p < 0.001$; η^2_p= 0.05), but in this case with higher variability for music ($p <$ 0.001). Again, stimulus type did not interact with any other factors. Variability decreased with age, irrespective of stimulus type (music and metronome) ($F_{5, 293}$= 10.437; $p < 0.001$; η^2_p= 0.15): those aged 6 showed higher variability than all other age groups (*ps* < 0.001), those aged 7 to 9-year-olds showed higher variability than those aged 10 and 11-year-olds (*ps* ≤ 0.04) (Figure 3D).

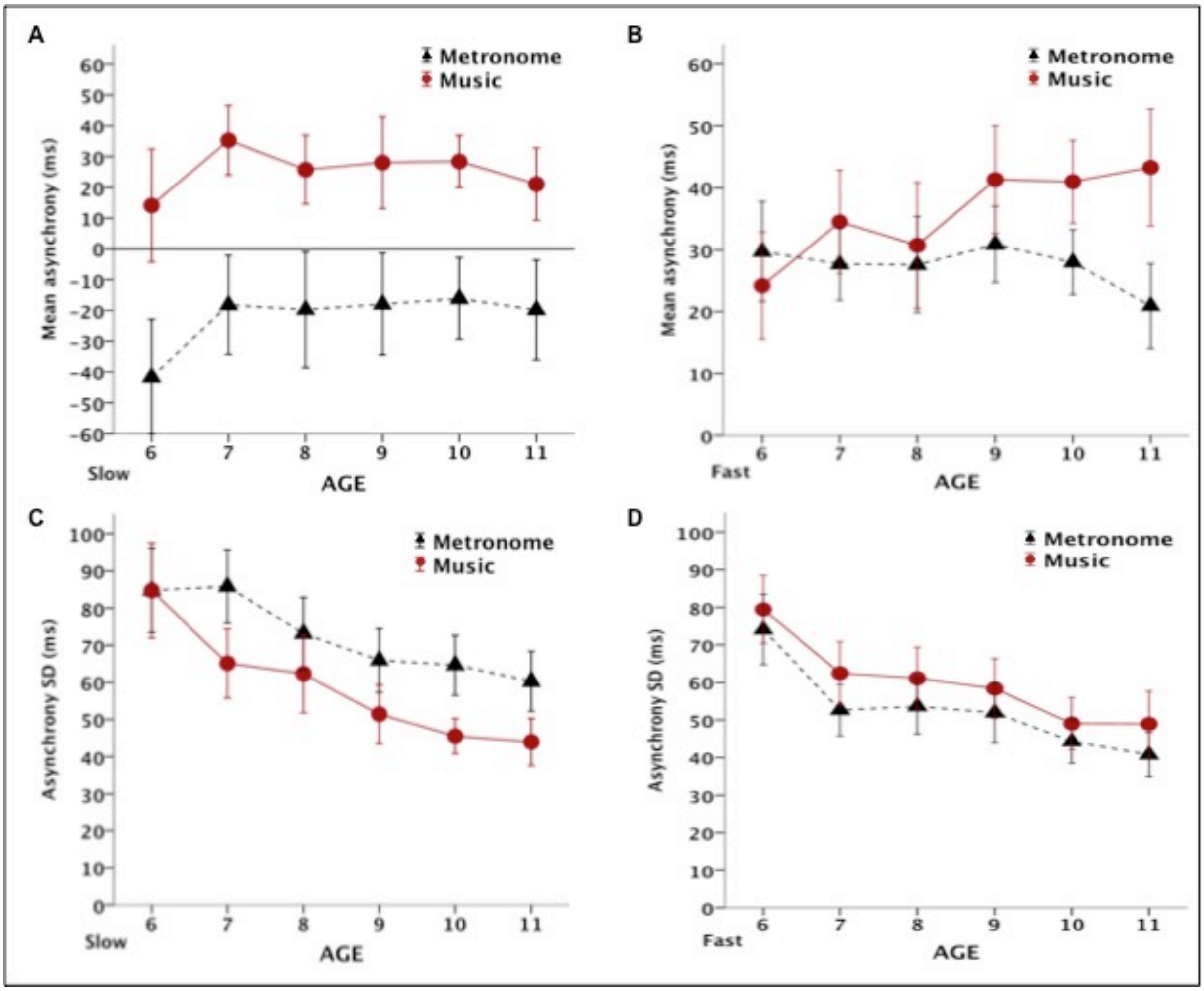

Figure 3. Synchronization accuracy and variability: A (slow) & B (fast) – Synchronization accuracy (mean asynchrony in ms: mean ± 2 Standard Error); C (slow) & D (fast) – Synchronization variability (mean asynchrony's standard deviation - SD) in ms as a function of age group and task type (metronome and music) and tempo (ISI: Slow= 1000 ms; Fast= 333 ms) (mean ± 2 Standard Error).

c) Inter Tap Interval accuracy (IT/ISI in %): no main effects or interactions were observed for either the fast or slow tempi (*ps* ≥ 0.05) (Figure 4A & 4B).

d) Inter Tap Interval Variability (ITI's Coefficient of Variation in %): no main effects were found for stimulus types in the variability of ITIs for either slow or fast tempo ($p > 0.08$). In the slow tempo, although a significant two-way interaction was observed between stimuli type and age ($F_{5,\ 293}$= 2.384; $p = 0.038$; η^2_p= 0.04), no difference comparing music versus metronome at each age were found (*ps* > 0.06), so this interaction mainly indicated a developmental effect ($F_{5,\ 293}$= 10.754; $p < 0.001$; η^2_p= 0.15), with greater variability found for children under eight years old compared to older ones (*ps* < 0.001). For the metronome, inter-tap variability was higher in the 7-year-olds compared to the 9 to 11-year-olds (*ps* < 0.009); and for music, it was higher in the 6, 7 and 8-year-olds than in the 9 to 11-year-olds (*ps* < 0.02), although the difference between 7 and 8 ys. was only marginal ($p = 0.06$) (Figure 4C).

Similarly, for the fast tempo, there was an effect of age ($F_{5, 293}$= 10.473; p < 0.001; η^2_p= 0.15): those aged 6 to 8-year-olds showed higher variability than those aged 10 and 11 ys. (ps ≤ 0.009) (Figure 4D). No other effects or interactions were significant (ps > 0.06).

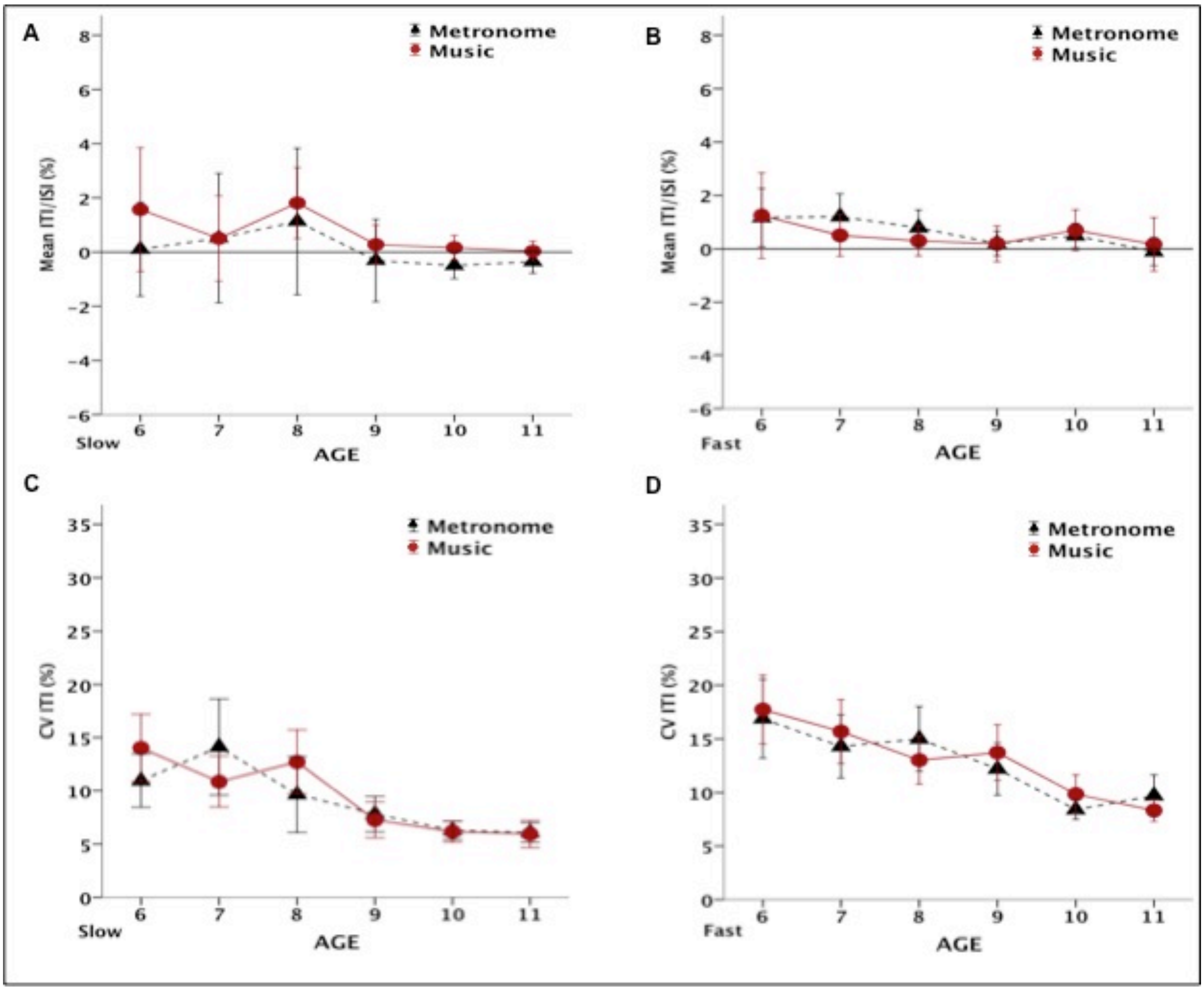

Figure 4. ITIs accuracy and variability: A (slow) & B (fast) – ITI accuracy (ITI/ISI in %) (mean ± 2 Standard Error); C (slow) & D (fast): ITI variability (ITI's CV=Coefficient of Variation in %) as a function of age group and task type (metronome and music) and tempo (ISI: Slow= 1000 ms; Fast= 333 ms) (mean ± 2 Standard Error).

5.1.4 Discussion of Analysis 1

The present analysis investigated the effects of age and sex on SMS finger tapping abilities with auditory metronome and music stimuli in typically developing school-aged boys and girls. Synchronization variability and inter-tap variability were sensitive to development, confirming a progressive downward curve in the variability with increasing age (Smoll, 1974; Volman & Geuze, 2000; Drewing et al., 2006;

McAuley et al., 2006; Monier & Droit-Volet, 2019), irrespective of the type of stimuli (music or metronome) and ISI, with synchronization variability being, on average, between 50 and 80 ms as shown previously (Repp, 2005; Repp & Su, 2013). FT variability largely improves with childhood development (Drewing et al., 2006; McAuley et al., 2006; Thompson, 2015; Monier & Droit-Volet, 2019) due to the higher efficiency of information processing (Vidal et al., 2015) and better attention necessary to coordinate movements (Large & Jones, 1999; Holm, 2017; Guérin, 2021) found in older children. This can also be influenced by the development of strategies for achieving coordination (e.g., moving the head or limbs together with the fingers) (Repp, 2005; Elliott et al., 2009).

Synchronization accuracy did not change with age, corroborating that this ability matures at a young age (6 ys.) as long as FT is measured under conditions which allow auditory feedback, the instructions are clear, and the children can practice before performing the task (Repp, 2005), as done here. However, other studies showed that synchronization accuracy did improve with age in children with a similar age range to this analysis (Drewing et al., 2006; McAulley et al., 2006; Monier & Droit-Volet, 2019), possibly due to the use of different ISIs. Contrary to our hypothesis, however, music did not facilitate FT age-related performance, mostly being comparable to the metronomic stimuli, as was found for adults in the study by Tranchant et al. (2016) using music with a high beat salience, similarly to the musical stimuli used here. Nonetheless, synchronization accuracy and variability were different in some respects for music versus metronome and varied according to tempo (ISI), confirming our hypothesis that the type of stimuli can lead to different patterns of FT, even though this generally did not change with age in our non-clinical sample. Sex only affected one of the eight tested models, showing negligible effects in terms of effect size.

Next, we discuss our results regarding effects of sex and stimulus type (music versus metronome) per ISI in more detail, but it should be noted that only indirect comparisons can be made with previous investigations because they varied from our study in respect of SMS modalities including the method that the subjects were asked to use to respond to the stimuli (e.g., FT and drumming with sticks), the ISIs, the measures used to assess performance and because there are only a few studies that compared music and metronome SMS development among school-aged children (6 – 11).

As regards the effect of sex, we only found a difference in the metronome slow tempo task, in which girls were more efficient in correcting for asynchronies, corroborating the findings of Wolff and Hurwitz (1976), although they used a different study protocol. However, the effect size of this finding was extremely small (η^2_p = 0.03) and was only apparent for this measure and did not interact with age, ISI and stimulus type in any of the other analyses. Therefore, we conclude that sex seems to have a negligible effect on this type of FT task in children, as shown by most authors (Smoll, 1974; Thomas & Moon, 1976; Volman & Geuse, 2000).

Regarding differences between music and metronome stimuli, it should be noted that rhythmic entrainment tap-asynchronies lower than 100 ms in either direction (anticipation or delaying), as was the case here on average, for all conditions at all ages, are usually perceived as simultaneous with the beat of the stimuli (metronome ISI or musical beat) (Muller et al., 1999; Repp & Su, 2013; Kilchenmann & Senn, 2015). Therefore, we found that from 6 years of age, performance could already be considered adequate in terms of accuracy. However, there were differences in synchrony and variability performance when using metronomic and music stimuli depending on ISI. This is not surprising considering that metronome beats are isochronous (discrete timing), while FT to music involves identification of the perceptual center in a complex stream of rhythmic events (Danielsen et al., 2019) that can lead to differences in FT performance.

In general, tap's asynchronies in the slow tempo task with the metronome were anticipated (negative asynchrony), corroborating the findings of Drewing et al. (2006) and McAuley (2006). Although there is no consensus about why this occurs, Muller et al. (1999) suggested that it may be due to the tendency most people have of synchronizing with the perceived interval in an endogenous manner through kinesthetic, auditory and tactile feedback, rather than focusing on the physical interval (exogenous). This results in anticipated tap asynchrony of around 25 to 80 ms for long intervals, and almost null anticipation for short intervals, and is known to occur from the age of 6 years (Repp, 2005; McAulley et al., 2006). In contrast, in the slow tempo task with musical stimuli there was *positive* (delayed) asynchrony irrespective of age, which we speculate can be explained by groove (Janata et al., 2012), as groove is caused by intrinsic musical properties such as rhythmic accents in the music stream, intervening sound intensities, multiple beat accentuations, event densities, varied intensities and/or sound fluctuations that are not present in the discreetly timed and empty interval metronome stimuli (Repp & Su, 2013). According to Pressing (2002), Madison (2006) Janata et al. (2012) and Stupacher et al. (2013), these factors can elicit spontaneous body movements (e.g., movements of the head, trunk, foot or hand), which in turn can stimulate extra rhythmic movements that delay motor responses by some tens of ms. This explanation, however, is speculative because we did not register these body movements. Similar *positive* asynchrony has also been reported in musicians due to more flexible and natural rhythmic fluctuations in performance (Repp, 2010; Janata et al., 2012; Repp & Su, 2013). It is, therefore, unlikely that music-increased delay in FT indicates worse performance if it occurs within 100 ms of the beat, as mentioned. Differently, for the fast tempo, there was a *positive* asynchrony for both music and metronome stimuli at all ages, possibly because it was not possible to anticipate FT at this very fast beat, as found while participants followed the beat of the metronome in the slow tempo. This finding has some support in a study by Repp (2003), who also found a reduction of tap anticipation to metronomes in other fast compared to slow ISIs.

Stimuli type interacted with age in that from 9 years of age, performance began to display the contrasting pattern seen for the slow tempo: an increase in delay in respect of musical responses and a decrease in delayed responses in respect of the metronome. To some extent, this confirms that older children are more able to adapt FT to different rates because the resonance curve for time processing broadens with increasing age (van Noorden & Moelants, 1999). We speculate that this was also due to endogenous factors related to typical sensorimotor and/or cognitive development, such as motor control and attention, allowing older children to tap more flexibly in the SMS FT rhythmic timing range following the pattern seen in experienced musicians mentioned above (Janata et al., 2012; Repp & Su, 2013). This flexibility can facilitate keeping time with musical rhythms, even though this can be associated with some delay costs (Repp, 2005; Loher & Palmer, 2009). These effects of groove in maintaining the correct timing (Madison et al., 2011; Kilchenmann & Senn, 2015; Engel et al., 2022) could also perhaps lessen synchronization variability, which might explain why we found this variability to be lower for the music than the metronome beat at the slow tempo.

However, the inverse was true for the fast tempo (variability was higher for music), possibly because, at higher speeds, people can take advantage of the higher neural entrainment that is more associated with mechanical/metronome stimuli

(Cameron et al., 2019), thereby reducing synchronization variability compared with musical stimuli.

The accuracy in reproducing and maintaining the inter-tap intervals was similar between stimulus types (music and metronome), ISIs, age groups, and sexes and compatible with previous studies (McAuley et al., 2006; Thompson, 2015; Monier & Droit-Volet, 2019), suggesting that this may not be the most useful performance measure for assessing developmental improvement in FT from the age of 6 years. This was different in regards to inter-tap variability, which, like synchronization variability, improved with age, for both music and metronome conditions. This confirms the results of many studies (Repp, 2005; McAuley, 2006; Repp and Su, 2013; Thompson et al., 2015), although some variations were found in the study by Drewing et al. (2006), possibly due to the use of different stimulus type, ISIs and/or age groups.

5.2 Analysis 2 - Sensorimotor synchronization with music and metronome in school-aged children: relationships with sensory profile and behavioral measures.

In Analysis 2 we included the eight FT tasks performed by the children, including regular tempo and tempo change tasks, besides behavioral measures from the CBCL (externalizing and internalizing raw sub-scores) and SSP2 (sensory and behavior raw sub-scores). We applied a robust statistical modeling (CFA/SEM) for using different measures in the same model. These analyses intended to investigate the reliability and the consistency of the tasks in assessing children’s FT abilities, as well as structural relationships between FT and behavioral measures. For this purpose we built four models with two main FT parameters: accuracy and variability; and four types of measures: mean asynchrony (ms), mean asynchrony’s SD (ms), Inter Stimulus Interval (ITI) relative to the ISI in percentage, and the Coefficient of Variation of the ITIs (CVITI) in percentage. Models are detailed below. You will note that ITI measures from the tempo change tasks are divided in fast and slow part due to the characteristics of the measures (mean ITI as percentage of ISI) which would bias the ITI means for the fast (ISI= 333 ms) and slow (ISI= 1000 ms) tempi. This division solves the problem of the mean ITI measures used in the models. The same does not happen with the regular tempo tasks because the ISIs doesn't change during the task. Differently, the mean asynchrony is calculated from the mean tap's asynchrony around the target ISI as explained in the Analysis 1, thus, the different ISIs does not influence tap's mean asynchrony in ms (Drewing et al, 2006), because it lies always in a positive or negative mean value around zero, which denotes perfect synchronization, positive values indicate that the tap was delayed in respect to the ISI target, negative values indicate that the tap was anticipated in respect to the ISI target. It's noteworthy to remember that all results are standardized in CFA/SEM approach for allowing the inclusion of various and different types of measures in the same model. Next we detail the models built for the present analyses.

5.2.1 Statistical analyses of Analysis 2

The four models (CFA) built for the analysis included two FT parameters and continuous measures (indicators) as described below:

Model 1) Synchronization ACCURACY (ASY): mean asynchrony around the target ISI in ms (8 indicators);

Model 2) Synchronization VARIABILITY (VAsy): mean asynchrony's standard deviation (SD) in ms (8 indicators);

Model 3) Inter Tap Interval ACCURACY (ITI): ITI as percentage of the ISI in %. The number 2 included in the variable's name indicates the second part of the task (e.g., ITI_MUS_FS= ITI's fast part, and ITI_MUS_FS2= ITI's slow part) (12 indicators);

Model 4) Inter Tap Interval VARIABILITY (CVITI): ITI's Coefficient of Variation in %. The number 2 included in the variable's name indicates the second part of the task (e.g., CVITI_MUS_FS= CVITI's fast part, and CVITI_MUS_FS2= CVITI's slow part) (12 indicators).

Age, sex and the behavioral measures from CBCL's externalizing/internalizing, SSP2 sensory/behavior raw sub-scores entered the final SEM models as covariates (age as continuous and sex as categorical – female/male). The analyses were carried out with Mplus software package, Version 8.5 (Muthén & Muthén 1998-2020). We initiated by examining the latent structure of all measures/indicators obtained from music and metronome FT using CFA. Specifically, CFA was used to provide evidence basis for the internal structure of four different models pertaining to the two main parameters: accuracy and variability, and including all measures from music and metronome FT tasks, as specified above, in the four models proposed. These models were first run under two main solutions: a) unidimensional: one *general factor* (e.g., ASY), irrespective of stimulus type and tempo; b) two-correlated factor solutions: one latent factor for music FT measures and one latent factor for metronome FT measures. In cases in which the two-correlated factor solutions had good statistical fit, we additionally ran a third model, called bifactor-(S-1) model, which was recently proposed by Eid et al. (2017), as it allows the evaluation of the indicators' and subdomains' reliability, consistency, and specificity for each task. In the bifactor-(S-1) model, one subdomain (latent factor) is chosen as a *reference scale* for comparison with the other domains. In our case, the metronome was used as the reference factor because it is a classical paradigm and widely used in the FT research field and well established (evidence based) by previous studies as a basic and reliable auditory stimulus for FT tasks. This provides the model with a common *general* factor including all tasks, irrespective of type and tempo, and two latent factors, music and metronome; note, however that when this type of bifactor model is applied to analyze different factors, which is the case in our analysis, they are not interchangeable (see Eid et al., 2017; Eid et al., 2018; Heinrich et al., 2020). The final SEM models included the FT measures as indicators for two latent factors: music and metronome; and the behavioral measures from the CBCL and SSP2 internalizing/externalizing and sensory/behavior sub-scores respectively, besides age and sex.

Model fit indices were evaluated according to the following fit measures and their cut-offs, as proposed by Schermelleh-Engel (2003): comparative fit index (CFI), root mean square error of approximation (RMSEA), standardized root mean square residual (SRMR), and χ^2 *p*-value. A RMSEA value equal to or less than 0.05 indicates a good approximate model fit. The χ^2 *p*-value for the corresponding test of approximate fit should be equal to or higher than 0.05 showing that the proposed model is not significantly different from the reference model tested. The CFI value should be greater than or equal to 0.97. Furthermore, an SRMR value less than 0.1 indicate a good model fit. We did not conduct any sort of transformations for the observed indicators (measures) before the analysis and the outliers were not excluded because we used maximum likelihood (ML) parameter estimates with standard errors and a chi-square test statistic that are robust to non-normality and non-independence of observations.

Results are presented as *standardized estimates* (*β*) as in *regressions* with covariates and *factor loadings* for FT indicators/tasks with their respective standard errors. Figure 5 shows an illustration of the final model of interest for SEM analysis.

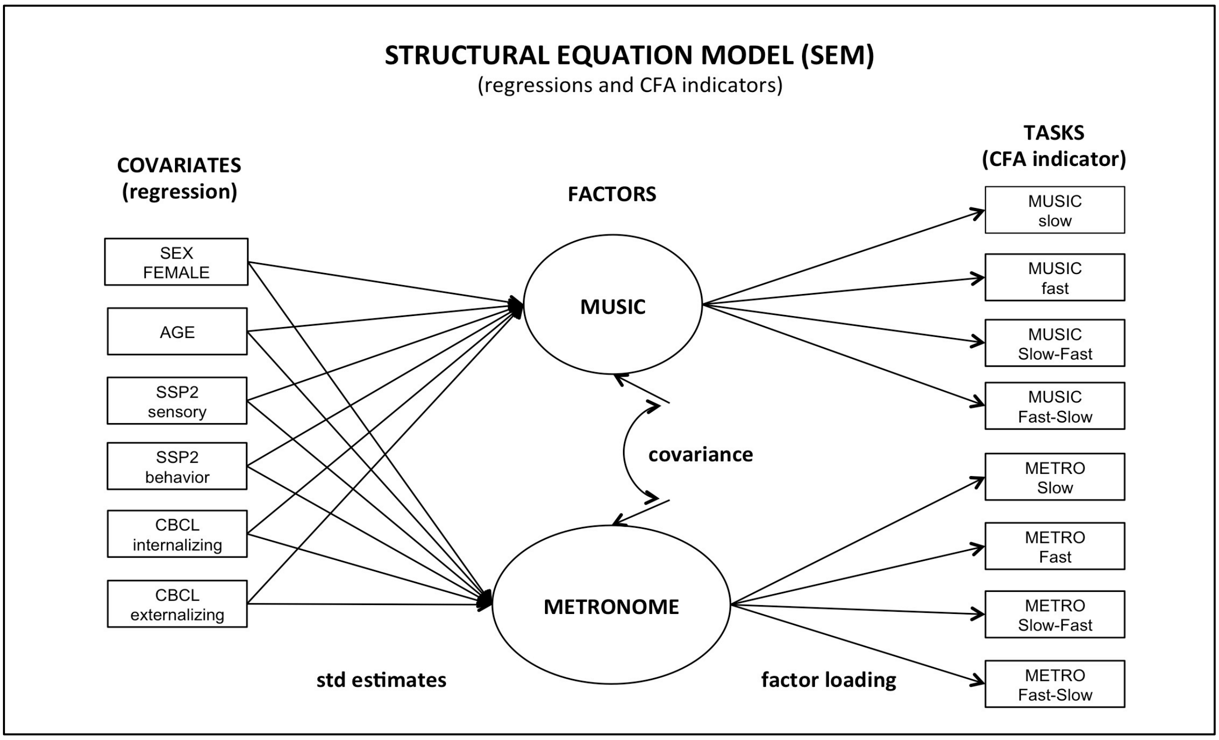

Figure 5. Structural Equation Model (SEM): Illustration of the model of interest built to explore the correlations of FT tasks (CFA indicators) to the factors including the effects of age, sex and behavioral measures obtained with the Child Behavioral Checklist (CBCL) and the Short Sensory Profile 2 (SSP2) as covariates.
Note: Ovals represent the latent factors (music and metronome); rectangles are indicators/tasks and covariates; single-headed arrows represent the impact of one variable on another (std estimates), factor loadings for the CFA indicators and residual variances of the latent factors; the double-headed arrows represent covariances between factors. METRO= metronome.

Regarding SEM FT *factor loadings*, there is no rule of thumb because they express the correlations between indicators and latent factors (e.g., FT to music and metronome factors), thus squared *factor loadings* are the amount of the indicators total variance attributable to the factor. For example, factor loadings equals to 0.30 would explain about 10% of the variable's total variance attributed to that factor. Some researchers state that the minimal level considered for an adequate interpretation of one indicator to the model lies between 0.30 and 0.40 and loadings higher than 0.70 would be excellent for practical significance because it would explain about 50% of the indicator's total variance explained by the factor, which is considered indicative of a well-defined factor structure (Hair et al., 2006, p. 107). The adequacy of the models was determined with the fit indices described above.

5.2.2 Results of Analysis 2

Initially, we present the descriptive statistics of the continuous measures analyzed in the models. Then, results from the bifactor model solution for FT measures (indicators) with GENERAL, MUSIC and METRONOME factors in two independent models: 1) ACCURACY (ASY-asynchrony) and 2) VARIABILITY (VAsy-asynchrony SD), then the final SEM models for FT tasks (indicators), latent factors (music/metronome) and covariates (Sex, Age, SSP2: Sensory/Behavior and CBCL: Externalizing/Internalizing). Table 7 shows the descriptive statistics of the continuous measures used in the final SEM analyses and discussion.

Table 7. Continuous measures used in the final SEM models.

Measures/Indicators	Mean	Standard Error	Standard Deviation
AGE (years)	9.18	0.10	1.67
SSP2_Sensory	22.14	0.76	13.27
SSP2_Behavior	29.19	1.01	17.65
CBCL_Externalizing	21.28	1.16	20.26
CBCL_Internalizing	23.88	1.24	21.57
ASY_MET_Slow	-21.11	3.34	58.24
ASY_MUS_Slow	26.15	2.50	43.75
ASY_MET_Fast	27.52	1.33	23.17
ASY_MUS_Fast	36.64	1.76	30.76
ASY_MET_SF	9.65	1.49	25.96
ASY_MUS_SF	21.98	1.47	25.69
ASY_MET_FS	16.64	1.56	27.20
ASY_MUS_FS	15.76	1.56	27.21
VAsy_MET_Slow	71.54	1.95	34.02
VAast_MUS_Slow	56.98	1.83	32.02
VAasy_MET_Fast	51.58	1.55	26.98
VAasy_MUS_Fast	58.44	1.74	30.47
VAasy_MET_SF	73.44	1.52	26.51
VAasy_MUS_SF	74.07	1.41	24.61
VAasy_MET_FS	67.90	1.46	25.57
VAasy_MUS_FS	77.91	1.34	23.40

Note: N= 305; mean age in years; SSP2= Short Sensory Profile 2; CBCL= Child Behavior Checklist; ASY= mean asynchrony in ms; VAsy= asynchrony's variability in ms; MET=metronome; MUS=music; SF= slow/fast; FS= fast/slow.

Next, Table 8 shows the descriptive statistics of continuous measures analyzed but not discussed (ITI and CVITI) due to the bad fit model indices explained above and presented in the next section.

Table 8. Descriptive statistics for continuous measures not discussed.

Measures	Mean	Standard Error	Standard Deviation
ITI_MET_Slow	0.04	0.33	5.80
ITI_MUS_Slow	0.64	0.24	4.12
ITI_MET_Fast	0.61	0.14	2.40
ITI_MUS_Fast	0.52	0.18	3.20
ITI_MET_SF	-.0.72	0.41	7.12
ITI_MUS_SF	-0.13	0.27	4.63
ITI_MET_SF2	0.58	0.25	4.31
ITI_MUS_SF2	0.64	0.37	6.45
ITI_MET_FS	1.43	0.22	3.91
ITI_MUS_FS	1.18	0.28	4.86
ITI_MET_FS2	0.03	0.56	9.81
ITI_MUS_FS2	-0.28	0.31	5.33
CVITI_MET_Slow	8.91	0.54	9.49
CVITI_MUS_Slow	9.07	0.45	7.82
CVITI_MET_Fast	12.26	0.51	8.94
CVITI_MUS_Fast	12.70	0.51	8.84
CVITI_MET_SF	8.04	0.41	7.15
CVITI_MUS_SF	7.71	0.36	6.32
CVITI_MET_SF2	15.05	0.76	13.32
CVITI_MUS_SF2	16.87	0.79	13.85
CVITI_MET_FS	11.85	0.61	10.57
CVITI_MUS_FS	14.31	0.75	13.10
CVITI_MET_FS2	10.23	0.67	11.65
CVITI_MUS_FS2	9.16	0.44	7.74

Note: N=305; ITI= ITI accuracy (ITI/ISI in %) and CVITI= ITI variability (ITI's coefficient of variation in %). MET= metronome; MUS= music; SF= slow/fast (slow part) and FS= fast/slow (fast part); SF2= slow/fast (fast part) and FS2= fast/slow (slow part).

5.2.3 Model fit indices [unidimensional, two-correlated and bifactor-(S-1) models, before entering the behavioral measures]

Before running the models with behavioral measures and demographics we determined model fit indices for the unidimensional, two-correlated and bifactor-(S-1) factor solution model for the two parameters (accuracy and variability), and the four types of measures described above under evaluation: ASY (mean asynchrony's accuracy), VAsy (mean asynchrony's variability), ITI (accuracy – ITI/ISI in %), CVITI (variability – ITI's CV in %). As can be seen in Table 9, none of the ITI and CVITI models showed acceptable fit, thus the final SEM models were not run in these cases and these measures will not be further discussed. The unidimensional models for the other two measures, ASY and VAsy, did not show a good fit for the data. The two-correlated factor solution showed good fit, but the bifactor-(S-1) models for ASY and VAsy showed better fit and will be analyzed in the next section. Thus only the relations of accuracy (ASY - mean asynchrony) and variability (VAsy - asynchrony's variability - SD) data with the behavior measures were analyzed through SEM and will be presented and discussed further in the analysis.

Table 9. Fit indices of the four tested models.

FT	Models	X^2(df)	*p*-value	RMSEA	CI-95%	CFI	TLI	SRMR
ASY	Unidimensional	46.262(20)	<0.01	0.06	0.041 to 0.091	0.9	0.85	0.05
	Two-correlated	**25.802(19)**	**0.13**	**0.03**	**0.000 to 0.065**	**0.96**	**0.95**	**0.04**
	BI-(S-1) (music)	**21.544(16)**	**0.16**	**0.03**	**0.000 to 0.067**	**0.97**	**0.95**	**0.04**
	BI-(S-1) (metro)	**16.191(16)**	**0.44**	**0.01**	**0.000 to 0.053**	**0.99**	**0.99**	**0.03**
ITI	Unidimensional	116.382(54)	<0.001	0.06	0.046 to 0.077	0.58	0.49	0.07
	Two-correlated	118.623(53)	<0.001	0.06	0.048 to 0.079	0.56	0.45	0.07
	BI-(S-1)	Not estimated						
VAsy	Unidimensional	67.403(20)	<0.001	0.09	0.066 to 0.112	0.96	0.94	0.04
	Two-correlated	**29.160(19)**	**0.06**	**0.04**	**0.000 to 0.071**	**0.99**	**0.99**	**0.03**
	BI-(S-1) (music)	**16.195(16)**	**0.44**	**0.01**	**0.000 to 0.054**	**1**	**1**	**0.02**
	BI-(S-1) (metro)	**26.473(16)**	**0.05**	**0.05**	**0.005 to 0.077**	**0.99**	**0.99**	**0.03**
CVITI	Unidimensional	158.590(54)	<0.001	0.08	0.065 to 0.094	0.86	0.82	0.06
	Two-correlated	125.995(53)	<0.001	0.07	0.052 to 0.082	0.9	0.88	0.06
	BI-(S-1)	Not estimated						

Note: FT= finger tapping data; ASY – accuracy; ITI – accuracy; VAsy - variability; CVITI – variability; Two-correlated (music and metronome); BI-(S-1)= bifactor models for general, music and metronome factors. Significant results are marked in bold. Not estimated= model did not converge in the initial CFA analysis. Significant results are marked in bold.

5.2.4 Findings from the bifactor-(S-1) models

The bifactor-(S-1) model was calculated to estimate the FT indicators' reliability, consistency, and specificity. The synchronization variability model (VAsy) showed higher coefficients of reliability (0.31 to 0.65), when compared to synchronization accuracy (ASY) (0.17 to 0.36). In the bifactor-(S-1) models using metronome factor (MET) as reference for the synchronization accuracy model (ASY), the first indicator showed the highest consistency [Asy_MUS_Slow (91.29%) MUS= music], whereas the other had more specificity variance (ranging from 54.27% to 67.18%). For the variability model (VAsy), the strongest consistency was observed in the VAsy_MUS_Slow (91.20%) and, in terms of specificity, in the VAsy_MUS_Fast (55.00%) (Table 10).

Table 10. Bifactor-(S-1) models results for music and metronome FT indicators.

FT INDICATOR	G Load	G Specific	G (variance)	Specific (variance)	Coefficient of Reliability	% of consistency	% of specificity
ASY_MET_Slow	0.43		0.18	0.00	0.18	1.00	0.00
ASY_MUS_Slow	0.40	0.12	0.16	0.01	0.17	0.91	0.09
ASY_MET_Fast	0.59		0.34	0.00	0.34	1.00	0.00
ASY_MUS_Fast	0.38	0.46	0.14	0.21	0.36	0.40	0.60
ASY_MET_SF	0.60		0.36	0.00	0.36	1.00	0.00
ASY_MUS_SF	0.35	0.38	0.12	0.14	0.26	0.46	0.54
ASY_MET_FS	0.46		0.21	0.00	0.21	1.00	0.00
ASY_MUS_FS	0.27	0.38	0.07	0.15	0.22	0.33	0.67
VAsy_MET_Slow	0.56		0.31	0.00	0.31	1.00	0.00
VAsy_MUS_Slow	0.60	0.19	0.36	0.03	0.39	0.91	0.09
VAsy_MET_Fast	0.72		0.51	0.00	0.51	1.00	0.00
VAsy_MUS_Fast	0.54	0.60	0.29	0.36	0.65	0.45	0.55
VAsy_MET_SF	0.68		0.46	0.00	0.46	1.00	0.00
VAsy_MUS_SF	0.52	0.44	0.27	0.20	0.46	0.58	0.42
VAsy_MET_FS	0.68		0.46	0.00	0.46	1.00	0.00
VAsy_MUS_FS	0.51	0.36	0.26	0.13	0.39	0.66	0.34

Note: N= 305; FT indicators: ASY= synchronization accuracy; VAsy= synchronization variability; G=general factor loadings; SF= slow/fast; FS= fast/slow: Specific= factor loadings specific to music indicators. MUS= music; MET= metronome.

The diagrams of the two good fitting bifactor-(S-1) models with their respective factor loadings and standard errors are shown in Figure 6 for synchronization accuracy (ASY) and Figure 7 for variability (VAsy).

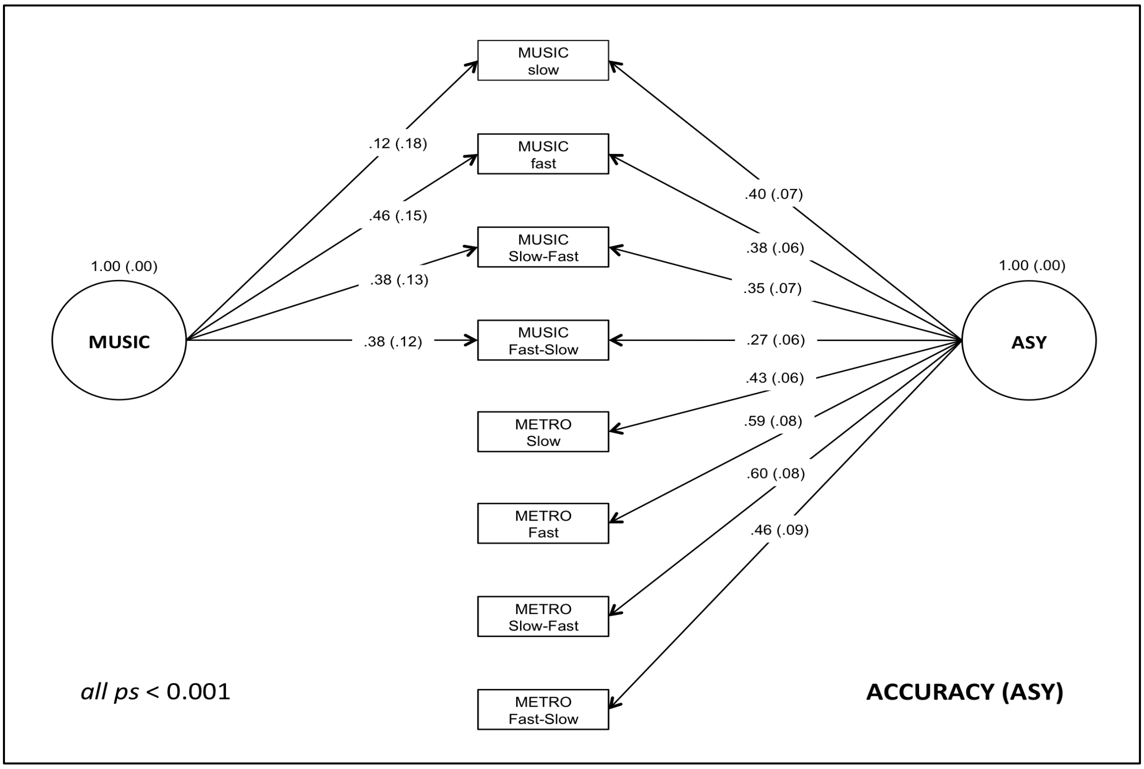

Figure 6. ACCURACY (ASY) Bifactor-(S-1) model for FT's synchronization accuracy.
Note: circles= latent music factor and general FT accuracy (ASY) factor; rectangles= indicators. Values on arrows between circles and rectangles are factor loadings for the general and specific MUSIC and ASY factors. Standard errors are given in parentheses.

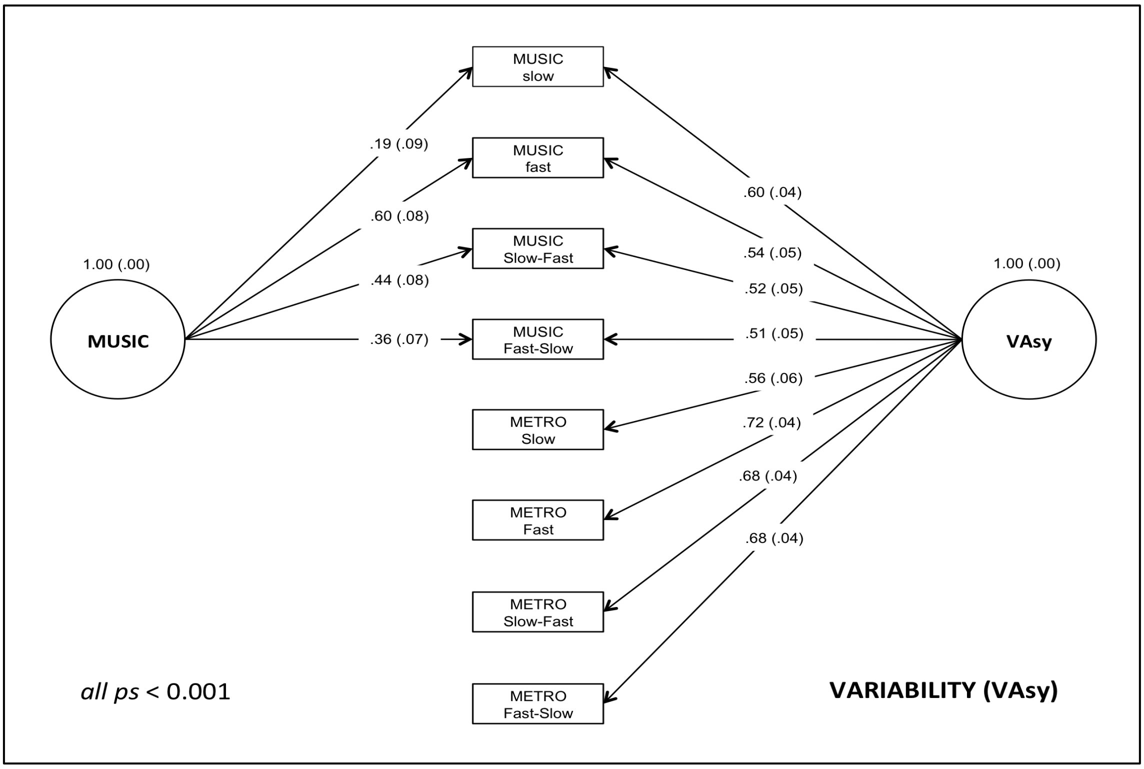

Figure 7. VARIABILITY (VAsy) Bifactor-(S-1) model for FT's synchronization variability.
Note: circles= latent music factor and general FT variability (VAsy) factor; rectangles= indicators. Values on arrows between circles and rectangles are factor loadings for the general and specific MUSIC and VAsy factors. Standard errors are given in parentheses.

5.2.5 Associations between finger tapping, sensory and behavioral measures (SEM).

Under the accuracy (ASY) model, age was statistically associated only with the music factor. The following covariates were associated with the metronome factor: sex and CBCL's internalizing and externalizing behaviors. CBCL's internalizing and externalizing behaviors were also statistically associated with music. Note, that CBCL had similar magnitude of effects (β) on both music and metronome latent factors, but in the opposite direction (Table 11; Figure 8). Under the variability model (VAsy), age was statistically associated with both music and metronome latent factors; sex was statistically associated only with the metronome factor. The CBCL and SSP2 measures were not associated with any of the factors (Table 11; Figure 9). These results are described in more detail next.

Table 11. SEM models and associations between FT with covariates and latent factors.

		Accuracy (ASY)			Variability (VAsy)		
Latent factors	**Covariates**	**Beta (β)**	**Standard Error**	**P-value**	**Beta (β)**	**Standard Error**	**P-value**
MUS	Female	0.10	0.08	0.23	-0.09	0.06	0.14
	Age	0.30	0.09	**<0.01**	-0.47	0.08	**<0.01**
	SSP2S	-0.07	0.09	0.46	-0.02	0.08	0.78
	SSP2B	-0.03	0.10	0.75	0.00	0.10	0.99
	CBCL-Inter	0.55	0.25	**0.03**	-0.20	0.18	0.27
	CBCL-Ext	-0.56	0.26	**0.03**	0.20	0.18	0.25
MET	Female	0.28	0.05	**<0.01**	-0.11	0.04	**<0.01**
	Age	-0.04	0.07	0.60	-0.47	0.07	**<0.01**
	SSP2S	-0.20	0.13	0.12	0.07	0.10	0.44
	SSP2B	0.17	0.12	0.14	-0.03	0.09	0.75
	CBCL-Inter	0.56	0.24	**0.02**	0.02	0.19	0.93
	CBCL-Ext	-0.54	0.25	**0.03**	-0.00	0.22	0.99

Note: SSP2S=sensory profile's sensory aspects; SSP2B=sensory profile's behavior aspects; CBCL-Inter=internalizing; CBCL-Ext=externalizing. Female= difference from male. Significant results are marked in bold; MET= metronome.

Figure 8 depicted the diagram for FT synchronization accuracy model (ASY) with the standardized coefficients and their respective standard errors (when the effect is from the covariates on the latent variables) and the factor loadings (when the observed indicators are underlying to the latent variables). Age was positively associated with accuracy on the music factor, indicating a lower accuracy with increasing age, although with minimum effects (β= 0.30; p < 0.01). Sex had significant association only with the metronome factor, where girls showed higher variance than boys, although with negligible effects (*β*= 0.28; *p* < 0.01). Regarding behavioral measures, in the case of SSP2's sensory and behavior measures, there were no significant associations of both measures, sensory and behavior, with FT accuracy (*βs* < 0.20; *ps* > 0.05). In the case of CBCL's internalizing and externalizing measures, results showed that higher levels of Internalizing behaviors were associated with lower FT accuracy in the music (*β*= 0.55; *p* < 0.05) and metronome factors (*β*= 0.56; *p* < 0.05). On the opposite direction, higher levels of Externalizing behaviors were associated with higher accuracy in both music (*β*= -0.56; *p* < 0.05) and metronome factors (*β*= -0.54; *p* < 0.05). Factor loadings for the eight indicators were moderate to strong ranging from 0.40 to 0.64. Finally, covariance between music and metronome latent factors was moderate (COV= 0.74; *p*< 0.001).

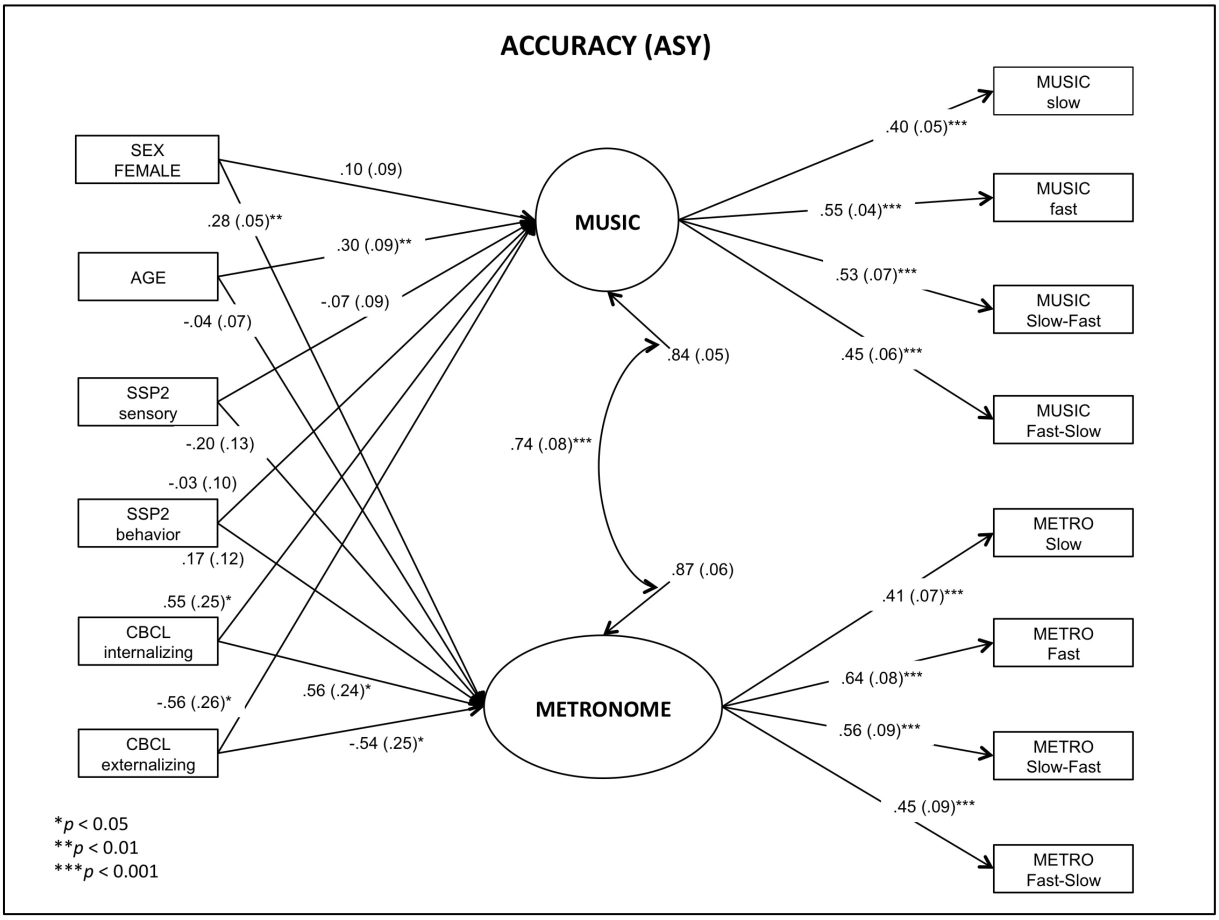

Figure 8. Structural Equation Model for FT accuracy (mean asynchrony) including the effects of age, sex and the behavioral measures (SSP2= sensory and behavior; CBCL= internalizing and Externalizing symptoms).
Note: Ovals represent latent factors music and metronome; rectangles represent observed variables; single headed arrows from ovals to rectangles are standardized estimates for covariates, factor loadings for indicators and factors residual variances; the double-headed arrow between the factors are correlations between the factors residual variances (number on latent factor arrow). Standard errors are in parentheses.

Figure 9 depicted the diagram for FT variability model (VAsy) with the standardized coefficients and their respective standard errors (when the effect is from the covariates on the latent variables) and the factor loadings (when the observed indicators are underlying to the latent variables). Age was significantly associated with variability in both music and metronome factors, with lower FT variability with increasing age (*βs*= -0.47; *ps* < 0.01). Sex showed significant effects only on the metronome, where the girls showed lower variance than boys, although with negligible effects (*β*= -0.11; *p* < 0.01). Regarding behavioral measures, results showed no significant associations of SSP2's sensory and behavior measures, or CBCL's internalizing and externalizing problems with FT variability (*ps* > 0.05). Factor loadings were strong, ranging from 0.56 to 0.72. Finally, covariance between music and metronome factors was moderate (COV= 0.74; *p* < 0.01).

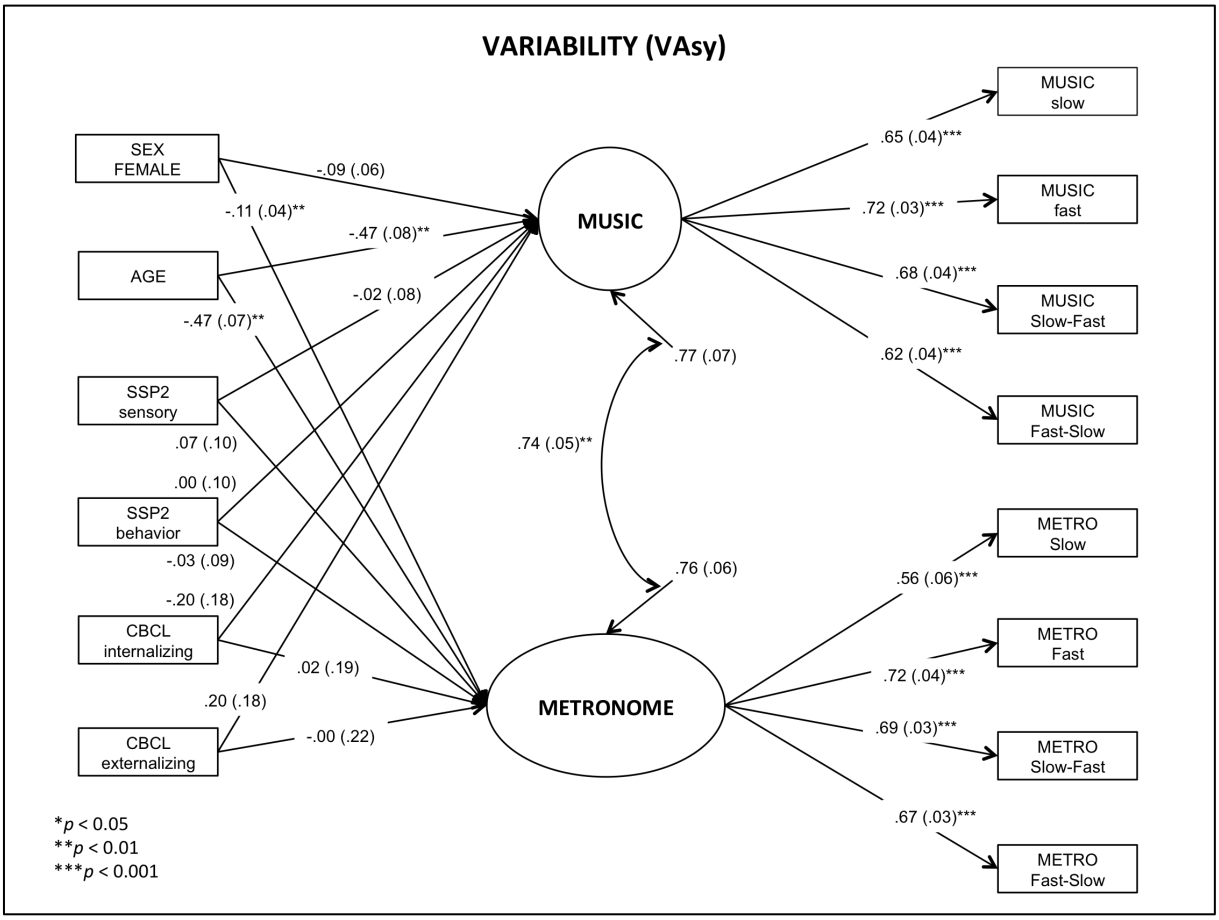

Figure 9. Structural Equation Model for FT variability (mean asynchrony's SD) including the effects of age, sex and the scores on behavioral measures (SSP2=sensory and behavior; CBCL= internalizing and externalizing symptoms).
Note: Ovals represent latent factors music and metronome; rectangles represent observed variables; single headed arrows from ovals to rectangles are standardized estimates for covariates, factor loadings for indicators and factors residual variances; the double-headed arrow between the factors are correlations between the factors residual variances (number on latent factor arrow). Standard errors are in parentheses.

5.2.6 Discussion of Analysis 2

In Analysis 2 we investigated relationships between all FT measures with SSP2's sensory/behavior profiles and CBCL's internalizing and externalizing behaviors, besides effects of age and sex. Direct comparisons of our findings with the literature are difficult to be made due to the scarcity of similar study designs. CFA/SEM approaches enabled us to extend basic knowledge from the field of FT paradigms with new evidence on these abilities in children (6 to 11 ys.) and it's relationships with behavior beyond the basic analysis of simple measures such as mean asynchronies and ITIs. In our research we were able to fit models to include all measures and it's relationships with each other, also analyzing the correlation of the indicators with music and metronome factors and the effects of covariates at once.

We will focus the discussion on the two SEM models built with the measures established by the good fit indices in the initial CFA analysis (synchronization accuracy - ASY and variability - VAsy) because they provided strong evidence of reliability, validity and specificity. For these models, overall, we found a moderate correlation of FT's metronome and music latent factors, confirming that both stimulus types are independent, but still complementary in explaining FT performance among school-aged children.

This is an important issue because we were interested in how these abilities develop with age and how they are influenced by sex and behavioral aspects from daily life in an ecological approach such as the social and school environment, comparing music as an ecological stimulus to metronomic sound as an artificial stimulus generally used in laboratory. Indeed, our results could perhaps serve as basis for future studies in the music education and music therapy fields in order to gather reliable measures for assessing sensorimotor synchronization abilities not only in typical developing children, but hoping our results could lead future studies with broader populations.

In Analysis 2, FT accuracy was associated with age only for the music factor, reproducing some results found in Analysis 1 regarding music's regular fast tempo, and some previous studies, although methods varied among them (Greene & Williams, 1993; Repp, 2005; Drewing et al., 2006; McAuley et al., 2006; Repp & Su, 2013; Thompson et al., 2015), confirming the evidence that relationships between children and musical stimuli at fast tempo can influence performance's accuracy, perhaps because of the specific characteristics of musical stimuli already cited in Analysis 1, such as groove, intervenient sounds and beat salience, which can influence performance, besides arousal and attentional aspects (Bååth et al., 2016; Holm et al., 2017). Music and metronome FT relationships with the behavioral measures from the SSP2 sensory and behavior scores did not reach significant associations with FT performance. This may have been due to possible confounders in terms of methods and data collection, and/or to the large variability of the scores from the questionnaires answered by the guardians (Delgado-Lobete et al., 2020), also found in other typical developing children studies (Pérez et al., 2019). Furthermore, only the SSP2's combined sub-scores for *sensory* and *behavior* problems were used in the analyses, so we encourage future studies to combine other sub-scores and quadrants to better assess different aspects of the sensory and behavior problems and their relationships with FT performance that were not explored here and could possibly confirm and expand our findings.

Regarding associations of Internalizing and Externalizing behaviors from the CBCL with FT, they were not significantly associated with FT variability, but were statistically associated with accuracy, where performance showed that lower accuracy in both music and metronome factors were associated with higher levels of Internalizing behaviors, which are similar to the results from Piek et al. (2010), who found that variability in sensorimotor behavior in infancy was associated with anxious and depression problems in school-aged children, and Mancini et al. (2017), who found associations between motor skills and internalizing problems, although they used different measures and methods.

For externalizing behaviors the effects were in the opposite direction, with higher FT accuracy having been related with higher levels of externalizing behaviors. There are some studies which show that externalizing and internalizing behaviors would be related to extroversion and introversion (Hyatt et al., 2019), respectively, leading us to speculate that our results could perhaps match findings that show that extroverted children respond better in tasks demanding fast motor responses as found by Wickett & Vernon (2000) and Stahl & Rammsayer (2008), also corroborating results from Jamshidzad et al. (2018).

Sex had negligible effects in both analyses, providing more evidence that sex does not *substantially* influence FT and its association with sensory and internalizing/externalizing behavior. Previous inconsistent findings regarding sex effects on FT may have stemmed from the use of different types of stimuli (metronome music) and or ISI and musical genre so it is as yet not possible to draw any formal conclusions on this subject. Notwithstanding, sex effects where extremely small, so in practical terms are unlikely to influence results in young, typically developing children.

6 GENERAL DISCUSSION

The present Thesis investigated the effects of age and sex on FT abilities (accuracy and variability) using auditory metronome and music stimuli in a broad sample of typically developing school-aged children (6 – 11) (Analysis 1) and it's relationships with SSP2 sensory profile and CBCL internalizing and externalizing behaviors (Analysis 2).

Results from Analysis 1 showed that variability measures were the most sensitive to developmental FT improvement with a downward curve in FT variability with increasing age that was confirmed in Analysis 2 and previous studies in the literature (Smoll, 1974; Thomas & Moon, 1976; Volman & Geuze, 2000; Repp, 2005; Drewing et al., 2006; McAuley et al., 2006; Repp & Su, 2013). In contrast to developmental effects on FT variability, FT accuracy was found in Analysis 2 to be associated with behavioral measures (externalizing/internalizing behaviors), suggesting that researchers interested in the relations of SMS with psychopathology could focus mainly on FT accuracy, although we still encourage further studies with variability measures to better clarify and confirm our findings. We also encourage future studies to include attention and inhibitory control tasks to investigate wether these factors influence FT performance with music and metronome in childhood, when the cognitive control of attention, thoughts, actions and emotions show great improvement (Zelazo et al., 2004) and could perhaps be related to FT performance. Relationships between attention and FT were found recently in adults by Guérin et al. (2021), using a dual-task paradigm, thus we argue that these protocols could also unravel attentional and executive functions effects on FT performance also in school-aged children because motor and cognitive functions are of great importance during development and academic performance (Pascual et al., 2019).

In the present research, we were also able to fill a gap in the FT literature regarding developmental studies by testing the reliability, validity and specificity for all tasks included in the experiment, bringing more evidence-based analysis through confirmatory factor analysis and structural equation modeling approach with music and metronome as latent factors and including age and sex, besides behavioral measures as covariates in the model. The fact that SSP2 was not associated with FT performance needs more attention. It could well be that this scale is not sensitive to sensory profile due to the high variability in the sub-scores in typical populations.

Alternatively, this may have happened because we only used combined sub-scores, so future studies might consider investigating this scale in more detail, for example, using specific items/answers and/or combined quadrants and different sensory patterns through the SEM approach, which would require a larger sample than that used here.

Although complex, Analysis 2 made it possible to better understand whether there is a differential association of FT skills to music and metronome stimuli, both of which made complementary contributions in explaining FT abilities. The CFA showed that all FT tasks, irrespective of stimulus types and tempi, are good indicators of FT performance, with moderate to strong loading factors. This gives us valuable information for future research and practical applications in the field of SMS research and practice, expanding knowledge on this subject with new information from different ISIs and maybe comparing different modalities and behavioral measures.

Furthermore, we also highlight some additional implications of our results for the music therapy field. By combining the automated assessment of FT abilities with both music and metronome we were able to provide reliable data regarding FT performance in a large sample of typically developing children aged 6 to 11 years. We therefore argue that doing so may be useful for the assessment of SMS FT abilities in clinical populations, at least for the tempos and stimuli used here. Although we did not include children with clinical conditions in our study, we encourage future studies to expand our findings. We hope the literature will benefit from using FT data from the Music Sync Task software combined and compared with other motor timing/control tasks containing various tempos and relating these behaviors to behavioral questionnaires in a more ecological approach. Future studies could also relate FT performance with music therapy assessment instruments, such as rhythm questionnaires and rhythmic tests, video recordings of rhythmic/motor performance (Thaut et al., 2015), and also motion capture technologies for recording multiple limb movements coordinated with music for both clinical assessment and research purposes (Johnston et al., 2018).

Moreover, our findings regarding stimulus type (music versus metronome) have implications not only in respect of developmental assessment, but also for multidisciplinary treatment approaches, including music therapy for cognitive and sensorimotor disorders in children, such as developmental coordination disorder (Whitall et al., 2008; Kartasidou et al., 2012), dyslexia (Colling et al., 2017), attention deficit and hyperactivity disorder (Toplak et al., 2006), autism (Srinivasan et al., 2013) and possibly speech/language impairment (Corriveau & Goswami, 2009). This is because although FT to music or metronomes may produce similar results for the rehabilitation of motor disabilities (e.g., developmental coordination disorders; motor control disorders) in the field of music therapy, music has often proved to be more stimulating in clinical settings because of its intrinsic motivational and positive emotional characteristics (Repp, 2005; Janata et al., 2012; Thaut et al., 2015).

Nonetheless, metronomes are useful for practicing rhythm within music training contexts and when purer time marker measures, free of cultural implications, are of interest (e.g., Parkinson's condition). In addition, the differential pattern of effects of responses to music and metronomes may pave the way for future studies of FT that can help to improve the understanding of rhythmic entrainment in respect of ecological and artificial sounds. This might also aid in the identification of specific difficulties related to SMS, or even speech processing in clinical populations (Patel & Joseph, 2003; Fenk-Oczlon & Fenk, 2009; Phillips-Silver et al., 2012; Lagrois et al., 2019), that might be more easily picked up using one or the other type of stimuli.

Overall, the FT accuracy at all tested ages was already quite high. In this sense, it is important to keep in mind that sensorimotor synchronization is a referential behavior that is naturally learned since early infancy (Pressing, 1999; Zentner & Eerola, 2010; Repp & Su, 2013). We also speculate that metric subdivisions of 500 ms present in musical stimuli could have benefitted performance, but due to the young age group studied here (6-11 years) our instructions were formulated to ensure that participants follow the *main beat* in music (4/4 metric in Fast= 180 BPM and Slow= 60 BPM). However, because we did not collect any other measure on the rhythmic subdivisions, it is difficult to hypothesize about this as a covert strategy to improve FT performance in our data. Furthermore, it is noteworthy that the executive control for movement coordination and the ability to inhibit distractors (e.g., visual, auditory) during a simple sensorimotor task develops fast at the age range studied here (Repp, 2005; Repp & Su, 2013) and this can also help to explain the good average accuracy and the downward curve in FT variability with increasing age for both music and metronome stimuli.

We also argue that the good average performance in all tasks are perhaps due to the fact that an adequate environment and best conditions were provided for facilitating FT, such as auditory feedback, clear instructions from the experimenter before the session, recorded instructions before each task, besides practice and the use of musical genre that are part of the participants culture, as pointed by Repp & Su, 2013. Additionally, children were standing in front of the percussion instrument and body movements were not prohibited during the tasks, thus contributing to better movement proprioception, which in turn can positively affect performance, as found by Kirchner & Tomaselo (2009) and Rose et al. (2021).

Finally, we hope that our findings can inspire and inform future research, always bearing in mind that methodological decisions must be made about costs and tradeoffs in choosing methods and procedures. One final consideration regards the FT tasks and the comparisons between musical and metronome stimuli. The results from our CFA/SEM analyses allowed the confirmation of Music Sync Task as a useful tool for FT assessment in ecological settings. Although the results from music and metronome stimuli were similar, they also showed to be independent and complementary factors in the assessment of FT abilities in school-aged children. Thus, we argue that further investigations are needed to extend and confirm our findings with broader populations.

7 CONCLUSIONS

7.1 CONCLUSIONS OF ANALYSIS 1

- FT accuracy is similar through all age groups, irrespective of task type and tempo, indicating that accuracy is almost at adult levels by the age of six years.
- FT accuracy differs between the slow and fast tempi, indicating that the performance in respect of music and metronome stimuli depends more on task tempo.
- FT variability decreases with increasing age, irrespective of stimulus type (music and metronome) and tempo, mainly between 6 and 9 year olds, stabilizing after this age, indicating that this measure is the most sensitive for capturing FT developmental effects.
- Effects of sex on FT performance were negligible, indicating that performance in FT tasks is similar for both male and female children aged 6 to 11 years.

7.2 CONCLUSIONS OF ANALYSIS 2

- FT variability decreases with age for both music and metronome factors.
- Music and metronome factors are correlated, but still independent and complementary in explaining accuracy and variability in FT performance.
- Higher FT accuracy is associated with lower Internalizing behaviors in both music and metronome factors.
- Higher FT accuracy is associated with higher Externalizing behaviors in both music and metronome factors.
- Sensory profile is not associated with FT accuracy or variability for either music and metronome factors.
- Sex does not substantially affect children’s FT performance for either music and metronome factors.

8 GENERAL CONCLUSIONS

- FT variability decreases from the age of six years, irrespective of stimulus type (music and metronome).
- Variability is the most sensitive parameter for capturing developmental effects on FT performance, irrespective of stimulus type (music and metronome).
- Sex has negligible effects on FT performance of children aged 6 to 11 years.
- FT accuracy, but not variability, depends more on tempo than stimulus type (music and metronome).
- Higher FT accuracy is associated with lower Internalizing behaviors, irrespective of stimulus type (music and metronome).
- Higher FT accuracy is associated with higher Externalizing behaviors, irrespective of stimulus type (music and metronome).
- Accuracy is the most sensitive parameter for capturing children’s behavioral problems on FT performance, irrespective of stimulus type (music and metronome).
- Music and metronome stimuli factors are correlated, but still independent and complementary in explaining children’s accuracy and variability on FT performance.

9 LIMITATIONS

The limitations of this research relate to possible sample confounders that we did not control for:

- Individual exposure to informal musical environments in social, family and educational contexts besides musical preferences not well captured by the musical questionnaire due to dubious answers given most by younger children (6-8 years) in our sample, which could have influenced the attention and the motivation for performing the tasks;
- The role of spontaneous body movements in FT during the experimental session could not be assessed because we were interested in allowing the participants to perform the task in the most natural way so we did no collect this data, also because this should be done in the laboratory with proper equipment which was not the objective of our research;
- Lack of manipulations of attack and duration of musical stimuli, which affect the perceived center of the beat and could have influenced the results.
- Effects of testing in the school environment, where visual and auditory distractions were present, even though the experiment at each school was performed in the same quiet room.

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11 APPENDIX

Appendix 1 – LETTER INVITING SCHOOLS TO TAKE PART IN THE STUDY

São Paulo, março de 2019.
Prezado(a) Diretor (a)

Conforme contato prévio, vimos solicitar gentilmente sua colaboração no projeto de pesquisa cujo título é "MÚSICA E SINCRONIZAÇÃO SENSÓRIO-MOTORA EM CRIANÇAS NA IDADE ESCOLAR: RELAÇÕES COM O PERFIL SENSORIAL E O COMPORTAMENTO", o qual tem como responsáveis os pesquisadores da Universidade Federal de São Paulo (UNIFESP), do Departamento de Psicobiologia. A infância é um período onde se desenvolvem várias habilidades necessárias ao desempenho escolar e ao comportamento adequado nos vários contextos da vida. Nesse período também ocorre a maturação das habilidades sensório-motoras. Entender melhor o desenvolvimento dessas habilidades permite possíveis intervenções para aprimorar o desenvolvimento pleno ao longo da infância. O objetivo da pesquisa é avaliar e comparar o desempenho de crianças com idade entre 6 e 10 anos em relação à faixa etária e o sexo em tarefas de sincronização sensório-motora com música e metrônomo.

Essa avaliação não implicará em nenhum risco à saúde ou bem-estar dos participantes. Os benefícios deste estudo poderão ser constatados ao final da pesquisa. Fica assegurado o direito à confidencialidade das informações, não sendo divulgada nenhuma identificação dos sujeitos participantes da pesquisa. Fica garantida a orientação acerca dos procedimentos e do andamento da pesquisa, bem como dos dados obtidos a partir do material analisado. Não há despesas pessoais para o participante, assim como não há compensação financeira pela participação na pesquisa. Os dados e o material das avaliações serão utilizados somente para fins desta pesquisa e de apresentações em congressos e palestras, guardando a identidade dos sujeitos avaliados. O projeto não envolve qualquer custo para a escola participante e todos os materiais necessários ao desenvolvimento da pesquisa serão abarcados pelo orçamento já previsto no projeto. Este estudo foi aprovado pelo Conselho de Ética em Pesquisa da Universidade Federal de São Paulo (Unifesp). – Rua Botucatu, 572 – 1º andar – cj 14, 5571-1062, FAX: 5539-7162 – E-mail: cepunifesp@unifesp.br.

Mas quais os benefícios efetivos para esta escola?
É importante ressaltar que a escola ou a direção/coordenação não terá seu nome divulgado em nenhum momento, exceto se quiser figurar na seção de agradecimentos nas publicações cientificas oriundas desta pesquisa. Os benefícios diretos para a escola são:

1) Além de contribuir no entendimento do desenvolvimento motor e do comportamento na infância, a escola receberá um Certificado da UNIFESP como "Escola Parceira da Ciência" E o aluno receberá o certificado "Aluno Amigo da Ciência".
2) Oferecemos gratuitamente 2 ou 3 palestras que podem ser escolhidas pela Direção da Escola com as opções abaixo, a serem ministradas na própria escola. Podem participar da palestra os profissionais da educação da escola bem como pais/responsáveis. O dia e horário deve ser agendado com a equipe de pesquisadores. Se a direção optar por um tema que não está na lista abaixo podemos discutir a possibilidade em virtude da expertise dos pesquisadores participantes.

Criança agitada tem o Transtorno da Hiperatividade?
Qual a diferença entre Problemas de Aprendizagem e Transtornos de Aprendizagem?
Desenvolvimento cognitivo e aprendizagem, o que a escola precisa saber.
Lidando com comportamentos difíceis na escola.
Música, Neurociências e educação: interfaces com a musicoterapia.

Esperamos contar com a sua valiosa colaboração.
Antecipadamente agradecemos,

PESQUISADORES RESPONSÁVEIS: Prof. Dra. Monica C Miranda & Doutorando Luiz Rogério J. Carrer
DEPARTAMENTO DE PSICOBIOLOGIA – UNIFESP
ENDEREÇO: Rua Napoleão de Barros, 925, 1ºandar Vila Clementino – São Paulo – Brasil – CEP 04039-06

Appendix 2 – MODEL OF DOCUMENT INDICATING ACCEPTANCE OF THE SCHOOLS IN TAKING PART IN THE STUDY

CARTA DE ADESÃO
UNIVERSIDADE FEDERAL DE SÃO PAULO
PROGRAMA DE PÓS-GRADUAÇÃO EM PSICOBIOLOGIA

O Programa de Pós-Graduação em Psicobiologia da Universidade Federal de São Paulo, através da orientação da Prof[a]. Dr[a]. Mônica Miranda, está realizando um levantamento de dados cognitivos, comportamentais e musicais em crianças de 6 e 10 anos de idade. O estudo objetiva avaliar padrões de percepção e expressão rítmicos e musicais de crianças com desenvolvimento típico através de tarefas de sincronização sensório-motora, comparando o desempenho por idade e sexo. Deste modo, verificar-se-á o comportamento das crianças com relação às habilidades sensório-motoras. Ainda não existem trabalhos no Brasil, o que demonstra a importância deste estudo frente à ausência de testes musicais específicos para a avaliação do impacto do ritmo no desenvolvimento cognitivo.

Como procedimento será realizada uma bateria de tarefas rítmicas musicais e a aplicação de escalas de comportamento, além de um questionário sobre o histórico sonoro-musical, cuja duração será de 40 minutos, aplicados individualmente. Fica garantido o sigilo absoluto em relação à identidade e demais dados dos participantes, cabendo a utilização das informações obtidas no estudo somente para fins de pesquisa.

Quaisquer dúvidas a respeito do projeto, favor contatar com Luiz Rogério Jorgensen Carrer, aluno e pesquisador do programa de Psicobiologia da Unifesp.
Gratos pela participação,
Prof[a]. Dr[a]. Mônica Miranda
Aluno de doutorado: Luiz Rogério Jorgensen Carrer (11- 99465-6091)

ESCOLA:____
Autorizado por: _______________________________Cargo/Função________________

Assinatura______________________________________

Appendix 3 – ACCEPTANCE OF THE STUDY PROTOCOL BY THE REGINAL EDUCATIONAL CITY BORD

UNIFESP
UNIVERSIDADE FEDERAL DE SÃO PAULO
1933

São Paulo, 28 de março de 2018
A/C DIRETORIA REGIONAL DE EDUCAÇÃO BUTANTÃ - DRE BT

Objeto: Termo de Compromisso para a realização de pesquisa científica.

Solicitamos por meio desta a autorização da diretoria regional de ensino do Butantã para que a escola municipal de ensino fundamental: EMEF Professor Júlio de Mesquita, situada na Rua Dr. José Aires Neto, 25 - Jardim Bonfiglioli, São Paulo - SP, CEP: 05594-040, possa participar do Projeto de Pesquisa de doutorado: "MÚSICA E SINCRONIZAÇÃO SENSÓRIO-MOTORA COM CRIANÇAS NA IDADE ESCOLAR: RELAÇÕES COM O PERFIL SENSORIAL E O COMPORTAMENTO.", desenvolvido pelo pesquisador na Universidade Federal de São Paulo (UNIFESP) e financiado pela FAPESP, pelo qual eu sou o pesquisador responsável pela realização.

Declaro concordar com as normas estabelecidas no Memorando Circular no. 003/2017 SME-G enviado pela Secretaria Municipal de Educação às escolas municipais no que tange a: a) o item I, III, IV e V; b) quanto ao item II, ressalto que o pesquisador é formado em instituição de ensino superior e atualmente é doutorando no Departamento de Psicobiologia da UNIFESP, Escola Paulista de Medicina/SP. c) quanto ao item IV, enviaremos as publicações pertinentes ao diretor do estabelecimento de ensino, nas quais o anonimato dos participantes da pesquisa é assegurado, mas não recomendamos condicionar a publicação à aprovação do conteúdo pela SME, pois caracterizaria uma violação da interpretação dos dados, o que estaria em desacordo com as normas de boas condutas científicas. Todos os procedimentos serão realizados respeitando as normas éticas vigentes (resolução 466 do Ministério da Saúde) vide termos de consentimento anexos ao projeto. Ressalto que, de acordo com a resolução acima citada, todos os dados serão utilizados somente para fins de pesquisa, não havendo registro de imagem de nenhum participante ou da escola. Ficamos à disposição para dar maiores esclarecimentos e sanar quaisquer dúvidas que os responsáveis pela escola poderão ter.

Desde já agradecemos por sua atenção.

Pesquisador responsável: MT MS Luiz Rogério Jorgensen Carrer

Musicoterapeuta; Mestre em Educação e Saúde (UNIFESP); Doutorando no departamento de Psicobiologia da UNIFESP; e-mail: rogercarrermt@gmail.com

Universidade Federal de São Paulo (UNIFESP). Departamento de Psicobiologia

Rua Botucatu, 862 - 1o andar - CEP 04023-062 - São Paulo / Brasil

Tel.: (55) (011) 2149.0155 - FAX (55-11) 5572.4092

Appendix 4 – INVITATION LETTER WITH INSTRUCTIONS TO PARENTS/GUARDIANS

PREZADOS PAIS/RESPONSÁVEL

Você está recebendo esse material porque a escola onde seu filho(a) estuda está participando de uma pesquisa desenvolvida pela Universidade Federal de São Paulo tendo como responsável o pesquisador Luiz Rogério J. Carrer. A seguir mostraremos um passo a passo sobre como preencher esses formulários da pesquisa encaminhados para você.

1) Leia a primeira folha (Termo de Consentimento Livre e Esclarecido - TCLE), ela explica como é a pesquisa em detalhes, e se você concorda que seu filho (a) participe, ao final tem um espaço para a sua assinatura. Após assinar essa autorização pode continuar para o passo seguinte.

2) Preencha o questionário de saúde (QBAI), a primeira página desse questionário pergunta sobre a saúde de seu filho(a). Se ele(a) tem ou teve alguma doença grave, você não precisa responder as outras fichas, já que a pesquisa incluirá na análise final crianças que não apresentam problemas de desenvolvimento e diante disso agradecemos imensamente a participação até aqui. De qualquer forma, devolva as fichas que você preencheu para a escola pois seu filho participará normalmente da atividade musical oferecida pela pesquisa.

3) Se seu filho(a) não apresentar problemas aparentes de desenvolvimento, continue preenchendo os outros questionários. Em cada um deles tem as instruções para o preenchimento.

4) Você receberá uma resposta sobre as possíveis alterações do comportamento da criança que pudermos observar pelos questionários.

O termo de consentimento (TCLE) tem o contato do pesquisador.

Agradecemos imensamente pelo seu tempo. Essa pesquisa será muito importante para as crianças brasileiras nessa fase do desenvolvimento.
Pesquisador responsável:
Luiz Rogério J. Carrer
Fone: 99465-6091

Appendix 5 – CONSENT FORM

TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO

Título da pesquisa: "Música e sincronização sensório-motora em crianças na idade escolar: relações com o perfil sensorial e o comportamento".

Senhores Pais ou responsáveis, a Universidade Federal de São Paulo – UNIFESP e o Programam de Pós-Graduação em Psicobiologia-UNIFESP-SP está realizando uma pesquisa sobre música e cognição de crianças com desenvolvimento típico. O objetivo é avaliar o desempenho de crianças com idade entre 6 e 10 anos comparando o desempenho em relação à faixa etária e o sexo em tarefas de sincronização sensório-motora com música e metrônomo. Os procedimentos serão realizados através da aplicação de tarefas de sincronização sensório motora e escalas de comportamento, serão realizados em uma única sessão com duração aproximada de quarenta minutos. Cada participante realizará as tarefas uma vez. A participação no projeto será encerrada após a avaliação. Essa avaliação não implicará em nenhum risco à saúde ou bem-estar dos participantes. Fica assegurado o direito de desistir de participar da pesquisa, conforme a resolução 466/12 do Conselho Nacional de Saúde/MS. Os benefícios deste estudo poderão ser constatados ao final da pesquisa. Fica assegurado o direito à confidencialidade das informações, não sendo divulgada nenhuma identificação dos sujeitos participantes da pesquisa. Fica garantida a orientação acerca dos procedimentos e do andamento da pesquisa, bem como dos dados obtidos a partir do material analisado. Não há despesas pessoais para o participante como exames ou consultas, assim como não há nenhum tipo de compensação financeira pela participação na pesquisa. Os dados e o material das avaliações serão utilizados somente para fins desta pesquisa e de apresentações em congressos e palestras, guardando a identidade dos sujeitos avaliados.

Acredito ter sido suficientemente informado sobre a descrição da pesquisa que li ou que foi lida para mim, descrevendo o estudo "Música e sincronização sensório-motora em crianças na idade escolar: relações com o perfil sensorial e o comportamento". Eu discuti com Luiz Rogério Jorgensen Carrer sobre a minha decisão em participar nesse estudo. Ficaram claros para mim quais são os propósitos do estudo, os procedimentos a serem realizados, as garantias de confidencialidade e de esclarecimentos permanentes. Ficou claro também que minha participação é isenta de despesas. Concordo voluntariamente em participar deste estudo e poderei retirar o meu consentimento a qualquer momento, antes ou durante o mesmo, sem penalidades ou prejuízo ou perda de qualquer benefício que eu possa ter adquirido.

Responsável legal pela criança: Declaro que obtive de forma apropriada e voluntária o Consentimento Livre e Esclarecido deste participante, ou representante legal para a participação neste estudo.

Nome:____Data:__________________

Assinatura: ____

Pesquisador principal: Declaro que obtive de forma apropriada e voluntária o Consentimento Livre e Esclarecido do participante (ou representante legal) para a participação neste estudo. Declaro ainda que me comprometo a cumprir todos os termos aqui descritos.
Assinatura:____ Data:____________________
Luiz Rogério Jorgensen Carrer
Endereço: R Napoleão de Barros, 925
CEP: 04024-002
TEL: 99465-6091
Em caso de dúvida sobre a ética da pesquisa o comitê de ética poderá ser contatado para esclarecimentos em qualquer momento da pesquisa no endereço abaixo:
Comitê de Ética em Pesquisa da Unifesp (CEP – UNIFESP)
Endereço: rua Botucatu, 572, 1^0 andar, conjunto 14
Bairro: VILA CLEMENTINO CEP: 04.023-061
UF: SP Município: SÃO PAULO
Telefones: 11-5571-1062 / 5539 –7162 – Email: cepunifesp@unifesp.br

Appendix 6 – ASSENT FORM

TERMO DE ASSENTIMENTO INFORMADO PARA MENORES

Meu nome é Luiz Rogério Jorgensen Carrer e estudo na Universidade Federal de São Paulo – UNIFESP. Meu trabalho é pesquisar sobre a cognição em crianças entre 6 e 10 anos de idade. O objetivo é avaliar o desempenho nas tarefas por idade e sexo. Eu vou informar você e convidá-lo para participar desta pesquisa. Você pode escolher se quer participar ou não. Discutimos esta pesquisa com seus pais ou responsáveis e eles sabem que também estamos pedindo seu acordo. Se você vai participar na pesquisa, seus pais ou responsáveis também terão que concordar. Mas se você não desejar fazer parte na pesquisa, não é obrigado, até mesmo se seus pais concordarem. Você pode discutir qualquer coisa deste formulário com seus pais, amigos ou qualquer um com quem você se sentir à vontade para conversar. Pode haver algumas palavras que não entenda ou coisas que você quer que eu explique mais detalhadamente porque você ficou mais interessado ou preocupado. A qualquer momento eu poderei parar para responder a você e explicar suas dúvidas. Este procedimento não oferece qualquer dano à saúde ou risco de desconforto. Os benefícios poderão ser apresentados após o término da pesquisa, indicando os resultados e a importância do estudo. Fica assegurado o direito à confidencialidade, ou seja, seu nome e outras informações pessoais não serão divulgados. Os resultados da pesquisa serão utilizados para estudos, apresentações e discussões sobre o assunto, mas sem revelar nenhum dado particular. Por fim, sua participação é voluntária e poderá sair da pesquisa, se assim o desejar.
Caso queira conversar com alguém pode procurar pelas seguintes pessoas:

Profa. Dra. Sabine Pompéia
Bióloga e orientadora UNIFESP-SP
5549-6899
Luiz Rogério Jorgensen Carrer
Pesquisador principal
Musicoterapeuta e doutorando - UNIFESP
Fones: 3721-0554 ou 99465-6091

Certificado do Assentimento

Eu entendi que a pesquisa é sobre testes rítmicos e musicais.

Assinatura da criança/adolescente:___________________________

Assinatura dos pais/responsáveis:___________________________________

Ass. Pesquisador principal:__________________________________
Dia/mês/ano:____

Appendix 7 – MUSIC AND SOUND HISTORY QUESTIONAIRE - HSM

Histórico Sonoro e Musical - HSM

NOME:____

IDADE: __________**DATA NASC.:** _____________**LOCAL:**___________________

PAI: ____

MÃE: ____

IRMÃOS/IDADE: ____

APRESENTA ALGUM PROBLEMA DE AUDIÇÃO? _______________________

ACOMPANHAMENTO MÉDICO ? _____________________________________

MEDICAÇÃO: _______________________**DESDE:**_________________________

ESCOLA: ____

SERIE: ____

PARTICIPA DE ATIVIDADES MUSICAIS NA ESCOLA? QUAIS?

____

PREFERÊNCIAS MUSICAIS:

____

SONS QUE GOSTA: ____

SONS QUE NÃO GOSTA: ____

CONHECIMENTO MUSICAL PRÉVIO:________________________________

____

INICIAÇÃO MUSICAL: NÃO ( ) SIM ( ) ONDE? _________________________

TEMPO: ________________________

TOCA ALGUM INSTRUMENTO: NÃO ( ) SIM ( ) QUAL?:________________

TEMPO: ________________________

CANTA? NÃO ( ) SIM ( )

AMBIENTE SONORO-MUSICAL FAMILIAR:

____

OUTROS:____

MÚSICAS DA FAMÍLIA:

____

____

Appendix 8 – CERTIFICATE OF PARTICIPATION

1 - PARTICIPANT


UNIFESP

UNIVERSIDADE FEDERAL DE SÃO PAULO

1933

Certificamos que o aluno ____________________________participou da pesquisa intitulada "Música e sincronização sensório-motora em crianças na idade escolar: relações com o Perfil Sensorial e o Comportamento.", recebendo assim, o selo de Aluno Amigo da Ciência.

2 - SCHOOL


UNIFESP

UNIVERSIDADE FEDERAL DE SÃO PAULO

1933

Certificamos que a escola ____________________________participou da pesquisa intitulada "Música e sincronização sensório-motora em crianças na idade escolar: relações com o Perfil Sensorial e o Comportamento.", recebendo assim, o selo de Escola Amiga da Ciência.

Appendix 9 – OTHER QUESTIONNAIRES

We did not include the Child Behavior Checklist (CBCL), Short Sensory Profile 2 - SSP2, Questionário Brasileiro do Ambiente Infantil (QBAI) and the Conner's abbreviated teacher rating scale (CATR'S) questionnaires because they are protected by copyright.

12 ATTACHMENT – ETHICAL APPROVAL

UNIFESP - HOSPITAL SÃO PAULO - HOSPITAL UNIVERSITÁRIO DA

PARECER CONSUBSTANCIADO DO CEP

DADOS DA EMENDA

Título da Pesquisa: Música e sincronização sensório-motora em crianças na idade escolar: relações com o perfil sensorial e o comportamento.

Pesquisador: Luiz Rogério Jorgensen Carrer

Área Temática:

Versão: 3

CAAE: 69206517.9.0000.5505

Instituição Proponente: Universidade Federal de São Paulo - UNIFESP/EPM

Patrocinador Principal: FUNDACAO DE AMPARO A PESQUISA DO ESTADO DE SAO PAULO
Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 3.006.801

Apresentação do Projeto:
Trata-se de EMENDA 1 ao protocolo original

Projeto CEP/UNIFESP n:0596/2017

A Sincronização Sensório-Motora (SSM) pode ser definida como a coordenação de movimentos corporais com estímulos externos, desde movimentos simples como bater palmas em
sincronismo com uma música, até movimentos rítmicos coordenados e complexos nas atividades do dia -a-dia como escrever, dançar ou realizar atividades esportivas. Embora essas habilidades sejam naturalmente desenvolvidas desde a infância, a presença de transtornos motores e do desenvolvimento pode estar associada a um baixo desempenho em tarefas que exigem a coordenação motora. As tarefas de finger tapping (bater os dedos) com base no paradigma da SSM vem contribuindo tanto para o diagnóstico, quanto no tratamento de transtornos motores e neurológicos, onde o treinamento dessas habilidades é utilizado para a reabilitação das funções sensóriomotoras. O presente projeto visa investigar a utilização de tarefas de finger tapping em sincronismo com um estímulo externo em duas condições:
música versus metrônomo. Serão selecionadas crianças com desenvolvimento típico, entre 6 e 10 anos de idade, de ambos os sexos, em escolas publicas e particulares. O desempenho nas tarefas

Endereço: Rua Francisco de Castro, 55
Bairro: VILA CLEMENTINO **CEP:** 04.020-050
UF: SP **Município:** SAO PAULO
Telefone: (11)5571-1062 **Fax:** (11)5539-7162 **E-mail:** cep@unifesp.edu.br

de SSM será correlacionado com os escores obtidos pelas crianças em escalas de comportamento e o Perfil Sensorial, além de escalas que avaliam as Funções Executivas no dia-a-dia. O estudo será realizado com a hipótese de que o estímulo musical facilita o
desempenho das crianças no finger tapping, e que existe uma relação entre as tarefas de SSM e o Perfil Sensorial das crianças, bem como no comportamento e nas Funções Executivas.

Objetivo da Pesquisa:

-Objetivo Primário: Analisar o desempenho de crianças com desenvolvimento típico, entre 6 e 10 anos de idade, em tarefas de finger tapping com o uso de metrônomo comparadas com a música e suas relações com o Perfil Sensorial e o comportamento.

-Objetivo Secundário: 1) Analisar e comparar índices de desempenho nas tarefas de finger tapping com metrônomo e música na amostra estudada de acordo com a faixa etária e o sexo.2) Correlacionar o desempenho nas tarefas de finger tapping com os escores do Perfil Sensorial e escalas de comportamento e Funções Executivas.

Avaliação dos Riscos e Benefícios:

Descritos no parecer original

Comentários e Considerações sobre a Pesquisa:

Trata-se de EMENDA 1 ao protocolo original
Justificativa da emenda:
1) Incluir a Dra. Sabine Pompeia, professora do departamento de Psicobiologia da UNIFESP/SP, como orientadora do doutorado e da pesquisa a ser realizada.

2) Alteração do orçamento com a aprovação da Fapesp para verba de pesquisa sob o processo
número: 2017/23917--8.

3) Alterar o número de participantes de 60 para 257.

Considerações sobre os Termos de apresentação obrigatória:

Documentos obrigatórios apresentados adequadamente para a emenda

Recomendações:

Nada consta

Conclusões ou Pendências e Lista de Inadequações:

emenda aprovada

Endereço: Rua Francisco de Castro, 55
Bairro: VILA CLEMENTINO **CEP:** 04.020-050
UF: SP **Município:** SAO PAULO
Telefone: (11)5571-1062 **Fax:** (11)5539-7162 **E-mail:** cep@unifesp.edu.br

Considerações Finais a critério do CEP:

Parecer acatado pelo colegiado.

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação
Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_1239186_E1.pdf	15/10/2018 12:35:26		Aceito
Outros	EmendaProjeto2018.pdf	15/10/2018 12:31:14	Luiz Rogério Jorgensen Carrer	Aceito
Outros	CartaResposta.docx	04/07/2017 11:48:14	Luiz Rogério Jorgensen Carrer	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TAIM.pdf	04/07/2017 11:35:12	Luiz Rogério Jorgensen Carrer	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE.pdf	04/07/2017 11:34:11	Luiz Rogério Jorgensen Carrer	Aceito
Projeto Detalhado / Brochura Investigador	ProjetoMusSincSensMotora.pdf	02/06/2017 12:17:17	Luiz Rogério Jorgensen Carrer	Aceito
Outros	ComEticaUnifesp.pdf	02/06/2017 12:15:08	Luiz Rogério Jorgensen Carrer	Aceito
Declaração de Instituição e Infraestrutura	DeclAFIP.pdf	02/06/2017 12:10:37	Luiz Rogério Jorgensen Carrer	Aceito
Folha de Rosto	FolhaDeRosto.pdf	02/06/2017 11:40:59	Luiz Rogério Jorgensen Carrer	Aceito

Situação do Parecer:

Aprovado

Necessita Apreciação da CONEP:

Não

SAO PAULO, 07 de Novembro de 2018

Assinado por:
Miguel Roberto Jorge
(Coordenador(a))

Endereço: Rua Francisco de Castro, 55
Bairro: VILA CLEMENTINO **CEP:** 04.020-050
UF: SP **Município:** SAO PAULO
Telefone: (11)5571-1062 **Fax:** (11)5539-7162 **E-mail:** cep@unifesp.edu.br