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Music and cognitive development during the early primary school years: Exploring associations and learning outcomes

Doctoral dissertation

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ABBREVIATIONS

3DM-H	Dyslexia Differential Diagnosis Maastricht - Hungarian
EFs	Executive functions
FDR	False discovery rate
MMA	Measures of Musical Abilities
PA	Phonological/phoneme awareness
RAN	Rapid automatized naming
RTE	Relative treatment effect
Rmcorr	Repeated measures correlation
SES	Socioeconomic status
WISC-IV	Wechsler Intelligence Scale for Children - Fourth Edition

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ABSTRACT

Prior research has provided inconclusive findings on the relations of musical abilities and music learning to children's cognitive development during the early primary school years. On the one hand, the present dissertation investigated the longitudinal nature of the relationship between music-related abilities and specific cognitive functions, especially reading-related abilities, in the first and the second school years to test if their associations would change as formal reading and musical experience increases. In addition, longitudinal associations between the improvements of music-related and non-musical cognitive abilities were estimated to explore potential developmental parallels between the music and the reading domains over this specific developmental period. On the other hand, from school entry to the end of the second school year, the impacts of the different implementation of body movement into classroom music learning on children's music-related and non-musical cognitive development were examined. Preliminary results suggested that one year of participation in intensive classroom music lessons was not associated with better cognitive abilities in second-grade children. Following children over the first two years of primary school, results indicated that compared to no-movement music lessons, music lessons including body movement did not support greater enhancements in musical or non-musical cognitive abilities. Furthermore, the incorporation of different movement forms in intense classroom music education promoted similar improvements both in musical and non-musical cognitive abilities. Concerning the nature of the music-reading relationship, highly specific associations were detected between musical abilities, reading, and its precursor skills at all measurement points over the first two school years, with their patterns being relatively different. Compared to longitudinal relations detected over the first school year, associations between the development of musical abilities, phonological processing, and reading appeared to be less specific over the second school year. Moreover, the acquisition of fluency in word reading was specifically influenced by the development of pitch perception over and above the development of the cognitive precursors of reading in the second school year. Overall, findings of this dissertation could point to the specific and somewhat varying nature of the music-reading relationship as well as the similar contribution of various movement-based and no-movement music education programs to children's cognitive development in the first two primary school years.

0. INTRODUCTION

There is a fundamental demand for general school education to provide children with knowledge and experience that can be applied beyond the immediate learning context. There have been thus constant efforts to design classroom curricula for children in the early primary school years that foster the acquisition of academic skills as well as general competencies like problem-solving, critical, analytical, and creative thinking, cooperation, communication, and social interaction. However, a crucial issue in education and psychology has been the extent to which skills or knowledge acquired in one domain can be applied in domains independent of the original learning environment. Transfer, or the broad impact of learning, can be observed in the generalisation of experience, which can facilitate the application of acquired knowledge to new situations (Bransford et al., 2000). The question is, under what conditions can learning be transferred?

Over the last few decades, art education has been considered a possible means of facilitating children's general skill development. Sustained engagement with music is a specific learning situation that requires intensive learning in various skill areas, including different aspects of perception, motor skills, and cognition (for a review, see Miendlarzewska & Trost, 2014), which are also essential for other non-musical cognitive tasks occurring in everyday life. This raises the question of whether music learning can effectively support the development of these non-musical cognitive functions in addition to musical abilities, especially in children who are highly receptive to experiences. Although artistic programs aim to improve art-specific skills, art educators often detect enhancements for non-artistic skills in children participating in the arts. Based on these observations, the transfer effects of music have been a subject of sustained and intense interest for many decades.

Current research shows that music learning in childhood has beneficial effects not only on perceptual, motor, and sensorimotor abilities related to music (e.g., Bolduc & Lefebvre, 2012; Ilari et al., 2016; Maróti et al., 2019) but also on specific domains such as language, including reading and its cognitive precursors (e.g., Degé & Schwarzer, 2011; Moreno et al., 2009; Rautenberg, 2015; Slater et al., 2014). Furthermore, research has demonstrated that music education can enhance general cognitive abilities, including executive functions (e.g., Bugos & DeMarie, 2017; Jaschke et al., 2018; Roden et al., 2012; Roden, Grube, et al., 2014) and, in some cases, intelligence (e.g., Schellenberg, 2004). It is important to note that much of the empirical evidence regarding music training has been obtained through various intensive programs with different age groups. Typically, children show significant improvements in specific aspects of a given skill (Cooper, 2019). Additionally, most educational programs incorporate different forms of movement in musical activities. However, the study of the effects of movement is still relatively unexplored. Although attempts have been made for years to explore the impact of music education in natural settings (see Tervaniemi et al., 2018, for a review), the effectiveness of comprehensive music education programs and the role of movement in these methods remains unclear.

A key area of research into the effects of music learning is the interrelationship between music and language. This line of research originates from the shared acoustic characteristics and complex structural organization of both music and language (Jentschke, 2018). The dominant theories (e.g., common acoustic processes hypothesis, Besson et al., 2011; top-down control hypothesis, Moreno & Bidelman, 2014; OPERA hypothesis, Patel, 2011, 2014) explaining the relationship assume that there are overlapping perceptual and cognitive mechanisms. This notion has inspired the study of the relations of music to phonological processing and reading. Although this area of research is now decades old, the nature of the relationship in childhood is still unclear. Some evidence suggests a general relationship between various musical and reading-related abilities (e.g., Degé et al., 2015; Steinbrink et al., 2019), while others suggest a specific relationship with either rhythmic (e.g., Douglas & Willats, 1994; Moritz et al., 2013) or tonal music processing (e.g., Forgeard et al., 2008; Loui et al., 2011). It is important to emphasize, however, that these studies typically do not take into account that both musical abilities (Gooding & Standley, 2011; Trainor & Corrigall, 2010) and reading-related abilities (Ziegler & Goswami, 2005) undergo significant normative development during childhood, the course of which may be modified by formal learning. It is therefore conceivable that the nature of the music-reading relationship may change from the beginning of reading and music learning. This raises the question of whether parallels can be identified in the development of music and reading.

Therefore, my doctoral research aimed to conduct a longitudinal investigation on the association between music and cognitive development in an ecologically valid setting during the early years of primary school. As part of this, a comprehensive evaluation was conducted to assess the impact of classroom music education programs on the development of schoolchildren from the beginning of school until the end of the second year. The studies incorporated body movement into the school music curricula, and it was of particular interest whether the different application of movement could promote distinct improvements in both musical and non-musical abilities. Additionally, the research involved a longitudinal investigation of the relationship between music and reading-related cognitive abilities, exploring whether the relationship between these domains changes with increasing experience in reading and music instruction.

This doctoral dissertation is organized into five chapters. Chapter 1 provides a review of the existing literature concerning the relationship between music and children's cognitive development, highlighting the significance of the doctoral research in this field. In Chapter 2, the objectives and questions of the doctoral research as well as the initial hypotheses are formulated. A separate chapter in the dissertation is dedicated to presenting the methods used in the doctoral research as the methodologies of the five studies were highly overlapping. Therefore, Chapter 3 provides a detailed description of the design and participants involved in the studies, as well as the measures, and some general statistical methods applied. Chapter 4 presents the five original studies in detail. After presenting the results of the cross-sectional examination concerning the dosage effect of one-year classroom music lessons on second graders' cognitive functioning in Study 1, I demonstrate in Study 2 and 3 how incorporating various movement forms into music lessons contributes to children's cognitive development over the first two school years. Next, I present the results of the longitudinal investigation into the nature of associations between musical and reading-related cognitive abilities for the first and second school years separately in Studies 4 and 5. Chapter 5 provides a summary and interpretation of the main findings of the current research in light of previous evidence. I also point out factors that may have contributed to the present findings and propose alternative frameworks for estimating of the transfer effects of music learning. Finally, the limitations of the studies and potential directions for future research are outlined.

1. LITERATURE REVIEW

In this chapter, I review the main topics of the specific field of music research that investigates the relations between music and cognitive functioning in the middle childhood years from the perspective of developmental cognitive psychology. First, the general concept of learning transfer and its implications for music learning in childhood are introduced. Then, I discuss the parallels of musical abilities with non-musical specific and general cognitive competencies as potential foundations of music learning transfer. Furthermore, the theoretical background and research evidence for the beneficial effects of childhood music instruction on cognitive development are elaborated, highlighting contextual factors that potentially affect the cognitive outcomes in school-aged children. At the end of this chapter, I point out some unanswered questions in the literature.

1.1 Transfer effects of music

Transfer of skills refers to the phenomenon when the effects of a dedicated training in a specified domain exceed the context of the initial training. This learning effect manifests itself in the generalization of experiences by facilitating the application of acquired knowledge in new contexts (Bransford et al., 2000). Studying such generalization across domains is of particular interest in cognitive and developmental psychology as it allows for the broader understanding of skill acquisition and its underlying mechanisms during childhood. Moreover, knowledge on the nature of transfer may help to design training programs to improve various skills. I briefly present the most prominent theoretical models on learning transfer which have stimulated research on studying the effects of music learning on cognitive development.

1.1.1 *Cognitive perspectives on the transfer of learning*

Traditionally, the types of transfer are differentiated based on the distance between the training and transfer domains, indicating the extent to which training-induced changes can be generalized (Barnett & Ceci, 2002; Diamond & Ling, 2019). Near transfer reflects the impacts of training in closely related domains, whereas far transfer emerges when the relationship between the training and target domains is less apparent. Although it seems evident that transfer is likely to occur between highly similar contexts and tasks, it is argued if training in a specified domain can lead to improvements in more distinct contexts. Thus, we might expect that the greater the distance between the original and target contexts, the less probable the transfer appears.

Approaches on skill transfer differ in their understanding of similarity and the probability of transfer assumed. According to the classical common-elements theory, transfer is dependent on the extent to which the original and target contexts have common situational and stimulus-related elements (Thorndike & Woodworth, 1901), indicating that far transfer occurs infrequently. More recent cognitive approaches redefined the nature of identical elements and emphasized that mental symbolic representations constructed in the initial and new situations are needed to be shared for the transfer to occur. In contrast to early views, the cognitive ones posit that transfer is a result of the development of cognitive skills, which can be potentially implemented in unpractised tasks with similar cognitive requirements. For instance, the production system framework (Singley & Anderson, 1989) claims that learning is associated with the acquisition and automatization of production rules, which facilitate the occurrence of transfer between tasks requiring common knowledge about the steps of performance. A complementary approach is the primitive elements theory of cognitive skills (Taatgen, 2013). It suggests that task-specific information processing elements are combined into increasingly larger task-general processing units during learning, which can be applied in new learning contexts when higher-order context-independent units are shared between the initial and novel task. Another explanation for transfer (Gathercole et al., 2019) highlights that cognitive routines automatized during a specific training can be employed in other contexts with identical requirements for cognitive processes. An alternative Bayesian account on learning and transfer (Smid et al., 2020) argues that transfer is dependent on the individual's perception of the training context. Cognitive training alters participants' priors by exposing cues about their contextual conditions, leading to posterior distributions about future situations. Transfer unfolds if the training provides participants with cues that are reliable and informative about novel contexts.

Despite their differences in the conceptions of transfer, there is agreement among cognitive models that the key element of transfer between tasks or contexts is knowledge and the emergence of transfer is indicated by cognitive improvements. However, a comprehensive view interpreting the role of learners, the necessary training conditions and latent mechanisms for a successful transfer is still not available.

1.1.2. The concept of transfer regarding music learning

Demonstrating that listening to music composed by Mozart can improve spatial-temporal abilities, the "Mozart effect" described by Rauscher, Shaw, and Ky (1993) generated considerable interest in exploring the potential for long-term musical experience to enhance various cognitive skills outside the music domain. Since then, research on the transfer of music learning endeavours to identify the areas where extended musical practice leads to increased performance. Traditionally, music literature evaluates the benefits of music learning based on the distance of transfer, indicating the extent to which mastering skills through musical activities can be generalized. Near transfer of music refers to enhanced performance in music-relevant abilities, therefore can be observed in auditory and fine motor skills. Far transfer is mainly seen as improvements in untrained non-musical areas like verbal and literacy skills, spatial and mathematical skills, executive functions, memory, general intelligence and academic achievement, and even social skills (for reviews, see Kraus & Chandrasekaran, 2010; Miendlarzewska & Trost, 2014). Following the cognitive views of learning transfer, the probability of musical experience-induced increases is supposedly dependent on the resemblance between the cognitive representations/processes shared by the training and target domains. Thus, the more common incidence of near transfer on music-specific skills and the relatively rare incidence of far transfer on non-musical abilities might be expected.

However, there is disagreement about the distinction between near and far transfer. For instance, it is questionable whether increases in directly trained music-related abilities could be considered as effects of near transfer. Moreover, Frischen and colleagues (2021) suggested that improvements in non-musical domains being actively involved during musical activities (e.g., attention, memory, executive functions) should be evaluated as evidence of near rather than far transfer. In a multidimensional framework, Moreno and Bidelman (2014) pointed out that music-induced cognitive transfer can be explained by the orthogonal dimensions of near-to-far transfer and sensory-to-cognitive processing which can be understood as endpoints of a continuum rather than absolute categories. Because of this theoretical issue, I evaluate the benefits of music learning based on whether the effects transfer to specific or general cognitive domains. Thus, following the definition of the American Psychological Association, I will use "domain-specificity" referring to cognitive benefits that are specific to a task or controlled by a certain function and "domain-generality" referring to cognitive enhancements affecting performance in a variety of tasks.

1.1.3. Music learning and brain plasticity

Exploring the effects of music lessons on the brain has received considerable attention to determine the neural foundations of music learning induced transfer. Expectations for widespread musical benefits are grounded in the multisensory nature and high demands of musical activities on a variety of sensory, motor, and cognitive functions. As several years of constant practice is required to become proficient in music-relevant abilities, early onset of music learning may have significant impacts on the functioning and structure of brain, implying its malleability in response to musical experience. Hence, brain plasticity might be facilitated by persistent engagement with formal musical activities (Dalla Bella, 2016).

There is mounting evidence from cross-sectional studies indicating structural and functional neural differences between adult musicians and non-musicians in the auditory (Pantev et al., 1998; Shahin et al., 2004; Strait & Kraus, 2014; Wong et al., 2007), motor (Amunts et al., 1997; Bermudez et al., 2009; Elbert et al., 1995; Hutchinson et al., 2003), multimodal encoding and integration (Bangert et al., 2006; Bangert & Altenmüller, 2003; Lahav et al., 2007; Zatorre et al., 2007) regions of the brain. Moreover, music-induced changes have been shown to be modulated by the types of instrumental training (Elbert et al., 1995; Pantev et al., 1998; Shahin et al., 2003), suggesting experience-specific neuroplasticity in trained musicians. In addition, the greatest neuroplastic effects have been detected in musicians who started receiving music training before the age of 7 years (Amunts et al., 1997; Elbert et al., 1995; Pantev et al., 1998; Wong et al., 2007). These neuroplastic benefits have been determined by the age of commencement even after controlling for the amount of training (Watanabe et al., 2007). This implies that there might be a limited period relatively early in life when the brain is particularly sensitive to active musical experience.

Concerning the relevance of early commencement, longitudinal studies have been designed to examine the impacts of music learning on structural and functional brain changes as indicators of transfer at the neural level in childhood. Findings suggest enhanced electrophysiological brain responses to rhythmic or melodic modulations in 11−13-year-old children (Putkinen et al., 2014), to pure, violin, and piano tones in 4−5-year-old children (Trainor et al., 2003), and to the sounds of the trained instrument in 4−6-year-old children (Fujioka et al., 2006) who take music education including instrument lessons compared to their nonmusician counterparts. Furthermore, the size of the anterior part of the corpus callosum (Schlaug et al., 2009), the primary motor and auditory areas (Hyde et al., 2009), and the gray matter volume in the temporo-occipital and insular cortex associated with music notation reading (Bergman Nutley et al., 2014) was found to be increased in musically trained children around 6 years of age. These results indicate that music learning has the potential to induce functional and structural changes early in the developing brain, presumably supporting the occurrence of behavioural benefits.

1.4.4 Transfer of music learning in the developing brain

Research on music training-induced neuroplastic changes supports the notion that the advantages of extended learning are modulated by the participant's age and prior experience. In general, the current developmental stage during which experiences take place may influence participants' learning outcomes (Jolles & Crone, 2012). Conceivably, skill acquisition over a specific period in development can be hindered by the immaturity of lower-level processes subserving that particular skill (Zelazo, 2004). However, specific experiences might even promote improvements during sensitive periods when the brain shows heightened susceptibility to environmental effects (Knudsen, 2004). Moreover, the onset, duration, and termination of these periods of increased sensitivity can be altered by training-related experience (Hensch, 2004). Together these findings suggest that the childhood years might be an ideal period to investigate music training-induced behavioural changes.

It is important to note that music learning starting at an early age coincide with dramatic developmental changes related to brain maturation (Galván, 2010). Thus, extended exposure to music in childhood potentially has an impact on the trajectory of normative cognitive development; however, the exact nature of music experience-dependent effects is not clear. It is possible that partaking in music lessons accelerates cognitive development because of an interplay between maturation and learning (Stiles, 2008). On the other hand, music training may alter the typical developmental trajectory of cognitive functions (Jolles & Crone, 2012). This underscores the need for studies examining how developmental and learning effects could be distinguished in musically trained children.

Research on music learning-related transfer effects in children basically endeavours to address both theoretical and practical issues by uncovering the extent to which music learning can facilitate increases in a variety of developing cognitive functions, the underlying mechanisms driving these changes, the level of maturation required for these enhancements to occur, and the types of music training programs which are effective in promoting such cognitive improvements over the course of childhood. Therefore, in the next chapters, I will summarize the core assumptions and empirical evidence regarding the cognitive foundations of music transfer and the potential benefits of music learning on children's cognitive development. First, I describe the concept of childhood musicality, its hypothesized relations to a set of specific and general cognitive functions, and results concerning these associations. I next discuss findings from music training studies aiming to improve cognitive functioning in preschool and school-aged children. I end with the evaluation of the efficiency of music learning in inducing transfer over the course of childhood.

1.2 Music and its relations to cognitive functions in childhood

Exploring the elements of musical experience that are closely related to cognitive functions is essential for gaining insights into the underpinnings of music learning-induced transfer. Studies conducted with children have primarily focused on identifying whether the components of musical abilities and/or partaking in formal music lessons correlate with non-musical cognitive abilities. Throughout the dissertation, I will use the term "cognitive abilities" to comprehensively refer to 1) domain-specific functions, e.g., speech perception, phonological processing, and reading, or 2) domain-general functions, e.g., executive functions and intelligence. Before I review the current knowledge concerning the relationship between music and cognitive abilities, first the concepts of music-related abilities in children are discussed.

1.2.1 Childhood musicality

There are several concepts in the literature that have been used to refer to human behaviours and competencies related to music (Levitin, 2012). This diversity reflects various views on the understanding and definition of musicality. On the one hand, definitions vary in the notions of the origin of musical competence. Accordingly, musicality has been conceptualized as an innate musical *talent* (Gagné, 1999), musical *expertise* resulting from musical training and persistent practice (Ericsson et al., 2005), or a potential for developing musical *ability* without any formal instruction or training (Shuter-Dyson, 1999). As the latter can be universal to all humans, it is worth considering ability or aptitude as starting points when evaluating natural capabilities that can be achieved irrespective of training. However, there is a lack of consensus on the set of capabilities that forms musical abilities. Even though auditory abilities are traditionally considered as the essence of musical abilities (Hallam, 2006), there is diversity regarding their fundamental sub-competencies (Shuter-Dyson, 1999). More recent concepts of musical ability (e.g., Buren et al., 2021; Hallam, 2006; Hallam & Prince, 2003; Karma, 2007; Levitin, 2012; Müllensiefen et al., 2014) represent more integrative views, which emphasize the inclusion of the responsive, performative, communicative, motivational, and composition/improvisation aspects of musicality beyond auditory abilities.

These differences in the understanding and definitions clearly indicate that musicality cannot be considered as a uniform trait but rather a complex construct encompassing several facets (see Buren et al., 2021, for recent concepts of childhood musical ability). When referring to childhood musicality, I will employ "musical abilities" in a plural form to emphasize the complexity of musical competencies. Among the sub-components of musicality, I will specifically focus on musical auditory processing and sensorimotor synchronization with music, which have been hypothesized and already documented to show relations to several non-musical cognitive functions in children.

1.2.1.1 Musical auditory processing

Although musical abilities are mostly understood as multifaceted competencies, there is great diversity in which sub-components are regarded as core aspects of musical auditory skills in children. Traditional views built on the belief that musical abilities could be measured, and test results could indicate the level of musicality that could be reached with and without formal music instruction (Devaney, 2019). Early measures of musical abilities have involved auditory discrimination tasks (Bentley, 1966; E. E. Gordon, 1965; Seashore, 1967), assessing the perception of specific properties of music. These measures were designed to test the core dimensions of musical "audiation", namely tonal and temporal auditory abilities using a collection of tasks. Gordon's tests, which has been developed to assess musical abilities from the age of 3 to adulthood (for a review, see Cutietta, 2021), are still applied in music research.

More recent measures have taken advantage of technology in order to be more appropriate for use with children. However, in most cases, instruments have been developed for selected research purposes (e.g., Ozernov-Palchik et al., 2018; Politimou et al., 2019) or test materials have not been published (Jungbluth & Hafen, 2005; Knigge et al., unpublished; cited in Steinbrink et al., 2019) or standardized (Asztalos & Csapó, 2017; Surján & Janurik, 2018). Many of these newly developed instruments utilize computer-based systems, which are adapted for tablet use (Ozernov-Palchik et al., 2018; Politimou et al., 2019; Steinbrink et al., 2019) or online completion (Asztalos & Csapó, 2017; Surján & Janurik, 2018). These technological improvements enable individual speed of test completion, reducing the cognitive requirements of the tasks. Test batteries typically comprise a variety of tasks measuring the different sub-components of musical abilities, including sensitivity to both tonal (pitch, melody, harmony) and temporal (duration, rhythm, tempo, meter, intensity) aspects of music. Moreover, there is increasing interest in applying music production tasks as well, involving both singing (Jungbluth & Hafen, 2005; Politimou et al., 2019) as well as rhythm (Knigge et al., unpublished; cited in Steinbrink et al., 2019) and meter reproduction (Jungbluth & Hafen, 2005) tasks.

1.2.1.2 Sensorimotor synchronization and entrainment

In general terms, sensorimotor synchronization refers to the temporal adjustment of movement to a periodically recurring external event (Repp, 2005). In music research, auditory-motor synchronization is the phenomenon when body movements are coordinated with the auditory rhythm or beat of music in time. Many forms of musical activities are dependent upon this rhythmic coordination, especially music performance, requiring musicians to synchronize their actions to the metronome, the beat of the music, or other musicians' actions when playing in an ensemble. Movement synchronization to music, however, can occur unconsciously and spontaneously and be often observable when individuals listen to music (Zelechowska, 2020). Entrainment in a musical sense has been conceptualized as a mechanism when multiple autonomous rhythmic processes are coordinated with each other (Clayton et al., 2005), which can manifest itself within an individual or between several performers. Although the distinction between synchronization and entrainment is not clearly defined in the music literature, entrainment is assumed to be an essential mechanism that supports the anticipation of subsequent beats (Large, 2000). Based on the Dynamic Attending Theory (Large, 2000; Large & Jones, 1999), tracking rhythmic patterns in music is governed by neural oscillatory mechanisms, which facilitate the prediction of the onset of sounds by constantly following the rhythmic structure of music with attention. In this dissertation, I am exclusively interested in sensorimotor synchronization as a behavioural response to music.

Sensorimotor synchronization is commonly assessed by tapping tasks, in which periodic auditory stimuli, mostly metronome signals, should be followed by finger tapping responses. Performance on this task may seem simple, but it places complex demands on a variety of functions, involving fine motor skills, auditory processing, attention, and cognitive control abilities (A. T. Tierney & Kraus, 2013b). Recently, there is a tendency that measures of musical abilities incorporate auditory-motor synchronization subtests (metric clapping/walking: Jungbluth & Hafen, 2005; tapping: Politimou et al., 2019). Furthermore, music research often applies tapping tasks per se assessing both synchronized and continuation tapping performance, asking children to coordinate finger tapping with an auditory beat and then to continue tapping with the same rate without the presence of the previous sound (Tierney & Kraus, 2013b).

1.2.2 Music and specific cognitive abilities: The music-language relationship

Music and language seem to be present in all human culture and have several commonalities, including their evolution, acquisition, and processing mechanisms (Jentschke, 2018). Both music and language are hierarchically organized complex systems, incorporating several domains (e.g., perception, cognition, emotion, motor) and different levels of processing (morphology, phonology, semantics, syntax, and pragmatics in language and melody, harmony, and rhythm in music; Besson et al., 2011), and supporting several functions (e.g., social bonding, survival; Fitch, 2006). Both the capacities for music and language appear to be innate, which can be mastered by learning (Fitch, 2006). Although traditional views (e.g., Peretz & Coltheart, 2003) assumed that music and language are isolated modules having specialized representations, structure, and processing mechanisms, there is growing consensus that music and language share key perceptual, cognitive, and neurophysiological components (see Patel, 2008, for an extensive review). Since some common foundations for development in both capacities can be observed in infancy and early childhood, while adults demonstrate domain-specific processes in certain aspects of music and language, modularity could be regarded as emergent rather than predetermined (McMullen & Saffran, 2004). Hence, the childhood years provide great opportunities for unravelling the shared aspects of musical and language-related abilities, which might subserve improvements in both areas. The early years of primary school are an important period for phonological development and reading acquisition (Ziegler & Goswami, 2005). Therefore, this dissertation focuses on the relationship between musical competencies and phonological processing, reading, and its cognitive indicators during this crucial developmental period.

1.2.2.1 Speech processing

Research on the relationship between music and speech processing is originated in their shared cognitive and acoustic characteristics. Both systems comprise a limited set of sounds (notes and phonemes) marked by the same acoustic parameters, such as frequency, timing, and timbre (Kraus et al., 2009). It has been proposed that there might be shared sound category learning mechanisms, which extract patterns from sound sequences based on statistical regularities, enabling the formulation of discrete sound categories of musical notes and speech sounds

(McMullen & Saffran, 2004; Patel, 2008). For both domains, distinct sound units are organized hierarchically into a coherent auditory stream driven by specific syntactic rules (Patel, 2003b). Moreover, the processing of music and speech is dependent on common memory and attentional functions (Kraus & Chandrasekaran, 2010). It is thus widely accepted that general auditory encoding mechanisms mediate the relationship between music and speech processing.

There has been extensive research on the relationship between speech and music processing using neuroimaging methods, showing evidence for the relations between music training and speech sound discrimination (Strait et al., 2013), processing of syllabic duration and voice onset time (Chobert et al., 2014), and encoding of speech in noise (Strait et al., 2013) in children. The few behavioural studies conducted with school-aged children has indicated positive associations between musical auditory abilities and the production of foreign language phonemes (Milovanov et al., 2008) as well as between music training and perceiving pitch violations in both music and speech (Magne et al., 2006). Therefore, findings corroborate that speech and music processing share neural mechanisms and experience in music is associated with more precise speech processing in childhood (Besson et al., 2011; Kraus & Chandrasekaran, 2010).

1.2.2.2 Phonological processing skills

Beyond speech perception, the precision of low-level auditory processing might be important for higher level phonological processing skills, i.e., the ability to perceive, store, retrieve, and manipulate phonological information in language (Torgesen et al., 1994). Phonological awareness (PA) constitutes the explicit aspect of phonological processing, referring to the knowledge and the ability to manipulate the components of language (Torgesen et al., 1994). Phonological short-term memory (STM) and sometimes rapid automatized naming (RAN) are considered as implicit components of phonological processing skills, requiring access to phonological representations without the explicit knowledge of the building blocks of spoken language (Melby-Lervåg et al., 2012). Phonological STM allows the short-term access to phonological representations while operating sounds of spoken language (Melby-Lervåg & Hulme, 2010). RAN refers to the efficiency with which phonological representations of word pronunciations can be retrieved from long-term memory (Decker et al., 2013; Wolf & Bowers, 1999) and visual and verbal information are integrated (Kirby et al., 2010).

There are different approaches concerning the importance of the aspects of auditory processing in phonological development. Dominant views pointed out the relevance of mechanisms enabling the temporal encoding of the dynamically varying acoustic cues in speech. The ability to precisely process rapidly changing temporal cues is assumed to be critical for the discrimination of phonemic contrasts, thus for phonological processing (Tallal, 1980). On the other hand, the accurate encoding of slowly varying amplitude modulations is essential for the segmentation of speech into syllables and the encoding of prosodic features, such as speech rhythm and stress (Corriveau et al., 2007; Goswami et al., 2002). However, the precise processing of frequency-related acoustic cues also influences the perception of stress patterns and speech segmentation (Ziegler et al., 2012). Overall, both temporal and spectral auditory processing are vital for intact phonological development in childhood.

Based on the importance of basic auditory encoding in phonological development, it is possible that non-linguistic auditory processing abilities are associated with phonological processing. Numerous studies have thus investigated the potential connections between various components of musical abilities and phonological processing skills in typically developing children between the ages of 4 and 8 years. There is evidence that PA correlates with rhythmic and pitch-related musical abilities including perception and production skills (Anvari et al., 2002; Degé et al., 2015; Márta Janurik et al., 2022; Steinbrink et al., 2019). Some studies, however, indicated highly specific relations of PA to either temporal (rhythm discrimination: Douglas & Willats, 1994; Holliman et al., 2010; Ozernov-Palchik et al., 2018; rhythm production: David et al., 2007; Moritz et al., 2013) or tonal musical abilities (melody discrimination: Bolduc & Montésinos-Gelet, 2005; Forgeard et al., 2008; pitch perception/production: Lamb & Gregory, 1993; Loui et al., 2011). Moreover, more recent findings have pointed to the unique association between PA and sensorimotor synchronization in school-aged children (Bonacina et al., 2018; Kertész & Honbolygó, 2021). In 6-year-olds, non-alphanumeric RAN skills also appeared to have associations with rhythm discrimination (Ozernov-Palchik et al., 2018) and rhythm production (David et al., 2007; Degé et al., 2015). However, research regarding the relationship between phonological memory and rhythmic abilities has shown contradictory results (Degé et al., 2015; Steinbrink et al., 2019). Overall, the above findings are diverse and inconsistent; nonetheless, results indicate that there might be selective associations between non-linguistic auditory processing and phonological development even when the potential confounding effects of general cognitive abilities, intelligence, or socioeconomic background are controlled.

1.2.2.3 Reading

Converging evidence suggests that at the initial stages, reading acquisition is dependent on phonological processing skills (Hulme & Snowling, 2013). Sensitivity to the phonological structure (syllables, onsets, rhymes, phonemes) of spoken language determines the development of precise phonological representations (Perfetti, 1992), which affects the success in learning the mappings between speech sounds and visual symbols (Bradley & Bryant, 1983; Ziegler & Goswami, 2005). Thus, allowing the manipulation of phonological units, PA appears to play an important role in acquiring precise grapheme-phoneme correspondences underlying word reading (Stanovich & West, 1989). Additionally, short-term and working memory enables the maintenance and manipulation of phonological sequences during word decoding (Gathercole & Baddeley, 1993). Moreover, efficient retrieval of phonological representations of letters and word names from long-term memory also supports word decoding in beginning readers (Wagner & Torgesen, 1987). A large amount of research has demonstrated that PA, phonological STM, and RAN skills are fundamental indicators of reading development (for a review, see Melby-Lervåg et al., 2012). Based on the close relationship between reading and phonological processing skills, it is conceivable that non-linguistic auditory mechanisms could be related not only to phonological processing skills but also to reading ability.

Prior research has provided evidence for the relations of musical abilities to early literacy skills, including letter-sound knowledge (Anvari et al., 2002; Ozernov-Palchik et al., 2018), word matching, concepts about print (Lamb & Gregory, 1993), nonsense word (Forgeard, Schlaug, et al., 2008) and word reading accuracy (Douglas & Willats, 1994; Márta Janurik et al., 2022; Márta Janurik & Józsa, 2022) as well as reading prosody (Rautenberg, 2015). As observed in the case of phonological processing, results of these studies showed inconsistencies regarding the nature of music-reading associations in children at an early stage of reading acquisition (global correlations: Anvari et al., 2002; Forgeard et al., 2008; Janurik et al., 2022; Janurik & Józsa, 2022; selective relations to rhythm perception: Douglas & Willats, 1994; Ozernov-Palchik et al., 2018; Rautenberg, 2015; specific relations to pitch-related perception: Lamb & Gregory, 1993). Moreover, increasing evidence suggests links between sensorimotor synchronization and (pseudo/nonsense) word reading accuracy (Bonacina et al., 2018; Lê et al., 2020) and word reading fluency (Kertész & Honbolygó, 2021). These findings suggest that both non-linguistic spectral and temporal processing are relevant for some aspects of early reading development.

The special relationship between reading and temporal auditory processing has been explained by the mediating role of PA. This assumption originates in the temporal sampling hypothesis (Goswami, 2011), postulating that a specific deficit in temporal auditory encoding drives atypical reading and language development through impaired explicit phonological skills, especially through PA. In typically developing children, only a few studies have so far investigated the intermediary role of PA in the association between non-linguistic temporal auditory processing and reading. In kindergarteners, early reading ability (letter-sound knowledge) and rhythm discrimination were related both directly and indirectly driven by PA (Ozernov-Palchik et al., 2018). However, when assessing a population of third graders, rhythmic musical abilities only showed a direct influence on word/pseudoword reading (Lê et al., 2020). These controversial results might reflect the decreasing effect of PA on reading as children progress from an analytic to a more automatized method of reading (Kirby et al., 2003).

Nonetheless, it is also conceivable that other non-phonological functions may act as mediators in the establishment of relations between musical abilities and reading. As a first stage of word reading acquisition, children need to learn the associations between speech sounds and written letters (Ehri, 1995). The automatization of audio-visual integration of grapheme-phoneme representations plays a pivotal role in developing later fluent reading skills (Blomert, 2011). Similar multimodal integration processes substantiate the acquisition of music notation reading, requiring the learning of mappings between musical sounds and specific visual symbols (Hodges & Nolker, 2011). Additionally, both word and music notation reading show similar developmental stages, starting with the phase of letter-by-letter/note-by-note decoding and reaching automatization after years of practice in the decoding of orthographic (Vaessen & Blomert, 2010) and musical patterns (Stewart, 2003; Waters et al., 1997). This might suggest that multimodal processing mechanisms constitute an alternative link between word and music notation reading at the early stage of acquisition. However, the role of integration processes in the formation of music-reading associations has received less attention in studies conducted with school-aged children.

1.2.3 Music and general cognitive abilities

Although studies have uncovered several associations between music and specific cognitive functions like certain aspects of linguistic skills, it seems improbable that many specialized functions could be directly strengthened by musical activities. It has been suggested that taking music lessons might be associated with a general improvement in cognitive abilities, which potentially promotes additional increases in specific cognitive abilities. Executive functions and general intelligence have been proposed to act as intermediary cognitive functions; however, there is still an incoherent picture regarding a comprehensive relationship between participation in musical instruction and general cognitive abilities. Executive functions appear to support complex problem-solving (Senn et al., 2004) and may also have an impact on future school performance (Pascual et al., 2019). During primary school years, there are significant improvements in all aspects of executive functions (Best & Miller, 2010; Best et al., 2009; Romine & Reynolds, 2005). Therefore, this dissertation is particularly interested in examining the relationship between the components of executive functions and music in school-aged children.

1.2.3.1 Executive functions

The concept of executive functions (EFs) refers to a set of cognitive processes coordinated by the prefrontal cortex that enable the flexible adaptation of purposeful behaviour to contextual demands (Banich, 2009). The three core EFs are inhibitory control (selective attention and cognitive inhibition), cognitive flexibility (mental set shifting), and working memory (online maintenance of information and manipulation of representations) (Diamond, 2013; Miyake et al., 2000). These domain-general processes are generally invoked during musical activities: while listening to and memorizing musical passages, mentally shifting between different tasks, monitoring and controlling bimanual motoric functions during musical performance, and adjusting one's behaviour when synchronizing with others (Hannon & Trainor, 2007). EFs are thus especially implicated when playing an instrument (Bialystok & DePape, 2009).

The relationship between musical listening and production skills and the development of executive functions is a topic that has received limited attention in the literature. However, recent evidence suggests that musical auditory abilities, including pitch and rhythm perception, are significantly associated with performance on working memory, mental set shifting, and inhibition tasks in first graders (Janurik et al., 2019). Rather, empirical studies investigated potential links between EFs and taking (instrumental) music lessons mostly in children aged between 9 and 12 years who already had months/years of formal musical experience. Research revealed that participating in childhood music training relates to inhibition (Degé et al., 2011; Joret et al., 2017), selective attention, planning (Degé et al., 2011), working memory (Schellenberg, 2011), set shifting, fluency (Degé et al., 2011; Zuk et al., 2014), and processing speed (Zuk et al., 2014). These results reflect that the more extended musical experience is, the better the EF subcomponents are in childhood. However, correlational studies cannot clarify whether music instruction is the cause of improvements in EFs or whether children having superior EFs are more likely to engage in formal music instruction (Schellenberg, 2006; Swathi Swaminathan & Schellenberg, 2019).

1.2.3.2 Intelligence

The investigation of the potential relationship between music and IQ points to the long-standing question regarding the heritability or experience-dependent nature of intelligence. There is still intense interest in the association between formal musical experience and general intelligence, examining whether taking music lessons relates to superior IQ in childhood. Research has demonstrated a correlation between non-verbal intelligence and general musical ability (perception and production combined) in first-grade children (Janurik & Józsa, 2022). There is evidence that musically trained children aged 7−12 years demonstrate higher performance on IQ tasks than their non-musician peers (Hille et al., 2011; Schellenberg, 2011; Schellenberg & Mankarious, 2012). Moreover, the duration of music education has been linked to higher IQs in 6−12-year-old children (Corrigall et al., 2013; Corrigall & Schellenberg, 2015; Degé et al., 2011; Schellenberg, 2006). On the other hand, it has been proposed that higher socioeconomic status (Corrigall et al., 2013) is associated with the greater probability of children taking music lessons. However, when controlling for potential confounding variables like family income, parental education, and non-musical extracurricular activities, the positive correlation between music lessons and IQ remained apparent (Corrigall et al., 2013; Degé et al., 2011; Schellenberg, 2006). Recently, it has been shown in adults that music aptitude is strongly related to intelligence after musical experience is controlled (Swathi Swaminathan et al., 2017). Therefore, it seems plausible that not only superior general intelligence, but higher music aptitude may influence children's willingness to devote time to musical activities.

The relationship between music lessons and IQ is often explained by the mediating processes of EFs. As the subcomponents of EFs are involved in a wide range of cognitive tasks (Hannon & Trainor, 2007), especially in musical activities (Bialystok & DePape, 2009), EFs have been assumed to drive the association between musical experience and intelligence. However, findings regarding the mediatory role of EFs are contradicting (Degé et al., 2011; Schellenberg, 2011).

1.3 Music learning and cognitive development in childhood

Music learning requires a complex set of perceptual, cognitive, and motor mechanisms. Auditory perception is an integral part of all musical activities. Listening to music relies upon selective attention, which enables the accurate perception and discrimination of musical sounds. Working memory processes allow for the online maintenance of musical sequences and ensure the later access to their representations. Playing an instrument further demands executive functions to plan, control, and coordinate fine motor actions in time. Music performance often requires the ability to read the symbolic notation system, demanding visual and auditory information processing simultaneously. Moreover, music learning usually takes place in a social context, which allow the learners to communicate, cooperate, and share emotions with other group members (Miendlarzewska & Trost, 2014). As music learning challenges a wide range of sensory and cognitive functions, music instruction may be a valuable tool in enhancing domain-specific and general cognitive abilities during childhood.

However, an important challenge of music research conducted with children is to disentangle improvements related to normative development from enhancements induced by music learning. It is well documented that the middle childhood years are associated with increased improvements in many specific and general cognitive functions (e.g., Best & Miller, 2010; Gembris, 2006; Ziegler & Goswami, 2005). In order to better evaluate the potential of music learning in improving cognitive abilities in preschool and school-aged children, I briefly discuss age-related developments in each area, indicating the level of cognitive functioning to which formal music instruction contributes.

1.3.1 Musical abilities and sensorimotor synchronization

There is general agreement that musical abilities improve progressively through various stages during childhood without any formal music instruction (Gooding & Standley, 2011; Trainor & Corrigall, 2010). It has been shown that infants' early sensitivity to musical pitch and rhythm is refined by everyday exposure to music, leading to culture-specific knowledge about the tonal and temporal structure of music (Hannon & Trainor, 2007). During the preschool years, children's discrimination skills and the synchronization of movements to the characteristics of music improve considerably (Miyamoto, 2007; Provasi & Bobin-Bègue, 2003), with the latter consolidating around the age of 5 (Kirschner & Tomasello, 2009). The foundations of the ability to associate musical sounds with corresponding symbols are also developed (Miyamoto, 2007). By the time children start school, the sense of tonality (Kenney, 1997) as well as key and harmony perception (Corrigall & Trainor, 2009) show improvement. Furthermore, the advanced coordination of fine and gross motor movements allows for the better ability to reproduce rhythms by clapping and tapping (Huang, 2007) and to synchronize movements to rhythm (Drake et al., 2000). Through these enculturation processes, children acquire an implicit musical competence in listening and moving to music, memorizing and reproducing musical sequences as well as experiencing emotions conveyed by music (Hannon & Trainor, 2007). Developmental studies indicate that basic pitch and rhythmic discrimination abilities reach adult-like levels by 6–7 years of age, whereas higher order pitch and rhythm perception (the perception of melody, harmony, and tempo) (Fancourt et al., 2013; Gembris, 2006; Trainor & Corrigall, 2010) and sensorimotor synchronization (Drake et al., 2000) seem to undergo a protracted development that extends into adolescence.

Nonetheless, some musical abilities appear to be further advanced by formal music instruction. Turmezeyné (2007) investigated the musical development of children in Grades 2 to 4 who received classroom music education based on traditional Kodály principles. The study found a significant improvement in auditory discrimination, including melody, rhythm, harmony, timbre, and dynamics, during this period. However, the development of each musical sub-skill varied over the two-year period. The findings of Janurik's study (2010) confirm that the rate of development of certain musical auditory abilities varies, and development is not necessarily linear across first and second grade. Empirical evidence suggests that the developmental advantages of musically trained preschoolers and school-aged children can be observed for pitch-related discrimination already at the early phases of explicit group-based music instruction. However, children with and without music education generally demonstrate similar developmental trajectories for rhythm perception (Bolduc & Lefebvre, 2012; Ilari et al., 2016). Concerning sensorimotor synchronization skills, group music instruction was associated with comparable enhancements in musically trained and untrained children (Ilari et al., 2016), even when music pedagogical methods with strong emphasis on rhythm had been applied (Groves, 1969; Maróti et al., 2019). However, these results differ from those of Mucsi et al. (2021), who found that first graders who participated in a seven-month rhythm-focused school music program demonstrated significantly greater development in rhythmic skills, both in perceptual and production performance, than their peers who participated in the traditional school music program. Additionally, Szabó et al. (2019) revealed that a six-month music program using the Music Island application was significantly more effective in supporting the development of music production skills in first graders compared to traditional school music lessons. However, it did not facilitate more improvements in discrimination skills. Asztalos and Csapó (2017) conducted a comparison of the musical abilities of children in music and traditional classes at different grades. The results indicated that in first grade, there was no difference in their performance on the full test (perception, auditory-visual connection). However, in second grade, the children in music classes demonstrated significantly higher musical ability. These findings imply that not all formal music education programs affect children's musical development comprehensively. It is plausible that group music instruction promotes improvements in higher-order musical auditory processing and memory for music during the preschool and early school years.

1.3.2 Phonological processing and reading

There is increasing evidence that music instruction could benefit basic auditory mechanisms even in domains unrelated to music. Based on the similarities between the acoustic features of musical and speech sounds, it has been suggested that shared auditory mechanisms could drive the transfer effects of music to speech and phonological processing, indirectly affecting reading ability. Besson, Chobert, and Marie (2011) argued that extended musical experience sharpens low-level sound processing mechanisms, which leads to enhanced sensitivity to spectral and temporal auditory features in both music and speech encoding. Improvements in domain-general auditory encoding may further benefit domain-specific processing in language, supporting the development of more accurate phonological representations in long-term memory (Besson et al., 2011; Moreno & Bidelman, 2014). According to the *OPERA hypothesis* (Patel, 2011, 2014), the advantages of music training on speech processing emerge as indicators of neural plasticity when five criteria are met: when music training activates *Overlapping* sensory and cognitive mechanisms for both music and speech processing, places higher demands on the *precision* of music processing, elicits strong *Emotions*, requires frequent *Repetition* and focused *Attention*. Auditory-motor timing skills has been suggested to fulfil all requirements of the OPERA hypothesis, promoting thus the occurrence of transfer from music training to phonological development. The *Precise Auditory Timing Hypothesis* (PATH; Tierney & Kraus, 2014) postulates that phonological skills can be efficiently improved by music training with a particular focus on rhythmic synchronization.

One important notion is that certain aspects of phonological sensitivity develops without formal instruction as part of normative language acquisition (Ziegler & Goswami, 2005). Cross-linguistic research has indicated similar patterns for children's phonological development, showing hierarchical progresses from syllable-level phonological awareness to onset-rime awareness over the preschool years, whereas the explicit awareness of phonemes developing only as a consequence of formal reading instruction (Goswami & Bryant, 1990; Wimmer et al., 1991). Although it might seem evident that children prior to school commencement demonstrate natural improvements in verbal short-term memory and the non-alphanumeric aspects of rapid naming skills, exposure to alphabetic orthography may facilitate the encoding and manipulation of phonological information as well as the efficient transformation of visual objects into phonological codes (see Peterson et al., 2018, for the impacts of reading instruction). Music research is thus interested in whether and to what extent non-linguistic training programs could foster children's normative development in phonological processing and reading.

Findings of longitudinal studies mostly indicate that music lessons have additional benefits on children's phonological and reading development. In typically developing children between the ages of 4 to 8, music instruction has been found to enhance PA (Bolduc & Lefebvre, 2012; Degé & Schwarzer, 2011; Herrera et al., 2011; Linnavalli et al., 2018; Moritz et al., 2013; Patscheke et al., 2019), RAN skills (non-alphabetic RAN: Herrera et al., 2011; alphanumeric RAN: Slater et al., 2014), and reading ability (Hurwitz et al., 1975; Moreno et al., 2009; Rautenberg, 2015; Slater et al., 2014). These benefits were evident when examining the effects of music lessons compared to sports training (Degé & Schwarzer, 2011; Patscheke et al., 2019), visual arts training (Moreno et al., 2009; Rautenberg, 2015), dance lessons (Linnavalli et al., 2018), or to groups participating in no specialized training (Bolduc & Lefebvre, 2012; Herrera et al., 2011; Hurwitz et al., 1975; Slater et al., 2014). Moreover, music lessons appeared to have comparable impacts as phonological training (Degé & Schwarzer, 2011; Herrera et al., 2011), and led to greater gains when provided more intensively (Moritz et al., 2013). Nevertheless, some studies failed to observe superior achievements in children participating in formal musical activities (e.g., Gromko, 2005; Kempert et al., 2016; Yazejian & Peisner-Feinberg, 2009). Overall, research suggests that there are music learning methods for children which have the potential to accelerate some aspects of phonological and reading development. However, because of the variability of findings, the cognitive underpinnings of music training-related benefits cannot be clearly defined.

1.3.3 Executive functions

Even though the development of EFs begins early in life (Diamond, 2013), the preschool and early school years are associated with rapid increases in several subfunctions. The inhibitory control component shows dramatic improvements during preschool (Senn et al., 2004). In parallel, working memory demonstrates early but slower and more linear development (Best & Miller, 2010). Relying upon both inhibition and working memory (Diamond, 2013), set shifting begins to develop in the preschool years and shows a protracted developmental trajectory (Crone et al., 2004; Zelazo, 2006), like planning and verbal fluency skills (Romine & Reynolds, 2005). It has been indicated that focused training programs have the potential to enhance children's EFs if the activities build on a systematic curriculum constantly providing challenges with increasing difficulty, require repeated practice, engage participants' interests, and provide social and emotional support (Diamond & Lee, 2011). Learning to play an instrument and singing place high demands on attention and memory (Hannon & Trainor, 2007), auditory perception and coordination of movements (Zatorre et al., 2007) as well as on the integration of top-down, bottom-up, and multisensory processes (Trainor et al., 2009). Therefore, it seems plausible that regular musical practice in childhood leads to additional increases in several subcomponents of EFs. Furthermore, it has been proposed that improvements in EFs, especially in inhibitory control, might (partly) drive the influence of music training to specific and general cognitive abilities (Moreno & Bidelman, 2014; Moreno & Farzan, 2015).

A number of studies have examined the influence of music learning on the development of EFs in childhood and found evidence for enhanced EFs, including subfunctions like inhibition (Bolduc et al., 2020; Bugos & DeMarie, 2017; Degé et al., 2020; Frischen et al., 2019, 2021; Jaschke et al., 2018; Moreno et al., 2011), planning (Jaschke et al., 2018), processing speed (Roden, Könen, et al., 2014), and working memory (Guo et al., 2018; Roden et al., 2012; Roden, Grube, et al., 2014). Interestingly, not only children taking instrumental music lessons (Frischen et al., 2021; Guo et al., 2018; Roden et al., 2012; Roden, Grube, et al., 2014; Roden, Könen, et al., 2014) or combined instrumental-vocal training (Bugos & DeMarie, 2017), but children undergoing comprehensive (Bolduc et al., 2020; Degé et al., 2020; Frischen et al., 2019; Jaschke et al., 2018) and computerized receptive (Moreno et al., 2011) music programs demonstrated increases in EFs. However, there are also studies that found no superior performance of children receiving instrumental (D'Souza & Wiseheart, 2018) or comprehensive (Janus et al., 2016; Linnavalli et al., 2018) music programs. Thus, it is difficult to draw firm conclusions regarding the impacts of childhood music instruction on the development of EFs.

1.3.4 General intelligence

In addition to correlational studies revealing associations between taking music lessons and general intelligence, there is evidence that childhood music instruction enhances IQ. In 4‒9-year-old children, greater increases have been found in verbal (Kaviani et al., 2014; Moreno et al., 2011), nonverbal intelligence (Laczó, 1985; Portowitz et al., 2009), and full-scale IQ (Schellenberg, 2004) after receiving music lessons as compared to engaging in visual arts, drama, or no special training. Additionally, a study conducted in a Hungarian school setting pointed to the importance of the intensity of music learning, showing that after four years, children who participated in intensive music lessons had higher general intelligence compared to their peers who attended Kodály music lessons once a week (Barkóczi & Pléh, 1977). However, the lack of superior improvements for spatial, linguistic, and numerical reasoning have been also reported in musically trained preschool children (Mehr et al., 2013). Taken together, there is inconsistent evidence for the potential of music instruction to increase IQ in childhood. Even if its positive impacts are observable, the mechanisms underlying this music training-induced transfer are still not understood. As mentioned above, it is conceivable that partaking in music lessons improves children's general cognitive abilities, which might have an additional positive effect on intelligence. Careful examination of the role of EFs in mediating the impacts of music instruction on intelligence awaits future research.

1.4. The efficiency of music learning in promoting children's cognitive development

The abovementioned findings indicate that active participation in music education potentially associates with non-musical benefits in childhood. Despite the large number of studies conducted, neither the mechanisms driving the relationship between music-related and non-musical cognitive abilities nor the effectiveness of music learning programs in enhancing children's cognitive development are clear.

Several meta-analyses reported on the impacts of diverse childhood music training programs on the development of specific and general cognitive abilities. Regarding phonological and reading development, modest overall gains of music learning were reported when comparing the effects of music lessons to non-musical control activities or no special training (Butzlaff, 2000; R. L. Gordon et al., 2015; Standley, 2008). Concerning the development of phonological processing skills, modest training benefits were observed for rhyming with a significant effect of training duration, whereas only a trend toward a significant training effect was found in case of other phonological outcomes (R. L. Gordon et al., 2015).

As for reading acquisition, analyses revealed inconclusive findings, showing small significant (Standley, 2008) as well as non-significant effects (Butzlaff, 2000; R. L. Gordon et al., 2015). Standley (2008) pointed to inequal effects across age groups and populations, showing that younger individuals and children with special needs benefited most from music programs, independent of their duration. With respect to general cognitive abilities, recent meta-analyses indicated a weak overall impact of music training in childhood (Cooper, 2019; Sala & Gobet, 2020). Cooper (2019) initially showed small to medium mean effects of music learning on schoolchildren's general cognitive development, even when compared to active control activities. However, the higher level of methodological rigor was linked to non-significant influences on cognitive growth, indicating higher potential for music programs provided in more natural classroom settings. The analysis of Sala and Gobet (2020) confirmed the latter findings by revealing near-null impacts for studies applying active control groups and random assignment of participants.

Taken together, results of meta-analyses suggest that formal music learning might promote selective improvements in specific and general cognitive functions, but its effects may not surpass that of other non-musical training programs. Furthermore, regardless of the area studied, quality moderators were found to affect learning outcomes. Contradictory findings regarding transfer effects may therefore originate from the large amount of variability in the type of subject population, the age of participants studied, the design and outcome measures of the study, and the focus and intensity of music program. This diversity undoubtedly hinders the better understanding of the conditions necessary for music-induced transfer to be occur in cognitive functions during childhood. In the next sections, I highlight some factors that might influence the outcomes of music education programs.

1.4.1. Age and developmental stage of participants

As discussed above, music learning seems to have the greatest potential to promote neuroplastic changes in children before the age of seven (Amunts et al., 1997; Elbert et al., 1995; Pantev et al., 1998; Wong et al., 2007). This suggests that there might be a specific period in early childhood when musical experience has robust and lasting impacts on the brain and behaviour (Knudsen, 2004). Accordingly, one might assume that taking part in music lessons in the preschool or kindergarten ages could have larger influence on cognitive development compared to receiving music education later in the primary school years. A few recent meta-analyses have examined whether the age of participants account for differences in the efficiency of music instruction in childhood. With respect to literacy skills, Gordon and colleagues (2015) did not find any significant effect of age neither on the development of rhyming nor other phonological outcomes. Concerning general cognitive abilities, results of two meta-analyses conducted by Sala and Gobet (2017, 2020) revealed that age did not have any significant impact on the measures of memory, processing speed, or intelligence (verbal and non-verbal ability). Thus, the effectiveness of childhood music education programs appears to be independent of the age of participants.

Nonetheless, it is also possible that not age *per se*, but rather the developmental epoch during which formal musical experience occur might influence the educational outcomes. It has been documented that the development of brain regions implicated in musical activities (e.g., sensory, motor, frontal regions, corpus callosum) show distinct trajectories (for a brief summary, see Miendlarzewska & Trost, 2014). However, it is still not clearly understood how musical experience influences normative developmental processes that underpin the development of a variety of capacities. This issue is particularly relevant as the onset of formal music instruction typically coincides with the commencement of formal school instruction. There is evidence that the early primary school years are associated with dramatic normative increases in musical abilities (Gembris, 2006; Gooding & Standley, 2011), phonological skills (Ziegler & Goswami, 2005), and executive functions (Best & Miller, 2010). On the other hand, some music-related skills (e.g., music notation reading; Miyamoto, 2007; Stewart, 2003) and reading-related competencies (e.g., phoneme awareness: Wimmer et al., 1991; alphanumeric RAN: Wagner & Torgesen, 1987) are typically acquired through formal instruction. Thus, the development of certain capacities in school-aged children receiving music instruction might depend on how musical experience *and* formal instruction interact with normative development. It seems therefore conceivable that not only the benefits of music instruction but even the associations between the specific components of music-related and non-musical cognitive abilities vary with children's current stage of development. Thus, it is possible that certain links between musical and reading-related abilities emerge with explicit musical and reading experience.

Efforts have been made to test whether different patterns of relationships would emerge between components of music-related abilities and non-musical cognitive functions in children being at different stages of development. Some studies (e.g., Anvari et al., 2002; David et al., 2007; Steinbrink et al., 2019) reported slightly different patterns of relationships when examining different age groups. For example, Anvari and colleagues (2002) reported that the global index of music processing including tonal and temporal abilities was associated with phoneme awareness and reading in 4-year-old children. Moreover, music processing made a significant contribution to reading beyond phoneme awareness. Even though phoneme awareness showed associations with both pitch and rhythm processing in 5-year-old children, reading was specifically related to and predicted by pitch, but not rhythm, processing ability. In another study, Steinbrink and colleagues (2019) investigated the patterns of associations in groups of kindergarteners and third graders separately. Results indicated that in preschool children, both tonal (pitch and contour perception) and temporal (rhythm perception and reproduction) musical abilities were correlated with phonological awareness, whereas a specific relationship was observed between temporal musical abilities and phoneme awareness. In third graders, phoneme awareness was associated with pitch and rhythm processing skills (including both perception and production), while reading comprehension was specifically related to tempo perception. These marginal differences in the findings suggest that reading experience might play a role in the formation of relations between the distinct sub-components of musical, phonological processing skills, and reading. It should be also noted that these studies did not measure musical and reading-related abilities at the same level in the groups (i.e., Anvari et al. used a single music factor in 4-year-olds and separate pitch and rhythm processing factors in 5-year-olds, while Steinbrink et al. used different literacy measures in kindergarten children and third grades), clearly because of age-related considerations, which prevented the direct comparison of relations in children from different age groups. Nonetheless, results showed some differences and overlaps in the patterns of music-language associations, which draw our attention on the need for further longitudinal research investigating the stability of these cross-domain relationships over the course of the preschool and early school years.

Yet, music-language associations have been rarely investigated from a longitudinal perspective. In a longitudinal study, David and colleagues (2007) followed the contribution of rhythmic abilities to reading over the first 5 years of schooling. Findings indicated that rhythmic production abilities measured in the first school year maintained a significant relationship with reading ability from the first to the fifth year. However, when the shared variance with PA or RAN skills was controlled, rhythm could uniquely predict word and pseudoword reading only in certain grades. These results suggest that rhythm production does not have a stable association with reading above and beyond PA and RAN skills. Focusing specifically on rhythmic abilities, we cannot make any conclusions about the longitudinal role of tonal musical abilities in early reading achievement. Another study conducted by Forgeard and colleagues (2008) reported close relations between the increases in tonal processing and phoneme processing in normal-reading children (mean age 7 years at baseline) after 31 months of instrumental music lessons. Moreover, in a small subsample of children, improvement in pseudoword, but not real word, reading was related to improvement in both melody and rhythm discrimination abilities after receiving an average of 20 weeks of instrumental music instruction. These findings indicate the developmental parallels of musical and phonological processing abilities in the early stages of reading and music instruction.

1.4.2. Instructional setting and study design

Many previous longitudinal studies investigating the effects of music learning on schoolchildren's cognitive development randomly allocated participants into groups with different education programs (e.g., Bolduc & Lefebvre, 2012; Bugos & DeMarie, 2017; D'Souza & Wiseheart, 2018; Degé et al., 2020; Degé & Schwarzer, 2011; Frischen et al., 2019, 2021; Gromko, 2005; Guo et al., 2018; Herrera et al., 2011; Janus et al., 2016; Jaschke et al., 2018; Kaviani et al., 2014; Mehr et al., 2013; Moreno et al., 2011; Patscheke et al., 2019; Rautenberg, 2015; Schellenberg, 2004; Slater et al., 2014). Children participating in these research projects were sometimes trained with music specifically for the assessments, providing music lessons as out-of-school activities taking place at music schools, summer camps, or research laboratories. Even though these studies provided higher level of methodological quality, higher control has shown to be not necessarily advantageous for the transfer to occur. As mentioned earlier, meta-analyses indicated smaller effects for studies with more rigorous methodology (Cooper, 2019; Sala & Gobet, 2020). However, these analyses have pointed out that studies using higher levels of methodological rigor often have smaller sample sizes because of high attrition rates. This might originate in the more controlled allocation, presumably leading to lower motivational levels in children that influence the willingness to continue participation for long periods. Moreover, Tervaniemi and colleagues (2018) argued that small effects reported by studies using randomization might be resulted from the limited period of training time and intensity which prevents more robust music-induced neurocognitive enhancements to occur. These arguments point to the potential for music programs provided in natural settings.

Several projects have been initiated to investigate whether less intense but longer music programs taking place in everyday learning environments could promote cognitive improvements in children. There is now a growing interest in the effects of community-based music programs on children's cognitive development. There are longstanding music programs offering free opportunity to learn music to underprivileged children. Studies investigating the long-term impacts of participation in the Harmony Project (Los Angeles, USA) have shown enhancements in auditory neural processing (Kraus et al., 2014) as well as increases in sensorimotor synchronization (Slater et al., 2013), and literacy skills (Slater et al., 2014). Furthermore, similar neurocognitive benefits and better performance on a variety of cognitive tasks were detected in children who underwent music programs inspired by the Venezuelan El Sistema-based music instruction (see Habibi et al., 2018, for a review). Besides out-of-school community programs, in-school music programs have also been designed which integrate free music lessons into the general curricula. The clear advantage of this type of education is that wider communities from different socio-economic backgrounds would have access to group music programs even during the school hours. Findings of behavioural studies have indicated the beneficial cognitive effects of engaging in school music programs for both the kindergarten (e.g., Bugos & DeMarie, 2017; Linnavalli et al., 2018) and primary school populations (e.g., Jaschke et al., 2018; Roden et al., 2012; Roden, Könen, et al., 2014).

1.4.3. The content of music learning programs

Music education programs applied in longitudinal research varied considerably in their conceptualization. Most of the programs were based on comprehensive music curricula, including structured lessons on singing, listening, rhythmic and pitch-related exercises, music theory, creativity, and sometimes playing the chosen instrument. The curriculum of in-school music programs usually followed a traditional music educational approach (e.g., Orff, Kodály, Kindermusik), but sometimes specific curricula have been developed for research purposes. The content of such training programs was more accurately defined, often aiming to support the development of non-musical abilities. Other community-based music programs were specifically designed around instrumental training, which was organized either in small groups, larger ensembles, or sometimes in a one-on-one setting.

Yet, the role of the type of music programs in inducing cognitive improvements has not been studied systematically, despite the variability of music curricula. It has been argued that broader cognitive impacts can be achieved using complex learning paradigms which include diverse tasks with increasing difficulty and conditions resembling to real-life situations (Green & Bavelier, 2008). However, it is not clear whether generalizability could be greater for programs focusing on multiple rather than specific cognitive domains (Bergman Nutley et al., 2011; Diamond & Lee, 2011; Karbach & Kray, 2009). There is typically no distinction between the types of music instruction in meta-analyses examining the impacts of music lessons on cognitive measures. In a recent meta-analysis, Cooper (2019) included the type of music program as a potential moderator. However, the analysis did not confirm that various types of music education programs would differently influence the cognitive growth of children. Even though this suggests that the role of program type is irrelevant, it is conceivable that differences in their musical content might affect the cognitive outcomes of music programs.

The examination of the possible contribution of body movement to music-induced cognitive enhancements has received little attention in music research, although different types of movement are often incorporated in both comprehensive and instrumental music curricula. Various fine and gross body movements (e.g., clapping, stepping, body percussions, drumming, tapping) are mostly applied in accordance with the rhythmic, tonal, and dynamic characteristics of music, whereas movement is sometimes used for creating free dance-like expressions. There is empirical evidence that the connection between body movement and auditory processing relies on shared neural foundations. Auditory perception and the perception and production of movement appear to recruit overlapping neural networks (Gazzola et al., 2006) and the vestibular system might mediate the connection between auditory and motor system (Todd, 1999). In addition, some motor and cognitive functions have common neural bases and show similarly protracted developmental trajectories (Diamond, 2000). Performance on tasks requiring complex motor skills and higher order cognitive abilities have been found to be closely related in school-aged children (van der Fels et al., 2015). It seems therefore plausible that music educational programs incorporating movement elements have additional impacts on both music-related and non-musical cognitive development in childhood.

A few studies have investigated the influence of combined music and movement programs on the acquisition of music-related and non-musical abilities in childhood. Regarding musical auditory abilities, Lewis (1988) reported that the influence of a 12-session long movement-based music instruction was not considerable for all listening abilities. The advantages of receiving music lessons combined with movement were detected in the perception of dynamics for first graders and the perception of dynamics, melody, and overall music perception for third graders. In another study (Rohwer, 1998) with a population of sixth graders, 10 weeks of movement-based music instruction significantly improved children’s synchronized tapping skills compared to the music instruction using no movement elements. Investigating the impacts of a supplementary classroom music and movement curriculum in preschoolers, children participating in the music intervention twice a week for 26 weeks did not show greater enhancements in phonological awareness than their counterparts receiving no supplementary intervention (Yazejian & Peisner-Feinberg, 2009).

In conclusion, prior research suggests that the relationship between the certain aspects of musical, reading-related, and general cognitive abilities and thus the advances of music learning might depend on the developmental period in which the examination and/or learning takes place. It appears that the educational setting might also influence learning outcomes in childhood. Both music training and community-based music programs have been proven to have some potential to support children's development in a variety of capacities; however, music learning in a more natural setting might lead to greater impacts on children's development. In addition, there might be curricular features that can considerably facilitate children's development in specific and/or general cognitive functions. Based on the close relations of auditory, motor, and cognitive processes in the brain, it seems conceivable that bodily involvement in music learning could contribute to cognitive development in childhood. The possible effects of the inclusion of movement in classroom music education programs needs thus further research in school-age children.

1.5. Context of the present studies

1.5.1. Educational background

Music education has a long tradition in the Hungarian school system. The integration of music into general primary school education dates back to the 19th century in Hungary. In 1869, the first music curriculum was introduced, which mandated weekly music lessons for all children in public primary schools (Szabó, 1993). Since 1948, the concept of Zoltán Kodály has formed the pedagogical basis of mandatory music instruction in public primary schools (Nagy, 2012). The content and intensity of the music curriculum specified for different age groups has changed over time in line with the goals of music instruction. In 1978, the curriculum was reformed globally, formulating the core content for primary school music education. Later, in 1995, the National Core Curriculum was implemented, regulating common requirements for wider age ranges (i.e., Grades 1−6 and Grades 7−10; Nagy, 2012). The 2020 Core Curriculum includes music curricula for both intensive and regular music classes in primary schools. It has been developed for Grades 1−4 and Grades 5−8. In primary schools, the ultimate goals of music education for the lower grades are the improvement of basic musical competencies and skills, singing, active music listening and music creation, reading and writing musical notation, as well as the development of musical taste and integrated personality through musical appreciation.

In Hungary, the traditional music curriculum follows the educational principles of Zoltán Kodály, a composer, ethnomusicologist, and educator. Kodály’s pedagogical concept emphasizes the importance of structured music instruction from early childhood in fostering a lifelong appreciation for music. The concept is a comprehensive approach to music education that covers various aspects of music, including theory, history, and practical performance. It focuses on teaching the fundamental principles of music, training musical hearing, acquiring music literacy (reading and writing notation), and developing music comprehension through singing and folk songs from the native culture (Dobszay, 1972). Therefore, collective singing, rhythmic games, and listening activities are typically used to improve vocal abilities and basic listening skills. In rhythmic musical activities, clapping, stamping, and tapping are used as supplementary forms of body movement to accompany musical features. The basic theoretical concepts of music and the understanding of musical tonality and syntax are supported using solfège and relative solmization. In the ‘moveable-do’ system, each note is paired with a syllable that represents the note’s position in the scale (i.e., do-re-mi-fa-sol-la-ti; the tonic is do and the dominant is sol). Furthermore, each syllable can be represented by a hand sign, which also indicates the pitch position of the note. Additionally, there are rhythmic syllables that represent different rhythmic values (Göktürk Cary, 2012).

Kodály, as an educator, emphasized the significance of making music accessible to all children (Choksy, 1999). In line with his views, Hungarian primary school education provides children with twice-a-week classroom music lessons from the beginning of first grade, regardless of their familial socioeconomic background.

1.5.2. New approaches in music education

Hungarian music education in recent decades has been dominated by a quantity-oriented perspective, which has resulted in an overemphasis on the acquisition of music theory knowledge in music lessons. There is a lack of methodological tools in music education to provide children with active and enjoyable activities (Janurik, 2018). This approach has prevented many children from experiencing the joy of singing, listening to music with understanding, communicating through music, and expressing themselves through active music-making. The absence of pleasure in music may have contributed to the generally negative attitudes (Janurik, 2007) and low level of motivation (Józsa et al., 2017) among children towards school music lessons, which is already evident in the very first year of primary school (Mucsi et al., 2019). This highlights the need for a thorough overhaul of music education methods (Nemes, 2014).

In recent years, there have been significant efforts to renew classroom music education in Hungary. It is generally argued that music education should provide children with actively participatory, challenging, and socially interactive music activities in the school environment. Music lessons should engage students in concentration, encourage cooperation, provide feedback, and offer positive reinforcement (Márta Janurik & Józsa, 2018). One aspect of this renewal involves the use of digital devices in education to support children's intrinsic motivation towards music learning. The use of digital devices can maintain students' interest and motivation while also improving the effectiveness of music lessons. Márta Janurik's research group from the Faculty of Music at the University of Szeged has developed *Music Island* as part of the Content Pedagogy Research Programme of the Hungarian Academy of Sciences. This software can be run on various platforms and involves a program designed to aid in the classroom music education of lower-grade children. The program aims to enhance music perception, singing, music reading skills, as well as to support the acquisition of musical knowledge through enjoyable activities, enabling children to experience the creative use of music during the sessions while promoting cooperation (Szabó, 2018; Szabó et al., 2019).

Another important aspect of this pedagogical renewal is the approach that incorporates body movement into music education. The Active Music Learning Group was established by music educators from the Liszt Academy of Music as part of the Content Pedagogy Research Programme of the Hungarian Academy of Sciences. The group aims to modernise music teaching and develop new methods for classroom music education based on movement experience. Movement-based music programs are designed to meet schoolchildren's need for exercise. They combine various forms of musical activities with movement elements to support the development of music perception, appreciation, and production. The aim is to generate children's interest in music by providing a multimodal musical experience and the joy of making music together (for further details on the background and educational motives, see Nemes, 2014). Based on the concept of Kodály, the movement-based approach is structured around a curriculum that includes vocal and ear training, the learning of folk songs, relative solmization, hand signs, rhythmic duration syllables, music theory, and music literacy. In addition to traditional musical activities, movement-based music instruction involves body movements that correspond to changes in the music, such as changes in rhythm, pitch, and form.

As part of the Active Music Learning initiative, two classroom music programs that incorporate body movement have been designed for children in their early school years. Despite sharing the same pedagogical goals, the various models of movement-based music education differ in their use of body movements. The Creative Singing-Movement Games model involves the music educator selecting and directing the movements, whereas the Dynamic Music Learning model encourages children to improvise and use their own movements in response to the music.

The educational approach of Creative Singing-Movement Games combines Kodály-based music instruction with some aspects of the Dalcroze method. It was created and adapted for classroom music instruction by Borbála Szirányi and Edina Barabás from the Kodály Institute of the Liszt Ferenc Academy of Music. This method intentionally incorporates body movement into musical activities by connecting sounds to particular movements. Fixed movement choreographies are designed to express and strictly follow the formal, rhythmic, or melodic features of music. Initially, the teacher introduces the movements to the children, who then imitate them individually before practicing in pairs or groups, depending on the choreography. As children progress, the teacher encourages them to create their own movement choreographies in collaboration with the group members. The movement elements are then regularly repeated during listening and vocal activities to promote self-expression and improve phrasing and singing technique. The music program also includes a 'body-rhythm system' that links particular movements (e.g., clapping, snapping, walking, stamping, jumping, etc.) with traditional rhythmic duration syllables. Children learn to associate each movement with a specific rhythmic value in rhythmic games, enabling them to experience rhythm by combining auditory, visual, and kinesthetic elements. The repeated practice of these rhythm-motion pairs aims to enhance children's ability to decode and interpret rhythmic musical patterns. For a detailed explanation of the model, see the handbook by Szirányi (2021).

The Dynamic Music Learning model is based on music education principles and methods developed by Klára Kokas. These have been adapted for traditional classroom settings by Tamara Farnadi (János Richter Secondary School of Music, Győr) and Gabriella Deszpot (Kodály Institute of the Liszt Ferenc Academy of Music). The model combines music, movement, and imagination to promote a comprehensive understanding of music. The model utilizes Hungarian folk songs, classical music masterpieces, and movement games to incorporate body movement as a means of both receiving and expressing music. Music lessons begin with collective singing, which frames each session. Listening and reflection phases are interspersed between singing phases. During the listening phase, children are encouraged to use their creativity to improvise movement combinations that respond to the changing qualities of the particular musical piece. The nature of movement elements is not fixed, allowing children to express themselves freely and create individual or group movement choreographies. During the collective reflection phase, participants have the opportunity to share their musical experiences with the group. This can be achieved through demonstrating their movements, expressing themselves verbally, or creating visual artwork. The receptive, reflective, and expressive phases subtly vary when showing the same musical piece to children repeatedly. Movement-based music appreciation not only supports music acquisition but also encourages emotional expression and social interactions. For a comprehensive description of the model, see the handbook by Deszpot et al. (2021).

Maróti and colleagues (2019) conducted a comprehensive evaluation of the effects of these movement-based classroom music programs in school-aged children. The study aimed to determine whether the traditional solfeggio-based Kodály curriculum and two movement-based music curricula, which implemented either fixed of free movement components into the Kodály curriculum, would have distinct impacts on the musical, reading-related, and general cognitive development of 6–7-year-old children. After eight months, children who received the movement-based music program showed greater improvement in pitch discrimination, phonological skills, and working memory than those who had traditional Kodály music lessons. On the other hand, children in the traditional music classes demonstrated greater increases in executive functions compared to those in the movement-based classes. However, since no interaction effects were significant, it cannot be concluded that either the movement-based or the traditional Kodály curriculum is better at promoting enhancements in cognitive measures. Nevertheless, these results suggest that classroom music education may lead to specific cognitive improvements in schoolchildren depending on the inclusion and diverse application of body movement in musical activities.

2. RESEARCH OBJECTIVES, QUESTIONS, AND HYPOTHESES

2.1. General research objectives

The main aim of the present dissertation was to examine the relations of music to cognitive functions over the course of the early primary school years in an ecologically valid setting. The literature review revealed inconclusive findings on the extent to which formal music education could influence children's cognitive development, as well as the context and elements of instruction that could be effective in inducing such benefits during this developmental period. Besides, the relations of music processing abilities to specific and general cognitive functions that could explain the mechanisms underlying cross-domain skill transfer are unclear. Moreover, little is known about the stability of these relations over the early school years and the potential longitudinal associations between the improvements of music-related and non-musical abilities.

Thus, to address these questions, the present studies investigated cognitive development in schoolchildren who received classroom music education as part of the core curriculum. I focused on children in their first school years to estimate the contribution of classroom music lessons to music-related and non-musical cognitive growth in the initial period of formal school instruction. The school environment enabled the investigation of music-induced transfer effects in a natural setting. The lack of random allocation allowed participants (and their parents) to select the class based on their preferences and motivations. Additionally, the comprehensive school music curricula, which provided complex learning conditions and demanded multiple domains, were assumed to promote broader cognitive enhancements in children.

Studies examined the effects of classroom music learning in multiple groups of children to compare the efficacy of various music learning programs. The longitudinal study design was used to investigate between-group differences on several occasions and the patterns of development over the first two school years concurrently. The cross-sectional investigation might advance our understanding of how different musical experiences (quantitatively and qualitatively) are associated with the levels of cognitive functioning at certain points of children's development. Moreover, the longitudinal examination may help to clarify whether various classroom music curricula that incorporate different body movement elements could promote cognitive improvements in distinct ways.

Beyond the between-groups comparisons, the present research enabled examining the patterns of relations of music-related abilities to specific and general cognitive functions from the beginning of schooling to the end of second grade. This longitudinal approach may help to understand whether these cross-domain relationships are persistent or change with formal reading and music instruction. In addition, close relations between increases in these abilities may indicate that music-related competencies develop in parallel with non-musical cognitive functions during this prominent period of development.

In sum, this dissertation had two fundamental objectives: 1) to uncover how various classroom music learning programs with or without body movement contribute to children's music-related and non-musical cognitive development, and 2) to investigate the nature of relations of music-related abilities to non-musical cognitive functions longitudinally over the first school years. To address questions related to these objectives, five studies were conducted. In the next sections, the research questions and hypotheses are discussed in more details.

2.2. Research questions

In the dissertation, I aimed to address five main research questions of which three were related to the effects of school music learning on cognitive development and two were related to the longitudinal associations between musical and reading-related abilities.

1) Does the amount of classroom music education experience play a role in cognitive development? Is greater classroom music experience associated with better musical, reading-related, and general cognitive abilities in second graders?
2) Does the incorporation of body movement into classroom music education programs have additional impacts on children's cognitive development in the first two years of school?
3) Do various movement-based music programs employing body movement differently have distinct effects on children's cognitive development in the first two years of school?
4) Do music-related abilities have stable patterns of relations to phonological processing and word reading over the first two years of schooling? Does the ability to integrate musical auditory and visual information correlate with reading-related abilities in the early years of formal reading and music instruction?
5) Do the developmental trajectories of musical and reading-related abilities show similarities? Do the patterns of association between the improvements in musical and reading-related abilities remain consistent across the first and the second years of schooling?

2.3. Hypotheses

Based on the literature, nine hypotheses were formulated, which were tested through five empirical studies. The structure and the major hypotheses of the five studies included in the dissertation are summarized in **Figure 2.3.1**.

Hypothesis 1. *Children with more extensive formal musical experience would show higher musical and reading-related competencies.*
Comparing the effects of the same music program with varying intensity is not typical in music research. As previous research suggests that classroom music lessons is more likely to be associated with specific improvements in cognitive functioning rather than the enhancements in general intelligence (e.g., Forgeard et al., 2008; Jaschke et al., 2018; Maróti et al., 2019; Roden et al., 2012; Roden, Könen, et al., 2014), the exploratory hypothesis was made that children with more intensive music lessons would demonstrate superior performance in musical and reading-related cognitive abilities, but not in IQ measures, compared to those with less intensive music lessons after one year of classroom music education. Results related to this hypothesis are given in **Thesis 1**.

Hypothesis 2. *Music curriculum incorporating body movement would have greater effects on specific cognitive functions.*
Based on the findings of the study by Maróti and colleagues (2019), more pronounced increases were predicted for children in the class receiving a movement-based music curriculum, but not for children receiving the traditional Kodály curriculum, specifically in pitch discrimination, phoneme awareness, working memory, and sensorimotor synchronization. Results related to this hypothesis are given in **Thesis 2**.

Hypothesis 3. *Music curriculum using directed body movements would have greater influence on specific cognitive functions.*
Practising auditory-motor coordination is an important aspect of predetermined movement choreographies (Szirányi, 2021), but it is less prevalent in free body movement (Deszpot et al., 2021). Therefore, it was hypothesized that sensorimotor synchronization would be more enhanced in the class with the movement-based curriculum incorporating teacher-directed movement. It was expected that this class would show improved performance in executive functions due to the potential association between enhanced sensorimotor synchronization and

better executive functioning (Miendlarzewska & Trost, 2014). Exploratory hypotheses were made for the greater gains of sensorimotor synchronization and executive functions in the class taking part in music lessons that applied directed movement elements. Results related to this hypothesis are given in **Thesis 3**.

Hypothesis 4. *There are specific relations between the subcomponents of music-related abilities, word reading, and the precursors of reading.*
Based on the contradictory findings of music research (e.g., Degé et al., 2015; Douglas & Willats, 1994; Forgeard et al., 2008; Janurik et al., 2022; Loui et al., 2011; Moritz et al., 2013; Rautenberg, 2015; Steinbrink et al., 2019), it was assumed that specific aspects of music-related abilities, rather than overall musical abilities encompassing both tonal and temporal aspects, would be related to PA, RAN, and reading in schoolchildren. Results related to this hypothesis are given in **Thesis 4**.

Hypothesis 5. *Musical audiovisual processing associates with rapid naming and word reading.*
The exploratory hypothesis was made that musical audiovisual processing might be directly related to RAN and word reading, but not to PA, due to their common reliance on the ability to associate visual and auditory information (Blomert, 2011; Hodges & Nolker, 2011; Stewart, 2003). Results related to this hypothesis are given in **Thesis 4**.

Hypothesis 6. *The pattern of the relations differs at various measurement points.*
Based on the small differences in the pattern of relations when examining children from different age groups (Anvari et al., 2002; Rautenberg, 2015; Steinbrink et al., 2019), the exploratory hypothesis was made that the magnitude of the relationship between distinct musical abilities to PA, RAN, and reading would differ at school entry and the end of the first/second school year due to increasing reading and musical experience. Results related to this hypothesis are given in **Thesis 4**.

Hypothesis 7. *Specific music perception abilities develop in parallel with PA, RAN, and reading.*
It was assumed that selective longitudinal associations would be observed between the improvements in pitch-related music perception and improvements in phonological processing skills. It was hypothesized that no significant associations would emerge between increases in

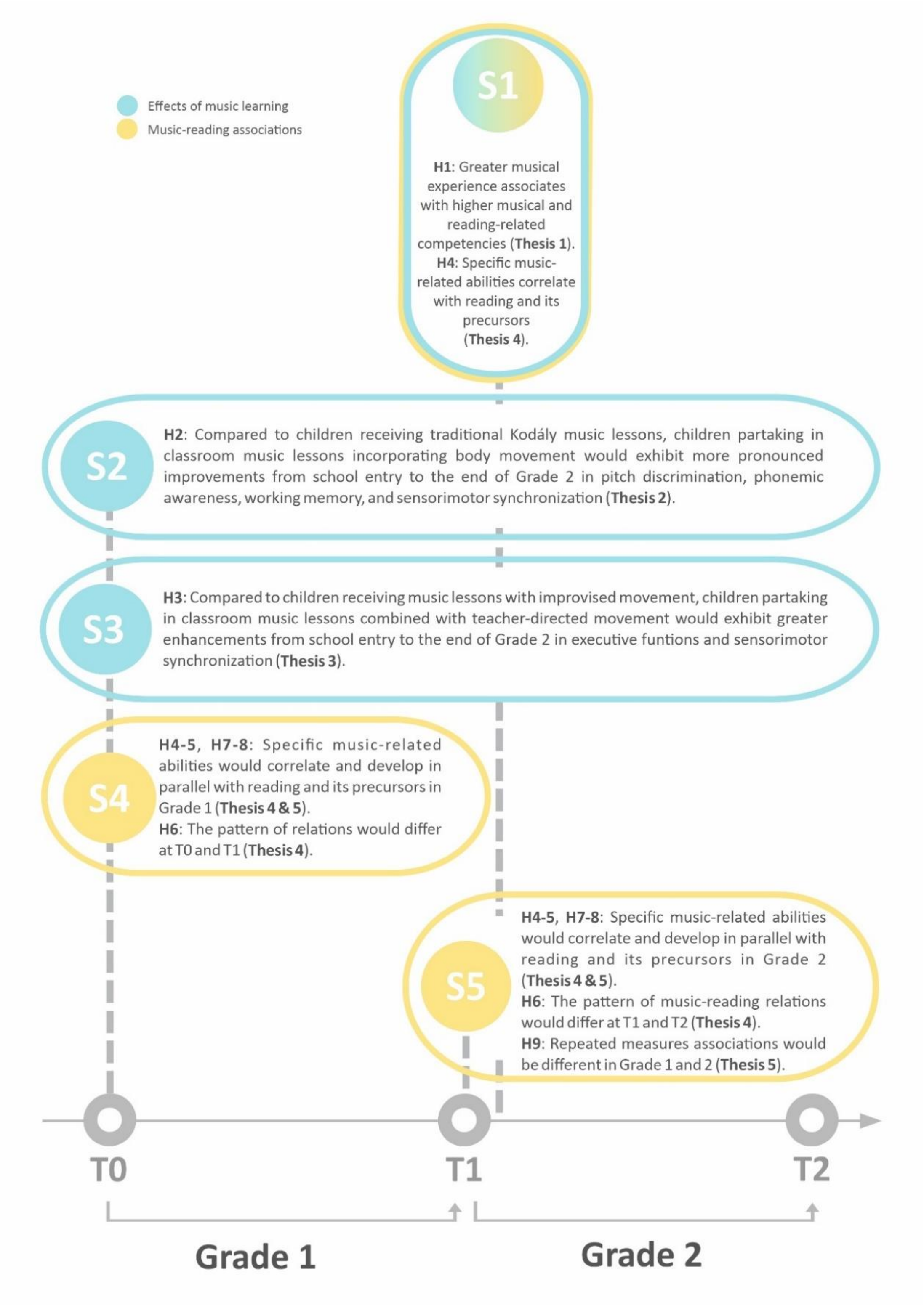
music perception and word reading (Forgeard, Schlaug, et al., 2008). Results related to this hypothesis are given in **Thesis 5**.

Hypothesis 8. *Musical audiovisual processing develops in parallel with RAN and reading.*
It was hypothesized that increases in musical audiovisual processing would be associated with increases in RAN and word reading, but not with increases in PA (Blomert, 2011; Hodges & Nolker, 2011; Stewart, 2003). Results related to this hypothesis are given in **Thesis 5**.

Hypothesis 9. *The patterns of associations between the development of musical and reading-related abilities show differences over the first and the second school years.*
The exploratory hypothesis was made that the magnitude of longitudinal relations of distinct musical abilities to PA, RAN, and reading would differ in the first and second school years (Forgeard, Schlaug, et al., 2008; Vaessen & Blomert, 2010). Results related to this hypothesis are given in **Thesis 5**.

Figure 2.3.1

Summary of the structure of studies and their hypotheses



Notes. *S1–5* = Study 1–5. Assessments: *T0* = School entry; *T1* = End of Grade 1 / Beginning of Grade 2; T2 = End of Grade 2.

3. GENERAL METHODS

In this Chapter, the methods of the studies included in this dissertation are described in detail. I created a separate chapter covering all methods as the methodologies that formed the basis of the five studies were overlapping in terms of the approach of music education, testing methods, and data analysis. Moreover, four of the five studies (Study 2–5) belonged to the same longitudinal research project, employing the same measurements. Thus, the design of the doctoral research is presented first, followed by a summary of participant details. Next, the measures applied in the five studies are described in detail, followed by the research procedures. Finally, the general statistical methods used in all studies are summarized in the last section.

3.1. Design

Study 1 examined the role of the amount of music education experience using an independent samples design. Studies 2 and 3 investigated the effects of classroom music education with or without movement using pretest-posttest quasi-experimental study designs. Participants were assigned to classrooms based on both school selection and self-selection. Furthermore, correlational research designs were used in Study 1, as well as Studies 4 and 5, to investigate the strength of the relationship between musical abilities and reading-related abilities at multiple measurement points.

3.2. Participants

The studies employed convenience sampling and contacted first primary school headteachers to participate. Four primary schools were invited to take part in this research. After the headteachers provided written consent for participation, classes participated voluntarily. Parents received written information about the research and provided written informed consent regarding their children's participation in the research. Participants gave an oral agreement at the beginning of testing and were informed about the possibility to terminate the measurement at any time. The Research Ethics Committee of Eötvös Loránd University Faculty of Education and Psychology, Budapest, Hungary approved the protocol for Study 1. Ethical approval for Studies 2−5 was obtained from the United Ethical Review Committee for Research in Psychology (EPKEB) in Budapest, Hungary (approval number: 2016/062). The studies were conducted in accordance with the Declaration of Helsinki.

Table 3.2.1 summarizes the characteristics of participants involved in the studies related to the doctoral research. All participants were native Hungarian speakers. The studies involved children who had not received any formal music education prior to school entry. School music instruction started for all children at the beginning of the first primary school year. For all classes, music lessons were held by professionally trained music teachers during the school hours in groups of 20 to 30.

Table 3.2.1.

Summary of the characteristics of the participants involved in the studies

Study	***N***	**Gender** [a]		**Measurement**	**Age** [b]	
		n	**%**		**M**	***SD***
S1	30	14	46.67		8.0	0.5
S2	40	26	65	T0	6.95	0.31
				T1	7.47	0.32
				T2	8.45	0.33
S3	40	18	45	T0	7.02	0.34
				T1	7.55	0.35
				T2	8.54	0.35
S4	85	45	52.94	T0	6.96	0.34
				T1	7.48	0.35
S5	80	44	55	T1	7.51	0.34
				T2	8.50	0.34

Note. *Study*: S1−5 = Study 1−5. *Measurement*: T0 = beginning of first grade, T1 = end of first grade, T2 = end of second grade.

[a] Reflects the number and percentage of boys participated in each study. [b] Age is shown in years.

3.3. Measures

3.3.1. General intelligence

Intelligence was estimated based on subtests selected from the Hungarian standardized version of the Wechsler Intelligence Scale for Children − Fourth Edition (WISC-IV; Nagyné Réz, Lányiné Engelmayer, Kuncz, Mészáros, & Mlinkó, 2008; Wechsler, 2003). Participants were measured with Block Design, Similarities/Vocabulary, and Digit Span to cover the main indices of the WISC-IV. I did not administer any subtests from the Processing Speed Index as being related to executive functioning for which other measures were applied. This selection enabled the assessment of the most prominent intelligence factors in a reduced testing time.

Block Design assessed children's visuospatial skills and non-verbal reasoning. Children were presented constructed models or pictures displaying red and white designs and asked to reproduce each model using red-and-white blocks. The complexity of the visual items increased across the trials. Only accurately constucted items that were completed within the specified time limit were scored. Time bonuses could be given for faster completion. Scores were used as an index for non-verbal intelligence.

Similarities subtest examined verbal reasoning and concept formation. Participants had to identify and express how two orally presented words (e.g., *milk* and *water*) were similar. Scoring was based on the degree to which the response described the most essential features of the items. Performance in this subtest was considered as an index for verbal intelligence in Study 1.

Vocabulary measured verbal knowledge. Words with increasing difficulty were orally presented to children and their task was to define the meaning of each item. Scores were given based on the sophistication of definitions. Scores were used as an index for verbal intelligence in Studies 2−5.

Digit Span tested verbal short-term and working memory. Children heard sequences of digits presented orally by the experimenter. In the forward condition, children had to repeat the sequence of numbers in the same order, while in the backward condition they had to repeat the sequence in a reversed order. The length of sequences increased gradually from 3 to 9 digits in the forward condition and from 2 to 9 digits in the backward condition. The longest correctly repeated sequence was calculated for the forward and backward tasks separately. The digit span score was defined by summing the scores obtained from the two conditions.

In cross-sectional analyses, age-specific norms were used for each intelligence subtest (Study 1). However, the raw scores were used in longitudinal analyses to better evaluate the developmental course of general cognitive functioning within the same age group (Studies 2−5). The reliability coefficients of the subtests obtained by Fisher's *z* transformation are good (Block Design: r_{xx} = .86; Similarities: r_{xx} = .86; Digit Span: r_{xx} =.87; Vocabulary: r_{xx} = .89). The characteristics of the measures related to general intelligence is summarized in **Table 3.3.1**.

Table 3.3.1

Summary of the measures of general intelligence

Subtest	Task	Range of scores	
		Raw	*Standard*
Block Design	Reproduce designs using red-and-white blocks.	0–68	1–19
Similarities	Define how two words are similar.	0–44	1–19
Vocabulary	Define the meaning of words.	0–68	1–19
Digit Span	Repeat the sequence of numbers in the same/reversed order.	0–32	1–19

3.3.2. Reading-related abilities

Reading-related abilities were estimated by the standardized Hungarian adaptation of the Dyslexia Differential Diagnosis Maastricht (3DM-H; Tóth, Csépe, Vaessen, & Blomert, 2014; Blomert & Vaessen, 2009). The computer-based test battery comprised 11 subtests examining the core cognitive functions relevant to reading and spelling performance. In the present studies, only three subtests were administered measuring word reading and its most prominent indicators, namely phoneme awareness (PA) and rapid automatized naming (RAN).

Reading subtest measured the accuracy, speed, and fluency of word reading. After a short practice phase including five items, blocks of words gradually increasing in length (number of letters and syllables) were displayed on the computer screen. Children were instructed to read aloud as many items as possible in 30 seconds. Instructions appeared on the screen and played via the headphones simultaneously. The subtest comprised three conditions with different types of words: high-frequent, low-frequent words, pseudo-words. Each condition included 75 test items. The first block of 15 items contained CVC (C = consonant, V = vowel) words, the second contained CVCC/CCVC words, the third contained CVCVC words, the fourth contained complex 2-syllable words, and the fifth contained 3-syllable words. For each word type, the reading fluency score was determined by the number of words read correctly in a second. In Study 2–4, a revised and shortened version of the subtest was employed to assess early reading ability in first graders. This shortened task comprised only two blocks of high-frequent words. The task was recorded if the child was able to read all the one-syllable practice items accurately.

The fluency score was calculated for the short reading subtest with the formula used for the original subtest.

The *Phoneme Deletion* subtest examined children's phoneme awareness. Children were asked to remove a specified speech sound from one-syllable pseudo-words and utter the resulting sound sequence. Instructions and test items were presented via the headphones. The subtest comprised two practice items followed by 27 test items organized into three blocks. The task required children to delete the initial or the last phoneme in the first and second blocks, and an inner phoneme in the third block. The complexity of pseudo-words increased from CVC (e.g., 'cák') to CCVC/CVCC and more complex one-syllable items (e.g., 'grunt'). The original subtest was shortened for first graders in Study 2–4. To avoid any misunderstandings, the task was registered if the participant completed the two practice trials correctly. The shortened subtest included only four CVC items, requiring the deletion of the first or the last phoneme of the pseudo-word. The accuracy score was defined by the proportion of correct responses and the speed score reflected the amount of time taken to articulate each response. Also taking the difficulty of items into account, both the accuracy and speed scores were estimated using hierarchic IRT (item-response theory) models. The transformed scores had a mean of 0 and a standard deviation of 1.

Rapid automatized naming (RAN) examined phonological lexical retrieval and the efficacy of the integration of visual and verbal information. Two RAN tasks were administered: children were asked to sequentially name digits (1, 4, 5, 6, 8), and drawings of everyday objects (fish, chair, pear, scissors, dog) as quickly as possible in the Digits and Pictures tasks, respectively. Instructions were presented on the computer screen and via the headphones at the same time. Each task began with five practice items to ensure that all participants used the correct name of the items. Two blocks were presented for both item types in which items were arranged pseudo-randomly into 3×5 matrices. The speed score was computed for each task separately based on the average number of items named correctly in a second. RAN tasks were employed in Study 2–5.

The subtests show good overall reliability. Concerning Reading Fluency, high-frequent word reading has an r_s of .90, low-frequent word reading has an r_s of .90, and pseudo-word reading has an r_s of .86. For Phoneme Deletion, the accuracy has an IRT-based reliability of .87 and the speed has an IRT-based reliability of .96. Regarding RAN, the digits subtest has an r_s of .90 and the pictures subtest has an r_s of .82. **Table 3.3.2** summarizes the characteristics of reading-related measures applied in the studies.

Table 3.3.2

Summary of the measures of reading-related abilities

Subtest	Task	Items	Scoring
Reading			
Original version	Read aloud as many items as possible in 30 seconds.	75	item / sec
Shortened version		30	item / sec
Phoneme Deletion			
Original version	Remove a specified speech sound from one-syllable pseudo-words and utter the resulting phoneme sequence.	27	*IRT* % correct
Shortened version		4	*IRT* % correct
Rapid Automatized Naming (RAN)			
Digits	Name the presented digits as quickly as possible.	30	item / sec
Pictures	Name the presented drawings as quickly as possible.	30	item / sec

3.3.3. Musical abilities and sensorimotor synchronization

3.3.3.1. Bentley's Measures of Musical Abilities (Study 1)

The *Measures of Musical Abilities* (MMA; Bentley, 1966) was designed to assess the core components of musical auditory abilities which are essential to active music making in childhood. The Hungarian adaptation of the test battery was developed by our research group using the manual of the German test version (Bentley, 1973). The Hungarian instructions were recorded with the Praat program (Version 4.5; Boersma & Weenink, 2007) and the musical auditory stimuli were recreated using several sound editor software (Finale 2012 v.2012.r1, MakeMusic Inc., 2012; Wavepad Sound Editor v.5.32, NCH Software, 2012; Tone Generator v.3.07, NCH Software, 2013). The test battery comprised four subtests.

The *Pitch Discrimination* subtest included 20 items with pairs of tones for which children had to indicate whether the two sounds were the same or the pitch of the comparison stimulus was higher or lower than the original one. In all trials, the first tone served as a reference with its fundamental frequency being fixed at 440 Hz. The frequency of the comparison tone varied between 414 Hz and 466 Hz. The difference between the reference and comparison tones gradually decreased from a frequency interval of a whole tone to 3/26 of a tone. The *Tonal Memory* subtest presented five-tone melodies and children had to detect the position of the one-tone change in the comparison melody. All comparison stimuli were contour-preserving.

Changes appeared twice at each tone position. The subtest consisted of ten items: half of the comparison stimuli showed a pitch interval change of a whole tone, the other half showed a semitone change. The *Chord Analysis* subtest comprised two- to four-note chords and required children to indicate the number of tones played at the same time. The subtest included 20 items of which 10 presented dyads, eight presented triads, and four presented tetrads. The *Rhythm Memory* subtest included pairs of four-beat rhythmic patterns with 4/4 time and participants had to decide whether the comparison rhythmic pattern was the same or indicate the exact beat where the second rhythmic pattern differed from the original one. From ten test items, two items comprised identical pairs of rhythmic patterns and eight items comprised a rhythmic pattern change. Changes appeared at each beat position twice.

For the Pitch Discrimination subtest, test stimuli were created with an online frequency generator (Tone Generator v.3.07, NCH Software, 2013). Musical stimuli were created using the piano timbre in the Tonal Memory, Chord Analysis, and Rhythm Memory subtests. Instructions and test stimuli were played via the headphones. Each test item was presented once during the testing phase. Children gave their responses orally, which were administered by the experimenter on a response sheet in writing. No time limit was set for participants to give their responses. For each subtest, the accuracy score was determined by the percentage of correct responses.

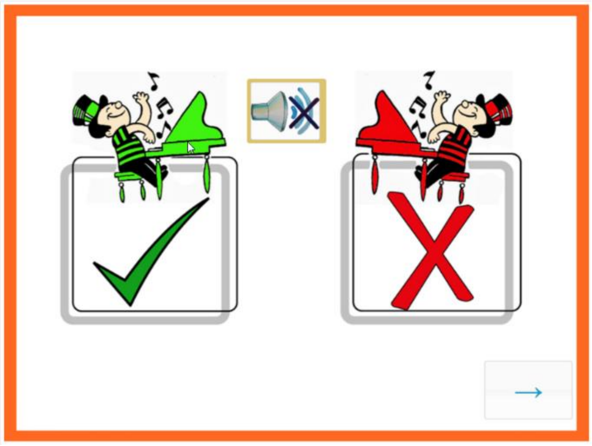
3.3.3.2. Online measure of musical abilities (Study 2–5)

The online measure of musical abilities was developed based on the musical tests of Asztalos and Csapó (2017). The eDia (Electronic Diagnostic Assessment; Csapó & Molnár, 2019) system was applied for data collection. This easy-to-use online platform enabled participants to perform the musical tests on the computer at their own pace. Short auditory explanations for musical terms, instructions, and test items were played via the headphones. The battery consisted of six subtest: five subtests estimated musical discrimination abilities and one subtest estimated musical audiovisual processing skills.

Discrimination subtests measured children’s musical auditory memory and their capability to differentiate musical patterns. Participants were presented pairs of musical stimuli and required to indicate whether the stimuli were identical or different. If the two consecutive items were the same, children had to select the green check mark. If the two stimuli were different, children had to click on the red cross (for an illustration, see **Figure 3.3.1**). The *Melody Discrimination* subtest included two- or four-bar-long melodies with simple rhythmic patterns (quarters, eighth notes, quarter rests). In case of difference, only one note was changed in the musical sequence, which was a second or third higher/lower compared to the note in the initial sequence. This modification did not affect the contour or the tonality of the original melody. In the *Pitch Discrimination* subtest, two notes were presented in succession. The difference between the notes could be one semitone. The *Rhythm Discrimination* subtest included three- or four-bar long rhythmic sequences with simple (quarter, eighth notes, quarter rests) and more complex rhythmic patterns (syncopation, sixteens, dotted quarters, triplets). The number of notes was not changed in the comparison sequence. In the *Harmony Discrimination* subtest, pairs of chords comprising three notes were presented. The initial and the comparison chord could differ only by one note, which indicated either a minor or a major second difference. The *Tempo Discrimination* subtest presented a reference melody and a comparison melody in the same or different (slower/faster) tempo. Tempo varied between 80 and 130 bpm (beats per minute), and the difference could be a minimum of 10 to a maximum of 30 bpm.

Figure 3.3.1

Screenshot of the online measure of music discrimination

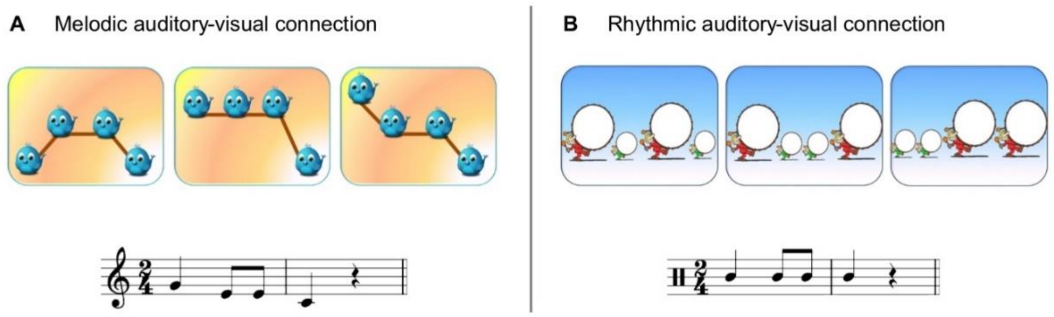


Note. In all discrimination tasks, "same" pairs could be indicated by clicking on the green check mark, and "different" pairs could be indicated by clicking on the red cross. By clicking on the blue arrow in the lower right corner, the task could be proceeded to the next trial.

Auditory-visual connection tasks assessed the ability to link musical sound sequences (melodies and rhythmic patterns) to their visual representations (for illustrations, see **Figure 3.3.2**). The *Melody Connection* task presented 10 short melodies for which participants had to choose the picture out of the three representing the contour of the melody heard. The *Rhythm Connection* task comprised five short rhythmic sequences. Pictures depicted quarter notes with big drums and eighth notes with small drums. Participants had to indicate which picture of the three representing the rhythmic pattern of the sequence played.

Figure 3.3.2

Examples of the items used in the auditory-visual connection tasks



Note. Visual representation of the melody contour in the Melody Connection task (A) and the rhythmic sequence heard in the Rhythm Connection task (B). For illustration purposes only, music notations below represent the melody and the rhythmic sequence played.

Each discrimination subtest consisted of 15 items. Regarding auditory-visual connection tasks, Melody Connection comprised 10 items and Rhythm Connection comprised 5 items. For each subtest, the accuracy score was determined by the number of correct responses. As auditory-visual connection tasks measured distinct aspects of musical audiovisual processing, the melody and rhythm tasks were scored separately. The online test demonstrates good overall reliability, with a Cronbach's α of .87. The internal consistency of the subtests ranges from .40 (Rhythm Discrimination) to .74 (Pitch Discrimination).

3.3.3.3. Sensorimotor synchronization (Study 2–3)

Two tapping tasks were employed to estimate children's sensorimotor synchronization. The tasks were designed by Maróti et al. (2019) based on the paradigm described by Tierney and Kraus (2013). Participants were asked to tap along to the click sounds of the metronome using the spacebar on the computer keyboard (*Synchronized Tapping)* and continue tapping at the same tempo once the sounds stopped (*Continuation Tapping*). Three trials were recorded at different tempi (1.5, 2, 2.5 Hz, corresponding to 90, 120, and 150 bpm, respectively). In the practice phase, the three tempi were presented to children as separate trials to assure the correct understanding of the tasks explained by the experimenter. Each test trial began with a habituation phase comprising 20 metronome clicks, which was immediately followed by the test phase including 20 clicks. The continuation phase of the trials automatically ended if the participant generated 20 taps after the metronome clicks stopped. Children heard the metronome via the headphones. Data were collected using MATLAB (R2015a; The MathWorks Inc., 2015). Tapping accuracy was defined by tapping variability, reflecting the standard deviation of the inter-tap intervals (ITIs) for each tempo. Accuracy scores were averaged for the synchronization and continuation trials separately. **Table 3.3.3** shows the characteristics of music-related measures applied in the studies.

Table 3.3.3

Summary of the measures of music-related abilities

Subtest	Task	Trials	Scoring
Bentley's MMA			
Pitch Discrimination	Decide whether the second tone is identical or played at a higher/lower pitch compared to the first one.	20	% correct
Tonal Memory	Detect the position of the one-tone change in the five-tone comparison melody.	10	% correct
Chord Analysis	Indicate the number of tones played at the same time in chords.	20	% correct
Rhythm Memory	Detect the position of the rhythmic change in the four-beat comparison rhythmic pattern.	10	% correct
Online measure of musical abilities			
Pitch Discrimination	Indicate whether the second note is the same or different compared to the first.	15	*n* correct
Melody Discrimination	Indicate whether the second melody is the same or different compared to the first.	15	*n* correct
Rhythm Discrimination	Indicate whether the second rhythmic pattern is the same or different compared to the first.	15	*n* correct
Harmony Discrimination	Indicate whether the second triad (chord) is the same or different compared to the first.	15	*n* correct
Tempo Discrimination	Indicate whether the second melody is played at the same or the different tempo compared to the first.	15	*n* correct
Melody Connection	Indicate which picture of three corresponds to the contour of the melody heard.	10	*n* correct
Rhythm Connection	Indicate which picture of three corresponds to the rhythmic pattern played.	5	*n* correct
Sensorimotor synchronization			
Synchronized Tapping	Tap along to metronome clicks.	2, 2.5, 1.5 Hz	*SD* of ITIs
Continuation Tapping	Continue tapping at the same tempo in the absence of the metronome.	2, 2.5, 1.5 Hz	*SD* of ITIs

3.3.4. Executive functions (Study 2–3)

Two measures were applied to assess the core aspects of executive functions and the executive aspects of verbal abilities. The *Verbal Fluency* test (Mészáros et al., 2011) estimated a set of cognitive abilities: organized search for task-relevant items, generation and use of strategies, inhibition of task-irrelevant items, updating information, flexible shifting between conditions, as well as verbal abilities, such as lexical access, verbal concept formation, and expressive language ability (Matute et al., 2004). The test asked children to produce as many items within a specific category as possible in 60 seconds. Phonemic fluency subtest comprised three letter fluency tasks, each requiring participants to name words starting with a specified phoneme (*k*, *t*, and *s*, respectively). The semantic fluency subtest included two tasks in which children had to list first animals, then fruits within the time limit. Each subtest started with one practice task to ensure that children fully understood the instructions. Accuracy scores were calculated for each task based on the number of correct words, excluding repetitions and out-of-category items. A composite verbal fluency score was defined by summing the accuracy scores from the two subtests.

The *Counting Span* test (Case et al., 1982) was applied to assess multiple functions of working memory such as information processing, storage, and rehearsal. The task comprised pictures showing blue circles as target stimuli and yellow circles and blue squares as distractors on the computer screen. The number of target stimuli displayed in each picture varied between two and eight. Pictures were presented in sequences organized into three blocks. The first sequence in each block included two pictures and each consecutive sequence increased with one picture. Each block consisted of five picture sequences, with the last sequence comprising thus six pictures. Participants were asked to count the blue circles aloud, repeat the final count after each picture, then at the end of each sequence recall the final counts for all picture in the order of appearance. The block was ended if the child was unable to repeat the counts in the correct order. The span score was determined for each block, indicating the length of picture sequence for which the participant recalled the final counts correctly. An overall counting span score was calculated based on the scores averaged across the three blocks. The characteristics of the measures of EFs are summarized in **Table 3.3.4**.

Table 3.3.4

Summary of the measures of executive functions

Subtest	Task	Trials	Scoring
Verbal Fluency			
Phonemic Fluency	Produce as many words starting with a specified phoneme as possible in 60 seconds.	3	*n* correct
Semantic Fluency	Produce as many items within a semantic category as possible in 60 seconds.	2	*n* correct
Counting Span	Count target items in each picture, then at the end of each sequence recall the final counts for all pictures in the order of appearance.	3	working memory span

3.3.5. Background questionnaire (Study 2–3)

The questionnaire was designed by our research group to obtain basic information from parents about the participants' age, gender, socioeconomic background, and formal musical experience at the beginning of primary school.

Socioeconomic status (SES) was evaluated by family income and maternal educational level. *Family income* was determined by the monthly earnings per capita and rated on a 5-point scale (1 = less than 100 000 HUF; 2 = 100 000–150 000 HUF; 3 = 150 000–200 000 HUF; 4 = 200 000–250 000 HUF; 5 = more than 250 000 HUF). *Maternal educational level* indicated the mother's highest educational achievement recorded on a 9-point scale (1 = No graduation, 2 = Primary education, 3 = Technical school, 4 = Vocational high school, 5 = Matriculation/Secondary school graduation, 6 = Post-secondary tertiary education, professional qualification, 7 = Bachelor degree, 8 = Master degree, 9 = Doctoral degree).

Formal musical background of participants was defined by the duration (months) of formal music education children engaged in before school music instruction.

3.4. Procedure

Measurements were conducted during the school hours. Testing took place in a quiet room in the school and was conducted by the experimenter. The order of sessions was counterbalanced across children. For all participant, the subtests were recorded in a fixed order. At the end of the study period, children were awarded small toys for their participation.

The study conducted by Maróti et al. (2019) laid the foundational groundwork for the longitudinal investigations presented in this dissertation. Utilizing a sample of children representative of our target population, the Maróti et al. study served as a crucial preliminary exploration into the cognitive, developmental, and pedagogical aspects that would be further examined over an extended period. Some changes were made to the composition of the test battery based on the experience gained from using the measures. To achieve a comprehensive assessment of musical abilities, all the subtests of the online battery developed by Asztalos and Csapó (2017) were administered to the children participating in the longitudinal studies. Moreover, instead of assessing attention, we opted for a thorough assessment of executive functions, using instruments to measure their different aspects. An important consideration in the selection of measures was to use validated tests where possible. The tests of general intelligence (WISC-IV Block Design, Digit Span, Vocabulary, Similarities; Nagyné Réz, Lányiné Engelmayer, Kuncz, Mészáros, & Mlinkó, 2008), the online test battery of musical abilities (Asztalos & Csapó, 2017) as well as the computer-based tests of reading, phoneme awareness, and rapid naming (3DM-H; Tóth, Csépe, Vaessen, & Blomert, 2014) were validated measures that have been tested on large sample of Hungarian children. Although the tests of sensorimotor synchronization, Counting Span and Verbal Fluency are not validated tests, they are widely used to test groups of children in previous research. Expert review ensured the content validity of the background questionnaire.

3.5. Data Analysis

Preliminary data analyses were performed using JASP (Version 0.16.3; JASP Team, 2022). To ensure that the observed data met the normality assumption of parametric statistical methods, Shapiro-Wilk tests were conducted to examine in each measure and group whether data deviated significantly from normal distribution. Means and standard deviations are reported for normally distributed data. In case of data that are not normally distributed, medians and median absolute deviations (*MAD*s) are presented.

To test potential between-group differences, two-tailed independent samples *t*-tests were conducted. In case of violating the assumption of normality, Mann-Whitney *U*-tests were run. The magnitude of the difference between the groups was indicated by effect size. As effect size indicators, Cohen's *d* is reported for parametric tests and rank-biserial correlation (r_B) is reported for non-parametric tests. Regarding Cohen's *d*, values below 0.2 are trivial, values between 0.2 and 0.5 reflect a small effect, between 0.5 and 0.8 reflect a medium effect, and above 0.8 reflect a large effect. Concerning rank-biserial correlation, values below 0.1 are trivial, values between 0.1 and 0.3 suggest a small, between 0.3 and 0.5 suggest a medium, and above 0.5 suggest a large effect (Goss-Sampson, 2020).

Correlation analyses were conducted to investigate the relationship between general cognitive functioning, musical abilities, and reading-related skills. As the normality assumption required for parametric testing did not met for several variables, non-parametric Spearman correlation coefficients were calculated. According to Field (2009), values between 0.1 and 0.3 indicate a small, values between 0.3 and 0.5 indicate a medium, and values above 0.5 indicate a large effect.

When conducting multiple comparisons, significance levels were corrected using the formula defined by Benjamini and Hochberg (1995). This method applies corrections in multiple testing procedures to control the False Discovery Rate (FDR), the expected ratio of the number of rejected null hypotheses ("false discoveries") which were erroneously rejected to the number of rejections. In contrast to the Bonferroni-type corrections, the FDR controlling method is more powerful though it controls the rate of Type I errors less strictly.

4. STUDIES

4.1 STUDY 1: The relation of music to reading-related and general cognitive competencies in second-grade children [1]

Study 1 aimed to investigate whether the advantages of comprehensive classroom music instruction could be observed in any functions after one year of formal music instruction. Building on the positive outcomes of previous longitudinal research (e.g., Degé & Schwarzer, 2011; Ilari et al., 2016; Jaschke et al., 2018; Rautenberg, 2015; Roden et al., 2012; Roden, Könen, et al., 2014), which investigated the impact of music education on school-aged children, a comprehensive study of children's cognitive performance in relation to school music instruction was conducted. This study compared two classes of 7−8-year-old children who received classroom music lessons according to either the regular or intensive Kodály music curricula. The aim was to investigate whether greater classroom music experience is associated with higher general cognitive, reading-related, and musical abilities at the beginning of second grade.

In addition, I examined the nature of the relationship between the subcomponents of musical auditory abilities and reading-related cognitive abilities in second-grade children. Given the contradictory research findings (e.g., Degé et al., 2015; Douglas & Willats, 1994; Forgeard et al., 2008; Loui et al., 2011; Moritz et al., 2013; Steinbrink et al., 2019), I sought to answer the question of whether only specific music and reading-related abilities are associated, or whether the music-reading relationship is global at this early stage of formal reading and music instruction.

Concerning the role of music education experience, I expected to find higher performance in music and reading-related abilities for children who received music lessons based on the intensive curriculum and thus had more classroom music experience (Hypothesis 1). Regarding the music-language relations, I expected that specific components of music discrimination abilities would be related to PA and word reading in second graders (Hypothesis 4).

[1] This chapter is based on the published paper: Lukács, B., Honbolygó, F. (2019). Task-dependent mechanisms in the perception of music and speech: Domain-specific transfer effects of elementary school music education. *Journal of Research in Music Education, 67*, 2, 153−170. https://doi.org/10.1177/0022429419836422

4.1.1 Methods

4.1.1.1 Participants

Thirty children in their second school year were recruited from the same public primary school in Hungary. Participants were between the ages 7 years 4 months and 8 years 11 months (M_{age} = 8 years, *SD* = 0.5). Children in two second-grade school classes received Kodály-based music lessons with different intensity in their classrooms. Fourteen children (4 boys; M_{age} = 8.31 years, *SD* = 0.49) attended the *Intensive class* and engaged in music lessons four times a week. Sixteen children (10 boys; M_{age} = 8.02 years, *SD* = 0.42) attended the *Regular class*, which provided twice-a-week classroom music lessons. All children were monolingual speakers of Hungarian.

4.1.1.2. School music curriculum

Children in both classes engaged in school music lessons following the music educational concept of Zoltán Kodály (the detailed description of the concept can be read in Section1.5.1 in Chapter 1). Music lessons were provided in 45-minute sessions once a week in the Regular class and four times a week in the Intensive class. For the Intensive class, the traditional Kodály curriculum was completed with twice-a-week extra choir lessons. By the time the last assessment carried out in the second school year, children had taken part in 44 weeks of music instruction in their school.

4.1.1.3. Measures

Children's general intelligence was estimated using the Block Design, Similarities, and Digit Span subtests from the WISC-IV. From the 3DM-H battery, the Phoneme Deletion and Reading (high-frequent, low-frequent words, pseudo-words) subtests were administered to examine phoneme awareness and the fluency of reading. Musical auditory abilities were assessed with Bentley's Measures of Musical Abilities (MMA). The detailed description of the tasks and their scorings are discussed in Section 3.3 in Chapter 3.

4.1.1.4. Procedure

Data collection was carried out in the beginning of the fall school term. Participants were tested in two individual sessions. Each session lasted approximately 30 min. Subtests of the WISC-

IV and 3DM-H were administered in one session, and subtests of the MMA were administered on another day in another session.

4.1.2 Results

4.1.2.1. Between-group differences

Results did not reveal any significant differences between the two classes regarding age, $t(28) = 1.74$, $p = .094$, $d = 0.64$, and gender, $\chi^2(1) = 3.45$, $p = .063$, $V = 0.34$. Means and standard deviations for the IQ, reading, phoneme awareness, and musical tasks are summarized for both classes in **Table 4.1.1**. Mean scores indicate higher performance on the Phoneme Deletion task and particularly on the Pitch Discrimination and Rhythm Memory tasks for children in the Intensive Class. On the other hand, children in the Regular Class scored higher in reading tasks as well as in Similarities and Block Design, measuring verbal and nonverbal IQ, respectively.

To test potential differences between the classes' performance in each measure, independent samples *t*-tests or in case of significant deviations from normal distribution Mann-Whitney *U* tests were run. As can be seen in **Table 4.1.1**, no significant differences were found between the classes in any measures, suggesting that at the beginning of second grade the performance of the Intense class and Regular class was comparable in general cognitive abilities, word reading, phoneme awareness, and music perception.

To be able to determine whether the observed data provide evidence for the lack of group differences, Bayesian independent samples *t*-tests and Mann-Whitney tests were conducted. The calculated Bayes Factors (BF_{01}) show the extent to which the observed data favors the null hypothesis (H_0) against the alternative hypothesis (H_1). BF_{01} values between 1 and 3 suggest anecdotal evidence, values between 3 and 10 suggest moderate evidence, and values above 10 suggest strong evidence for the null hypothesis. Values around 1 does not support either the lack or the existence of differences (M. D. Lee & Wagenmakers, 2013). Results revealed that all BF_{01} values ranged mostly between 1 and 3 (see also **Table 4.1.1**), indicating anecdotal evidence in favor of the null hypothesis. These findings corroborate the overall absence of group differences in all measured abilities.

Table 4.1.1

Descriptive statistics and between-group differences in IQ, language, and musical measures

Measures	**Intensive class**		**Regular class**		***t / U***	***p***	***d / r_B***	**BF_{01}**
	M	*SD*	*M*	*SD*				
General cognitive tasks								
Block Design [a]	9.07	3.47	9.50	2.71	95.50	.502	−.15	2.42
Similarities [a]	8.93	2.65	9.19	3.33	93.50	.450	−.17	2.52
Digit Span [a]	10.86	1.46	10.50	1.46	132.00	.399	.18	2.10
Language tasks								
High-frequent word reading	0.75	0.20	0.88	0.27	−1.49	.148	−.55	1.27
Low-frequent word reading	0.63	0.18	0.73	0.18	−1.54	.136	−.56	1.21
Pseudo-word reading	0.56	0.15	0.66	0.16	−1.74	.093	−.64	0.95
Phoneme Deletion	68.25	24.90	59.95	26.65	0.88	.388	.32	2.17
Musical tasks								
Pitch Discrimination [a]	50.00	23.37	39.69	19.02	134.50	.356	.20	2.04
Tonal Memory	37.93	24.75	38.81	20.81	−0.11	.916	−.04	2.89
Chord Analysis	34.29	11.58	33.13	14.48	0.24	.812	.09	2.84
Rhythm Memory [a]	30.71	20.93	22.50	8.56	137.00	.289	.22	1.99

[a] Mann-Whitney tests were performed as the assumption of normality was violated.

4.1.2.2. Correlation analysis

To investigate the relationship between reading-related and musical abilities, a series of correlation analyses were conducted. First, the relation of general intelligence to performance on the tasks of language and musical abilities was examined (see **Table 4.1.2**). Although Pitch Discrimination and Tonal Memory were significantly correlated with scores on the Similarities subtest, these associations did not survive corrections for multiple comparisons. Thus, scores in intelligence measures were not controlled in the subsequent analysis.

Table 4.1.2

Correlations between IQ measures and tests of reading, phoneme awareness, and musical abilities

Measures	**Block Design**	**Similarities**	**Digit Span**
Language tasks			
High-frequent word reading	.03	.13	−.05
Low-frequent word reading	.07	.08	−.01
Pseudo-word reading	.11	−.09	.04
Phoneme Deletion	.32	.09	.28
Musical tasks			
Pitch Discrimination	−.08	$.40^{*}$	.03
Tonal Memory	.08	$.40^{*}$	.31
Chord Analysis	.02	.29	.12
Rhythm Memory	−.12	−.17	.29

* $p < .05$.

Results of correlation analysis evaluating the relations of reading and phoneme awareness to musical abilities are presented in **Table 4.1.3**. The only significant association was observed between performance on the tasks of Tonal Memory and Phoneme Deletion (see also **Figure 4.1.1**), which remained significant even after the Benjamini-Hochberg correction was applied. It suggests a specific association between the measures of melody perception and phoneme awareness.

Table 4.1.3

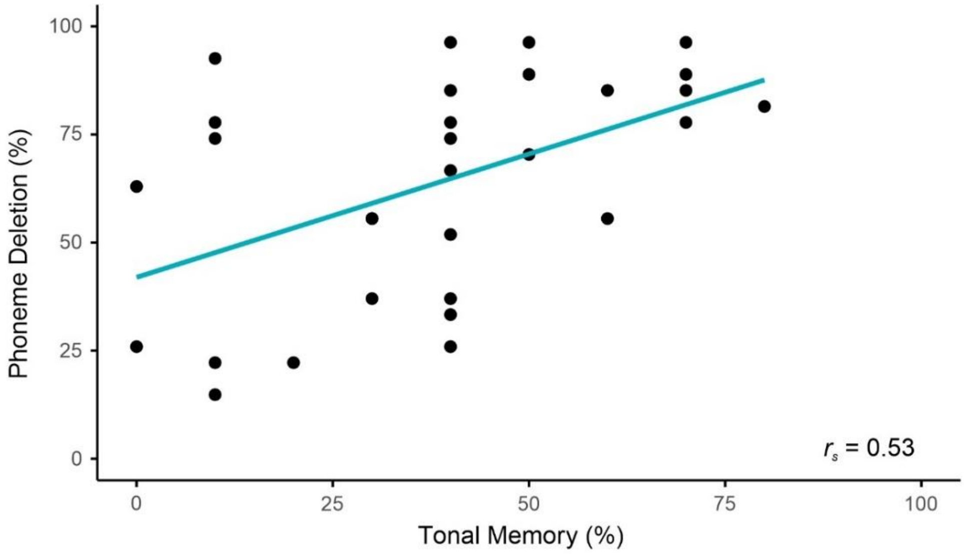
Correlations between musical measures and subtests of word reading and phoneme awareness

	Pitch Discrimination	**Tonal Memory**	**Chord Analysis**	**Rhythm Memory**
High-frequent Word Reading	.18	.26	−.18	−.03
Low-frequent Word Reading	.13	.11	−.12	−.02
Pseudo Word Reading	.06	−.03	−.22	.07
Phoneme Deletion	.30	$.53^{**}$	.10	.36

** $p < .01$.

Figure 4.1.1

Scatterplot showing the association between Tonal Memory and Phoneme Deletion



4.1.3 Discussion

The results of the group performance analyses did not show any significant differences in any of the measures between children who partook in intensive classroom music instruction and children who partook in less intensive music instruction over the first school year. The absence of between-class differences suggests that participating in comprehensive music lessons in the classroom context for one year with different intensity may not associate with different levels of music perception, phonological awareness, reading ability, and general intelligence. Thus, our results do not align with the findings of previous studies (e.g., Hurwitz et al., 1975; Rautenberg, 2015; Roden et al., 2012; Roden, Grube, et al., 2014; Roden, Könen, et al., 2014) reporting improved abilities in primary school children undergoing intense school-based music lessons.

Results of the correlation analysis revealed a specific association between the measures of Tonal Memory and Phoneme Deletion, indicating a close relationship between melody perception and phoneme awareness in second-grade children. This finding is in accordance with the results of previous studies showing that phonological awareness is specifically related to tonal musical abilities (Forgeard, Schlaug, et al., 2008; Loui et al., 2011). This association is generally explained by spectral auditory processing, arguing that the encoding of pitch-related acoustic features might be responsible for both the processing of melodies and speech sound sequences. Beyond the sensitivity to frequency changes, the processing of melodies requires the precise encoding of complex pitch pattern changes within the melody sequence. Speech also contains pitch pattern changes, which are essential for the detection of stress locations and speech segmentation (Jusczyk, 1999; Morton & Jassem, 1965). There is evidence that the processing of melodies at the cognitive level is influenced by the structural complexity of the pitch patterns included in the sequence (Patel, 2003a). Moreover, the processing of pitch changes has been connected to mechanisms involved in the processing of structure in speech sequences (Ziegler et al., 2012). Thus, pitch pattern processing appears to play an important role in the processing of structure in both melodic and speech sound sequences.

Unexpectedly, I did not find any significant relationships between musical auditory abilities and reading. This is not congruent with previous findings indicating associations between rhythm and/or tonal perception and word reading ability (e.g., Douglas & Willats, 1994; Forgeard et al., 2008). However, prior studies employed musical tasks requiring same/different judgments when examining the relations of music perception to word reading. In the present study, a Rhythm Memory task was applied, which included the processing of rhythmic values and rhythmic patterns at the same time. It is feasible that we could find an association with reading ability if musical tasks requiring discrimination of global patterns and not the detection local changes would have been applied.

In sum, the present results do not support the assumption that there is a connection between participation in more intensive music lessons and better music-related and non-musical cognitive abilities after one year of primary school instruction. It is possible that one year of school instruction was not long enough to find significant relations between more intensive music lessons and higher music-related and non-musical cognitive performance. This raises the question of whether there is any justification for future longitudinal comparisons of groups of children with different intensities of music instruction in the early stages of primary school. A shortcoming of the study is that the background of the participants was not measured, so it cannot be excluded that the socio-economic status (SES) of the children or their previous musical experiences influenced the results. To avoid the confounding of SES and formal musical background in determining the potential for transfer from classroom music education, a short background questionnaire was developed. This will help to better estimate the specific relationship between music and non-musical development in further studies. The present correlational results, at least in part, support the initial hypothesis that specific aspects of music perception are related to PA, but not to word reading. These findings have raised questions about whether the applied tasks influence the relations of music to reading-related abilities.

Therefore, in the next studies, a different music ability test, including discrimination tasks, was used to explore music-reading associations.

4.2 STUDY 2: The effects of classroom music education with or without body movement on children's cognitive development [2]

Study 2 examined whether incorporating body movement in classroom music learning enhances cognitive development in the early primary school years. Previous research (Lewis, 1988; Maróti et al., 2019; Rohwer, 1998; Yazejian & Peisner-Feinberg, 2009) has shown that movement-based music instruction has limited cognitive benefits in children. However, it is difficult to determine the extent to which movement-based school music learning can influence the development of various cognitive capabilities as most studies have focused on specific and distinct cognitive areas. Additionally, previous movement-based music learning programs have shown the potential to improve music-related abilities within a few months. However, improvements in non-musical cognitive functions may not be observed even after several months of music instruction. Therefore, it is possible that the non-musical benefits of movement-based music education programs may only become apparent after longer periods of learning.

Thus, Study 2 conducted comprehensive longitudinal research to investigate the causal relationship between music and cognitive ability. The study examined how school music education programs, with or without body movement, affect the development of musical abilities (perception, auditory-visual connection), rhythmic synchronization, phoneme awareness, rapid naming, reading, executive functions, and general intelligence from the beginning of schooling to the end of second grade. Based on the experience of Study 1, additional measures were incorporated into the test battery to screen for the possible role of background variables such as socioeconomic background and prior musical experience. Furthermore, to assess musical abilities, a large-sample online measurement tool was used. Using this new test has made it possible to test children's auditory-visual connection skills, which can capture the musical multimodal skills needed to learn to read and write music, an area that has been neglected in the literature.

Based on previous empirical evidence (Maróti et al., 2019), I hypothesized that the movement-based music learning method would lead to more significant improvements in cognitive abilities such as pitch discrimination, phoneme awareness, working memory, and sensorimotor synchronization during the first two years of primary school (Hypothesis 2).

[2] This chapter is based on the published paper: Lukács, B., Asztalos, K., Maróti, E., Farnadi, T., Deszpot, G., Szirányi, B., Nemes, L. N., Honbolygó, F. (2022). Movement-based music in the classroom: Investigating the effects of music programs incorporating body movement in primary school children. *Psychology of Aesthetics, Creativity, and the Arts*. Advance online publication. https://doi.org/10.1037/aca0000496

4.2.1. Methods

4.2.1.1. Participants

Initially, 49 children starting first grade were recruited from public primary schools in Budapest, Hungary. In accordance with the current purposes, naturalistic group allocation with no randomization was applied in the study. Therefore, group allocation was based on parents' (and children's) interest and the selection process of the institute. Participants attended first-grade classes with enhanced natural science curriculum, comprising 45-minute lessons related to natural environment and health maintenance twice per week. Besides, twice-a-week classroom music lessons were provided to all children. Twenty-seven children attended the *Directed Movement science (DM-science) class* with the movement-based music curriculum, which combined Kodály music lessons with teacher-directed movement elements. Moreover, 22 children attended the *No-Movement science (NM-science) class* with the general Kodály music curriculum, implementing no body movement into music lessons. Four children (two NM-science, two DM-science) discontinued participation in the study due to changing schools. Furthermore, five children attending the NM-science class were excluded from analyses as not completing more than two measures at either assessment point. Therefore, 40 first graders between the ages of 6 years 7 months and 7 years 5 months (M_{age} = 6.95 years, SD = 0.31) constituted the final sample. The DM-science class included 25 children (18 boys; M_{age} = 6.93 years, SD = 0.34) and the NM-science class included 15 children (8 boys; M_{age} = 6.99 years, SD = 0.26). Participants in both classes were all native Hungarian speakers. The sample comprised four bilingual children (Spanish n = 2, Russian n = 2).

4.2.1.2. School music curriculum

The participating classes received music lessons based on different curricula. Children in the NM-science class took part in traditional music lessons following the concept of Kodály, whereas children in the DM-science class underwent Kodály music lessons which were completed with body movement directed by music teachers. The detailed description of the traditional Kodály curriculum and the movement-based music curriculum including teacher-directed movement is shown in Section 1.5 in Chapter 1. The intensity of music curricula was identical in both classes, providing children with two 45-minute group music lessons each week. By the time the last assessment at the end of the second school year was conducted, children had received 63 weeks of music instruction in their school, excluding holidays.

4.2.1.3. Measures [3]

Children's musical abilities were measured with the revised online musical test battery, including all musical discrimination and auditory-visual connection tasks. Tapping ability was assessed using a synchronization task and a continuation task. At baseline (T0) and the end of first grade (T1), phoneme awareness and reading fluency for high-frequent words were tested with the shortened versions of the Phoneme Deletion and Reading subtests from the 3DM-H battery. At the end of second grade (T2), the original Phoneme Deletion and Reading subtests were recorded, the latter including three conditions for reading various word types (high-frequent words, low-frequent words, and pseudo-words). Phonological lexical retrieval and the efficiency of visual-verbal integration was measured using tasks on rapid naming of digits and pictures at T0 and T1. The different aspects of executive functions were estimated using the Digit Span task from WISC-IV, the Counting Span task, and the Verbal Fluency task. General intellectual abilities were assessed using the Vocabulary subtest as a verbal and the Block Design subtest as a nonverbal task from the WISC-IV. Moreover, parents were asked to complete the background questionnaire to investigate participants' socioeconomic status (maternal education, family income) and formal experience with music at the beginning of schooling. The detailed description of the tasks and their scorings can be seen in Section 3.3 in Chapter 3.

Concerning background information, parents of 32 participants completed the self-report questionnaire. Hence, only data of this subsample were included in analyses related to SES and musical experience.

4.2.1.4. Procedure

Individual testing was performed in two 45-minute sessions during the school hours. We administered the paper-pencil tests (IQ and verbal fluency tasks) and the computer-based tests (language-related tests, counting span task, tapping tests) in separate sessions. In groups of 10 to 15 children, the online musical ability tests were performed by the participants on their own in another 45-minute session. The experimenter and trained assistants administered the tests and monitored the online test completion.

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[3] As part of the 4-year longitudinal project, additional data were collected regarding children's creativity (Pásztor et al., 2015) and empathy (Bryant, 1982); however, the development of these skills is not presented in this work. The results concerning the effects of various classroom music learning programs on the participants' socioemotional development have been published in a study by Lukács (2021).

Three measurements were carried out over the 18-month period of the study. Participants were tested twice during the first primary school year: baseline assessments were conducted at school entry (T0) and assessments were repeated six months later at the end of the first year (T1). The last assessment was performed at the end of the second school year (T2).

4.2.1.5. Data Analysis

Because of the limited number of participants in each group and the violated assumptions of parametric tests, longitudinal data were analysed with the nparLD package in R (Noguchi et al., 2015), including nonparametric methods specifically designed for longitudinal data analysis. To estimate participants' development from school entry to the end of the second school year in each measure, the F1-LD-F1 statistical design was applied. In this design, LD indicates "longitudinal data" and F1 indicates the number of between-subjects (whole-plot) and within-subjects (sub-plot) factors in the models used, respectively. ANOVA-type analyses were performed where *Group* was used as the between-subjects factor and *Time* (T0, T1, T2) was used as the within-subjects factor. For each group and measurement point, we report relative treatment effects (RTEs) as indicators of effect size. RTEs can be interpreted as the probability that a randomly chosen observation from the whole sample has a smaller value than a randomly chosen observation from a certain subgroup. The value of the RTE ranges from 0 and 1. According to Noguchi et al. (2012), RTEs below .50 suggest that a person in a subgroup scores lower than a random person from the whole sample, whereas RTEs above .50 indicate that a person in a subgroup scores at least as high as a randomly chosen person from the whole sample. If the RTE is close to .50, there is no effect.

We conducted post hoc analyses with the nparcomp package in R (Konietschke et al., 2019), which comprises rank-based statistical methods. Between-group differences at each measurement point were tested with the npar.t.test function. Relative time effects in each class were compared with the nparcomp function. For both between-subjects and within-subjects contrasts, RTEs are calculated as measures of effect size. The level of significance was set to 0.05 for all effects, interactions, and post hoc differences.

4.2.2. Results

4.2.2.1. Baseline results

Table 4.2.1 presents the descriptive and test statistics for socioeconomic status and participants' formal musical experience for the classes at the beginning of the study. Mann-

Whitney tests did not reveal any significant differences between the NM-science class and the DM-science class in family income, maternal educational level, or children's musical background. Furthermore, no significant difference was found between the classes in age, $t(38) = -0.57$, $p = .571$, $d = -0.19$, and gender distribution, $\chi^2(1) = 1.44$, $p = .231$, $V = 0.19$. Therefore, these demographic variables were not included in the longitudinal analyses.

Table 4.2.1

Medians (MADs) and test statistics for the background measures at the beginning of schooling in the science classes

	NM-science class		**DM-science class**		***U***	***p***	***r***
	Mdn	*MAD*	*Mdn*	*MAD*			
Maternal education level	8	0	7	0	143.50	.054	0.39
Family income	3	1	2	1	100	.897	−0.03
Musical experience (months)	0	0	0	0	158.50	.229	−0.16

Note. *Maternal educational level*: 1 = No graduation, 2 = Primary education, 3 = Technical school, 4 = Vocational high school, 5 = Matriculation/Secondary school graduation, 6 = Post-secondary tertiary education, professional qualification, 7 = Bachelor degree, 8 = Master degree, 9 = Doctoral degree. *Family income* (monthly per capita): 1 = less than 100 000 HUF; 2 = 100 000–150 000 HUF; 3 = 150 000–200 000 HUF; 4 = 200 000–250 000 HUF; 5 = more than 250 000 HUF.

Medians and median absolute deviations (*MAD*s) for all measures and measurement points (T0−T2) are summarized for the NM-science class and the DM-science class in **Table 4.2.2**. Only a subgroup performed the measures of reading (DM-science class: $n = 13$, NM-science class: $n = 7$) and phoneme awareness (DM-science class: $n = 17$, NM-science class: $n = 5$) at T0. Hence, descriptive data related to T0 and T1 are based on the performance of this subsample in case of Reading Fluency and Phoneme Deletion.

Table 4.2.2

Medians (MADs) for all measures at the three time points (T0−T2) in the science classes

Measure	DM-science class			NM-science class		
	T0	T1	T2	T0	T1	T2
Melody Discrimination	7.0 (2.0)	7.0 (2.0)	7.0 (2.0)	7.0 (1.0)	6.0 (1.0)	7.0 (2.0)
Pitch Discrimination	7.0 (2.0)	8.0 (2.0)	9.0 (3.0)	6.0 (1.0)	5.0 (2.0)	7.0 (2.0)
Rhythm Discrimination	7.0 (1.0)	9.0 (2.0)	9.0 (1.0)	7.0 (2.0)	5.0 (2.0)	7.0 (1.0)
Harmony Discrimination	7.0 (1.0)	9.0 (1.0)	9.0 (1.0)	7.0 (2.0)	7.0 (2.0)	8.0 (2.0)
Tempo Discrimination	9.0 (2.0)	9.0 (1.0)	10.0 (1.0)	7.0 (3.0)	7.0 (2.0)	8.0 (1.0)
Melody Connection	5.0 (1.0)	7.0 (2.0)	8.0 (1.0)	2.5 (2.5)	6.0 (2.0)	7.0 (2.0)
Rhythm Connection	2.0 (1.0)	3.0 (1.0)	4.0 (1.0)	2.0 (1.0)	2.0 (2.0)	3.0 (1.0)
Synchronized Tapping	0.10 (0.02)	0.11 (0.02)	0.08 (0.02)	0.08 (0.02)	0.09 (0.02)	0.08 (0.02)
Continuation Tapping	0.10 (0.03)	0.10 (0.03)	0.09 (0.02)	0.11 (0.04)	0.10 (0.02)	0.10 (0.02)
Reading Fluency [a]	1.20 (0.30)	4.06 (1.21)	4.38 (1.53)	1.0 (0.60)	1.98 (0.88)	3.95 (0.70)
Phoneme Deletion [a]	−0.81 (0.66)	−0.08 (0.44)	0.38 (0.49)	−1.12 (0.32)	0.13 (0.59)	−0.37 (0.40)
RAN Digits	1.16 (0.34)	1.52 (0.20)	1.84 (0.15)	1.13 (0.24)	1.54 (0.21)	1.82 (0.19)
RAN Pictures	0.93 (0.17)	1.06 (0.12)	1.23 (0.15)	0.88 (0.12)	1.0 (0.17)	1.25 (0.10)
Digit Span	12.0 (1.0)	13.0 (1.0)	14.0 (2.0)	12.0 (1.0)	14.0 (1.0)	14.0 (2.0)
Counting Span	2.5 (0.5)	2.67 (0.34)	2.67 (0.66)	2.33 (0)	2.67 (0.33)	3.0 (0.33)
Verbal Fluency	28.0 (7.0)	35.0 (7.0)	45.0 (9.0)	26.0 (8.0)	40.0 (9.0)	56.0 (12.0)
Verbal IQ	23.0 (4.0)	28.0 (5.0)	37.0 (5.0)	26.0 (4.0)	34.0 (4.0)	39.0 (2.0)
Nonverbal IQ	28.0 (6.0)	30.0 (4.0)	38.0 (5.0)	22.0 (5.0)	26.0 (3.0)	32.0 (3.0)

[a] T0 and T1 data are based on the performance of the subsample completing the test at baseline.

Table 4.2.3 shows the results from the Mann-Whitney tests of baseline group differences. Performance in the Tempo Discrimination task differed significantly between the classes at T0, for which medians indicate that at school entry children in the DM-science class earned significantly higher scores in the measure of tempo perception as compared to children in the NM-science class. Moreover, a significant difference was found between the classes in Synchronized Tapping variability, which suggests that the NM-science class tapped along to the metronome with a significantly lower variability than the DM-science class. Results of the Bayesian analysis confirmed these differences between the classes at T0.

Table 4.2.3

Differences between the science classes at baseline in all measures

Measure	U	p	r_B	BF_{01}
Melody Discrimination	175.5	.745	–0.06	3.10
Pitch Discrimination	192.0	.910	0	3.05
Rhythm Discrimination	220.0	.365	0.17	2.19
Harmony Discrimination	203.0	.672	0.08	2.35
Tempo Discrimination	263.5	**.034**	0.41	0.49
Melody Connection	218.5	.203	0.25	1.73
Rhythm Connection	167.5	.834	–0.04	2.97
Synchronized Tapping	263.0	**.035**	0.40	0.75
Continuation Tapping	189.0	.978	0.01	3.09
Reading Fluency [a]	57.5	.362	0.35	1.72
Phoneme Deletion [a]	59.0	.218	0.39	1.94
RAN Digits	228.0	.267	0.22	1.91
RAN Pictures	205.0	.639	0.09	2.66
Digit Span	183.5	.921	–0.02	2.97
Counting Span	192.5	.724	0.07	3.03
Verbal Fluency	169.5	.625	–0.10	2.53
Verbal IQ	121.0	.064	–0.36	0.90
Nonverbal IQ	257.0	.052	0.37	1.30

Note. Significant *p*-values below .05 are written in bold.
[a] Results are based on data from participants who completed the test at baseline.

4.2.2.2. Longitudinal results

Results of the longitudinal data analysis testing participants' improvements from T0 to T2 for all measures in the NM-science class and the DM-science class are reported in **Table 4.2.4**. In the following, only significant effects are discussed in detail.

With respect to musical discrimination abilities, a significant Time × Group interaction was found for Melody Discrimination specifically, DM-science: RTE_{T0} = .49, RTE_{T1} = .57, RTE_{T2} = .55; NM-science: RTE_{T0} = .53, RTE_{T1} = .31, RTE_{T2} = .49, with no main effects of Time or Group (see also **Figure 4.2.1**). Post hoc pairwise group comparisons did not reveal any significant difference between the classes at T0 (p = .730) and T2 (p = .526). However, the DM-science class showed superior melody perception ability compared to the NM-science class at T1, $T = -3.53$, p = .001, RTE = .24. When testing Time effects in the NM-science class, a significant decrease was observed from T0 to T1, $T = -2.74$, p = .030, RTE = .25, while there was no significant change in performance between T1 and T2 (p = .168). Performance of children in the DM-science class did not change significantly between T0−T1 (p = .606) or T1−T2 (p = .956). As the melody perception ability of the classes was comparable at T2, the interaction might suggest different developmental patterns, but not different advantages for the classes after 18 months of school music lessons. Furthermore, analyses revealed significant main effects of Group for Rhythm Discrimination, $RTE_{DM\text{-}science}$ = .57, $RTE_{NM\text{-}science}$ = .38, Harmony Discrimination, $RTE_{DM\text{-}science}$ = .55, $RTE_{NM\text{-}science}$ = .41, and Tempo Discrimination, $RTE_{DM\text{-}science}$ = .58, $RTE_{NM\text{-}science}$ = .36, with the RTEs indicating the overall higher performance of the DM-science class in these tasks. The main effect of Time was significant in Pitch Discrimination, RTE_{T0} = .43, RTE_{T1} = .46, RTE_{T2} =.56, and Tempo Discrimination, RTE_{T0} = .45, RTE_{T1} = .43, RTE_{T2} = .54, suggesting that both the NM-science class and the DM-science class improved significantly over this specific 18-month period in pitch and tempo perception.

Regarding the musical auditory-visual connection tasks, only the main effect of Time was found to be significant for both Melody Connection, RTE_{T0} = .33, RTE_{T1} = .51, RTE_{T2} = .61, and Rhythm Connection, RTE_{T0} = .39, RTE_{T1} = .49, RTE_{T2} = .58. This suggests considerable increases in musical audiovisual processing during these early school years in both classes.

Table 4.2.4

Results of the longitudinal data analysis for the science classes

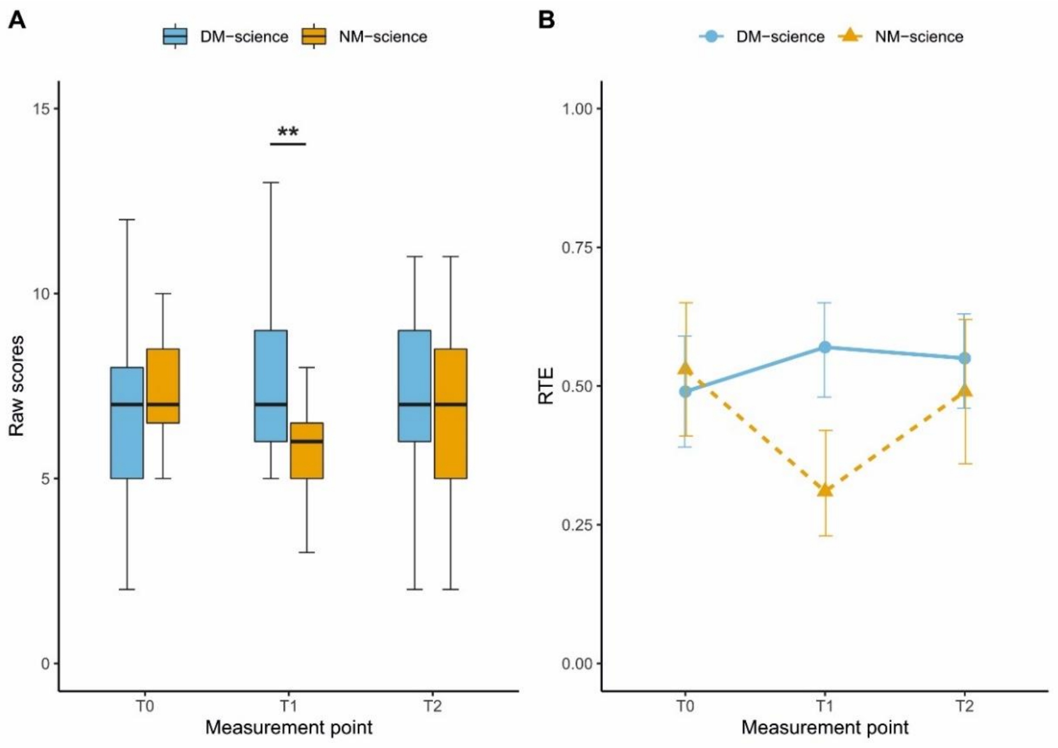
Measure	Group effect		Time effect		Group × Time interaction	
	F **(df)**	***p***	***F*** **(df)**	***p***	***F*** **(df)**	***p***
Melody Discrimination	1.83 (1)	.176	1.50 (1.95)	.224	5.06 (1.95)	**.007**
Pitch Discrimination	3.17 (1)	.075	3.78 (1.90)	**.025**	2.29 (1.90)	.105
Rhythm Discrimination	10.03 (1)	**.002**	0.87 (1.62)	.401	1.51 (1.62)	.224
Harmony Discrimination	5.61 (1)	**.018**	2.81 (1.97)	.061	1.27 (1.97)	.280
Tempo Discrimination	10.14 (1)	**.002**	3.35 (1.80)	**.040**	0.64 (1.80)	.514
Melody Connection	2.86 (1)	.091	17.55 (1.71)	$\mathbf{1.843 \times 10^{-7}}$	0.16 (1.71)	.815
Rhythm Connection	1.48 (1)	.224	9.30 (1.88)	**.0001**	2.20 (1.88)	.114
Synchronized Tapping	3.24 (1)	.072	3.78 (1.93)	**.024**	1.68 (1.93)	.187
Continuation Tapping	0.39 (1)	.530	1.25 (1.62)	.281	1.11 (1.62)	.321
Reading Fluency [a]	1.20 (1)	.273	108.92 (1)	$\mathbf{1.689 \times 10^{-25}}$	1.73 (1)	.189
Phoneme Deletion [a]	0.68 (1)	.410	32.63 (1)	$\mathbf{1.113 \times 10^{-8}}$	6.54 (1)	**.011**
RAN Digits	0.40 (1)	.529	126.24 (1.93)	$\mathbf{9.413 \times 10^{-54}}$	1.38 (1.93)	.251
RAN Pictures	0.44 (1)	.508	60.77 (2)	$\mathbf{4.748 \times 10^{-27}}$	2.16 (2)	.115
Digit Span	0.16 (1)	.688	22.67 (1.96)	$\mathbf{2.154 \times 10^{-10}}$	0.23 (1.96)	.787
Counting Span	0.0002 (1)	.990	16.28 (1.80)	$\mathbf{3.083 \times 10^{-7}}$	0.96 (1.80)	.374
Verbal Fluency	1.44 (1)	.230	74.97 (1.84)	$\mathbf{8.467 \times 10^{-31}}$	1.25 (1.84)	.284
Verbal IQ	4.03 (1)	**.045**	85.77 (1.90)	$\mathbf{2.831 \times 10^{-36}}$	3.52 (1.90)	**.032**
Nonverbal IQ	3.52 (1)	.061	36.56 (1.76)	$\mathbf{6.440 \times 10^{-15}}$	0.72 (1.76)	.471

Note. For all nparLD analyses, the denominator degrees of freedom are set to infinity. Significant *p*-values below .05 are written in bold.

[a] Analysis was conducted using data from T0 and T1 and based on the performance scores of participants who completed the test at baseline.

Figure 4.2.1

Performance on the Melody Discrimination task for all time points in the science classes



Note. (A) Boxplots showing the changes in performance on the Melody Discrimination test from T0 to T2. Asterisks indicate significant differences between the groups. $^{**}p < .01$. (B) Relative treatment effects (RTEs) for each measurement point by groups. Error bars show the 95% confidence intervals for RTEs.

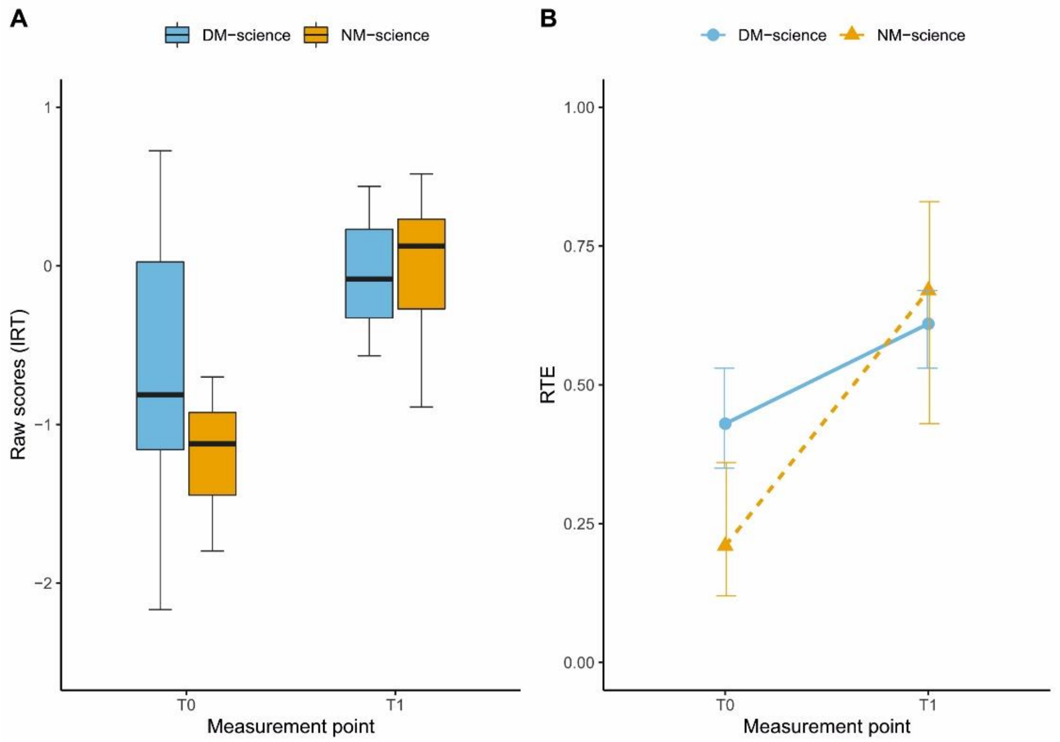
As for tapping ability, analyses revealed a significant main effect of Time specifically for Synchronized Tapping, $RTE_{T0} = .50$, $RTE_{T1} = .55$, $RTE_{T2} = .41$, but not for Continuation Tapping, indicating specific enhancements for both classes in the ability to synchronize finger tapping to the metronome.

With respect to reading and phoneme awareness, longitudinal analysis was conducted using T0 and T1 data from the subgroup of participants who completed the tests of Reading and Phoneme Deletion at school entry. A significant main effect of Time emerged for Reading Fluency, $RTE_{T0} = .31$, $RTE_{T1} = .66$, and Phoneme Deletion, $RTE_{T0} = .32$, $RTE_{T1} = .64$, implying considerable improvements over the first school year for both classes in word reading and phoneme awareness. Moreover, the analysis revealed a significant Group × Time interaction for Phoneme Deletion (see **Figure 4.2.2**), DM-science class: $RTE_{T0} = .43$, $RTE_{T1} = .61$; NM-science class: $RTE_{T0} = .21$, $RTE_{T1} = .67$. Based on post hoc analyses, the

NM-science class demonstrated larger increase from T0 to T1, $T = 9.39$, $p = <.001$, RTE = .96, than the DM-science class, $T = 2.35$, $p = .029$, RTE = .67. However, no group differences were observed at any time points ($ps \geq .135$). Together, these time effects and the lack of group differences might imply that although the developmental courses differed between the NM-science class and the DM-science class in phoneme awareness, the more intense improvement of the NM-science class supported the compensation of initial between-group differences by the end of the second school year.

Figure 4.2.2

Performance on the Phoneme Deletion task for T0 and T1 in the science classes



Note. (A) Boxplots showing the changes in performance on the Phoneme Deletion subtest from T0 to T1. (B) Relative treatment effects (RTEs) for each measurement point by groups. Error bars show the 95% confidence intervals for RTEs.

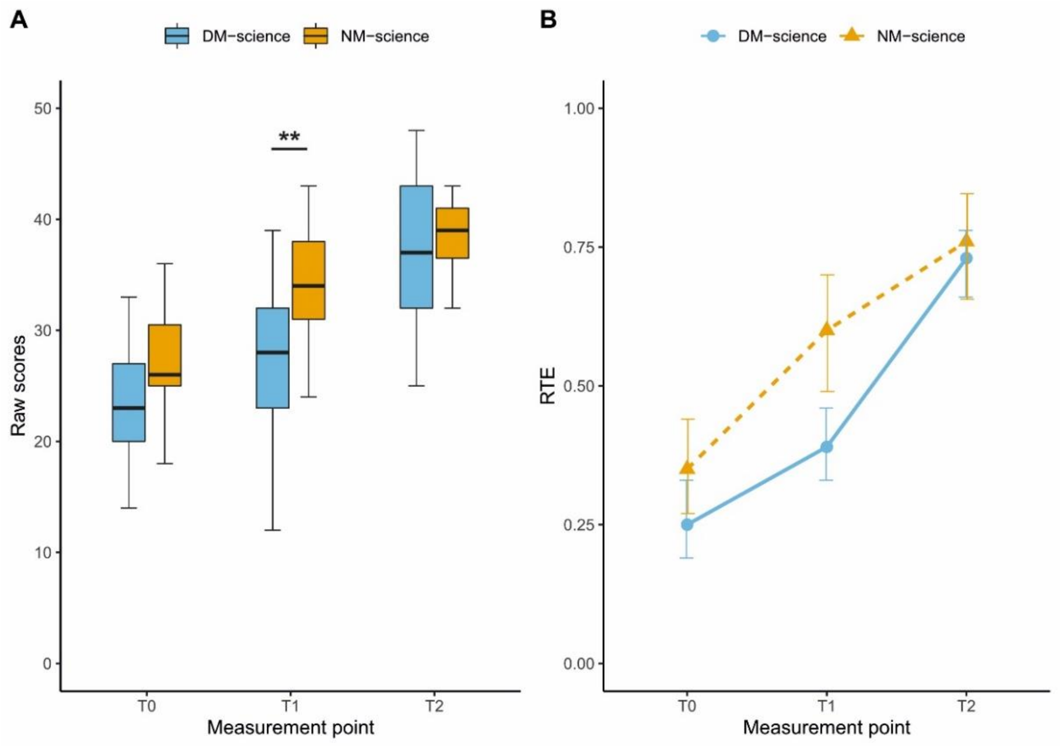
Furthermore, based on performance at T2 in the more complex tasks of reading and phoneme awareness, group differences were tested using data of the whole sample. Results revealed no significant differences between the classes in Reading Fluency, $t(38) = 1.69$, $p = .100$, $d = 0.55$, or Phoneme Deletion, $U = 257$, $p = .053$, $r_B = .37$. This suggests comparable word reading ability and phoneme awareness at the end of the second school year in the classes.

Concerning rapid naming skills, the main effect of Time was significant for RAN Digits, RTE_{T0} = .24, RTE_{T1} = .52, RTE_{T2} = .73, and RAN Pictures, RTE_{T0} = .32, RTE_{T1} = .49, RTE_{T2} = .68. As for executive functions, significant main effects of Time were found for Digit Span, RTE_{T0} = .37, RTE_{T1} = .53, RTE_{T2} = .62, Counting Span, RTE_{T0} = .37, RTE_{T1} = .50, RTE_{T2} = .63, and Verbal Fluency, RTE_{T0} = .31, RTE_{T1} = .53, RTE_{T2} = .70. These effects suggest general increases for both classes over 18 months in RAN ability and several components of executive functions.

Regarding intelligence, longitudinal analysis showed that the main effect of Time was significant for Verbal IQ, RTE_{T0} = .30, RTE_{T1} = .50, RTE_{T2} = .75, and Nonverbal IQ, RTE_{T0} = .35, RTE_{T1} = .45, RTE_{T2} = .65, which imply an overall increase in both classes. Moreover, as for Verbal IQ, a significant Group × Time interaction was found, DM-science: RTE_{T0} = .25, RTE_{T1} = .39, RTE_{T2} = .73; NM-science: RTE_{T0} = .35, RTE_{T1} = .60, RTE_{T2} = .76, as well as a significant Group effect, $RTE_{DM\text{-}science}$ = .46, $RTE_{NM\text{-}science}$ = .57 was observed (see also **Figure 4.2.3**). Based on the RTEs, the NM-science class exhibited a general superior performance in the Vocabulary task. Although the post hoc analysis confirmed that at T1 the NM-science class had significantly higher scores compared to the DM-science class, $T = 3.09$, $p = .005$, RTE = .76, no significant differences were found between the classes at T0 and T2 (ps $\geq .052$). When contrasting the time effects, children in both classes demonstrated significant improvements between T0 and T1 (DM-science: $T = 2.47$, $p = .049$, RTE = .69; NM-science: $T = 3.47$, $p = .009$, RTE = .80) as well as between T1 and T2 (DM-science: $T = 6.86$, $p = 8.308 \times 10^{-8}$, RTE = .86; NM-science: $T = 2.64$, $p = .048$, RTE = .75). Relative treatment effects indicated that the rate of improvements differed between the classes during the different assessment periods: the NM-science class showed greater growth between T0 to T1, whereas the DM-science class improved more from T1 to T2. Thus, based on the lack of group difference at the last measurement points, the overall increase did not differ between the classes in Verbal IQ.

Figure 4.2.3

Performance on the measure of Verbal IQ for all time points in the science classes



Note. (A) Boxplots showing the changes in performance on the WISC-IV Vocabulary subtest test from T0 to T2. Asterisks indicate significant differences between the groups. $^{**}p < .01$. (B) Relative treatment effects (RTEs) for each measurement point by groups. Error bars show the 95% confidence intervals for RTEs.

4.2.3. Discussion

The results of this study did not confirm the initial hypothesis regarding the specific benefits of movement-based music education. In most of the examined areas, children who engaged in the traditional Kodály music lessons (NM-science class) for one and a half years showed similar improvements to those who engaged in Kodály music lessons combined with directed movement (DM-science class).

Comparable enhancements were detected for pitch and tempo perception in the science classes regarding music discrimination abilities. However, contrary to the initial expectations based on the findings of Maróti et al. (2019), greater improvements for pitch discrimination were not observed in the DM-science class. Surprisingly, performance on some measures of music-related abilities (Rhythm and Harmony Discrimination, Continuation Tapping performance) did not improve considerably during the two school years in any classes. The findings of the comparison of the science classes align with previous evidence (Lewis, 1988), indicating that the tonal and temporal music perception abilities were similar in groups of children who had 12 movement-based music lessons and those who had no movement-based music lessons.

Moreover, children in both classes showed comparable improvements in tapping to the metronome, but their performance on the continuation tapping task remained constant. This difference in the developmental patterns between synchronized and continuation tapping can be explained by prior research (Kertész & Honbolygó, 2021; Provasi & Bobin-Bègue, 2003), suggesting that the ability to maintain a steady beat develops before the capability of synchronizing finger tapping to external periodic stimuli. Simultaneously, this implies that music lessons that include directed body movement may not facilitate further enhancements in the processes that enable the precise timing of auditory-motor coordination required for finger tapping.

For certain music-related and non-musical competencies, the results revealed distinct developmental trajectories in the NM-science class and the DM-science class. Regarding Melody Discrimination, the performance of children in the DM-science class showed a relative stagnation over the 18-month investigation period, while the performance of children in the NM-science class significantly declined during the first year, and then stagnated during the second school year. These developmental patterns do not imply that either music program is better suited to support the development of melody perception in the classes. Furthermore, group differences were observed in Harmony and Tempo Discrimination, indicating the initial differences between the classes, and suggesting that children in the DM-science class have superior temporal and harmony perception abilities.

With respect to non-musical abilities, the science classes demonstrated similar improvements in RAN, word reading, and executive functions during the first school years. However, children in the NM-science class showed greater improvement in phoneme awareness over the first school year as compared to their peers in the DM-science class. In addition, the classes exhibited different rates of development in verbal IQ: enhancements were more pronounced during the first school year in the DM-science class, while enhancements during the second school year were more pronounced in the NM-science class. Even though the developmental courses of phoneme awareness and verbal IQ slightly differed between the classes, their performance was comparable in both areas by the end of the second school year. These patterns thus indicate that the overall benefits of the musical programs were comparable.

Overall, these findings suggest that the inclusion of movement in classroom-based Kodály music lessons does not provide any additional developmental benefits over the first 18 months of schooling. These findings align with previous studies (Maróti et al., 2019; Yazejian & Peisner-Feinberg, 2009), implying limited evidence for the advantages of taking part in movement-based comprehensive music programs compared to traditional comprehensive music lessons without movement elements. At the same time, the present results contrast with Rohwer's (1998) study, which found that movement-based music instruction improved more primary school children's performance on the sensorimotor synchronization task. However, Rohwer's study investigated sixth graders. Therefore, it is possible that the degree of enhancement a child can gain from the movement-based music lesson may depend on the developmental period in which the music instruction takes place.

In summary, the findings indicate that the 18-month-long music instruction incorporating movement did not lead to better development in either music-related or non-musical domains. It should be also noted that the content of the movement-based music curricula varied across previous studies, raising the possibility that the different implementations of motion in musical activities could have induced distinct developmental changes. Thus, in *Study 3*, I explored whether classroom music lessons that implemented body movements differently could lead to specific transfer effects over a period of one and a half years in schoolchildren.

4.3 STUDY 3: The impacts of classroom music education combined with directed or improvised body movement on children's cognitive development [4]

Study 3 aimed to investigate whether different implementations of movement in classroom music education led to specific improvements during the first years of primary school. Current research on the contribution of diverse movement-based music education programs to music-related and non-musical cognitive development in the early school years is limited. In the pilot study conducted by Maróti et al. (2019), it was found that the application of different movements during music lessons did not have a differential impact on children's development over an 8-month period in their first year of school. Thus, in the present study, the focus was on whether the different use of movement impacted schoolchildren's cognitive development over an extended 18-month learning period. The study followed the development of participants' musical abilities, rhythmic synchronization, phoneme awareness, rapid naming, reading, executive functions, and general intelligence from the beginning of schooling until the end of second grade. The measures and procedures employed in the current study were identical to those used in Study 2.

It was hypothesized that the class with the movement-based curriculum incorporating teacher-directed movement would exhibit enhanced sensorimotor synchronization, as auditory-motor coordination is directly trained through fixed movement sequences (Szirányi, 2021). Additionally, it was also expected that this class would perform better in executive functions due to the potential association between sensorimotor synchronization and executive functioning (Miendlarzewska & Trost, 2014) (Hypothesis 3).

4.3.1. Methods

4.3.1.1. Participants

Fifty-three children from two first-grade classes were recruited to take part in intense school music education following one of the movement-based curricula. These newly developed school music education programs implemented either directed or improvised body movement elements into musical activities. In both intense music classes, participants received 45-minute music lessons four times a week. In this study, naturalistic group allocation based on parents'

[4] This chapter is based on the published paper: Lukács, B., Asztalos, K., Maróti, E., Farnadi, T., Deszpot, G., Szirányi, B., Nemes, L. N., Honbolygó, F. (2022). Movement-based music in the classroom: Investigating the effects of music programs incorporating body movement in primary school children. *Psychology of Aesthetics, Creativity, and the Arts*. Advanced online publication. https://doi.org/10.1037/aca0000496

(children's) interest and the institutes' selection process was used with no randomization. Thirty-two children from a primary school in Budapest attended the *Directed Movement music (DM-music) class* with the movement-based curriculum that completed Kodály music lessons with teacher-directed movements. Twenty-one children from a primary school in Győr attended the *Improvised Movement music (IM-music) class* in which Kodály music lessons were combined with improvisational body movements. Over the assessment period, five participants (four DM-music, one IM-music) changed schools. Moreover, eight participants (six DM-music, two IM-music) were excluded from analyses as having missing data on more than two measures at either measurement point. Thus, the final sample comprised 40 children aged between 6 years 3 months and 7 years 9 months (M_{age} = 7.02 years, *SD* = 0.34). The DM-music class included 22 children (9 boys; M_{age} = 6.93 years, *SD* = 0.31) and the IM-music class included 18 children (9 boys; M_{age} = 7.13 years, *SD* = 0.35). The sample comprised only one bilingual child with English as her second language.

4.3.1.2. School music curriculum

The participating classes engaged in intense music instruction based on the newly developed movement-based curricula. Children in the DM-music class had Kodály music lessons combined with teacher-directed body movement, while children in the IM-music class received Kodály music lessons in which movement improvisations were encouraged. The detailed description of the movement-based music programs is shown in Section 1.5.2 in Chapter 1. The intensity of music curricula was the same in the classes, providing children with four 45-minute music lessons weekly. By the time the last assessment at the end of the second school year was conducted, children had received 63 weeks of music instruction in their schools, excluding holidays.

4.3.1.3. Measures, Procedure, and Data Analysis

The measures, the test procedure, and the methods of non-parametric longitudinal data analysis were adapted from Study 2. The detailed description can be read in Section 4.2.1.

Regarding the background information, only one parent did not complete the questionnaire. Thus, data of 39 participants were added to statistical analyses concerning SES and children's musical experience.

4.3.2. Results

4.3.2.1. Baseline results

Descriptive statistics for socioeconomic status and children's formal musical experience are shown for the classes in **Table 4.3.1**. Results of the Mann-Whitney tests did not show any significant differences between the classes at school entry in family income or children's musical background. However, a significant difference emerged between the classes in maternal educational level, $U = 260.5$, $p = .028$, $r = .38$. The detailed examination of the data related to maternal education revealed that most of the mothers in both classes graduated from university (95.2% in the DM-music class, 83.3% in the IM-music class). Thus, data that were originally coded on a 9-point scale were recoded into a dichotomous variable, indicating whether the mother graduated from university. Using this converted variable, the difference between the classes was not significant, $\chi^2(1) = 1.49$, $p = .222$, $V = 0.20$, suggesting that the ratio of mothers with university graduation was comparable in the DM-music class and the IM-music class. Moreover, the classes did not differ regarding age, $t(38) = -1.89$, $p = .066$, $d = -0.60$, and gender distribution, $\chi^2(1) = 0.33$, $p = .565$, $V = 0.09$. Therefore, demographic variables were not added to the longitudinal models.

Table 4.3.1

Medians (MADs) and test statistics for the background measures at school entry in the music classes

	DM-music class		**IM-music class**		***U***	***p***	***r***
	Mdn	*MAD*	*Mdn*	*MAD*			
Maternal education level	8	0	7	0.5	260.50	**.028**	0.38
Family income	3	1	2	1	254	.063	0.34
Musical experience (months)	0	0	0	0	219	.536	0.11

Note. *Maternal educational level*: 1 = No graduation, 2 = Primary education, 3 = Technical school, 4 = Vocational high school, 5 = Matriculation/Secondary school graduation, 6 = Post-secondary tertiary education, professional qualification, 7 = Bachelor degree, 8 = Master degree, 9 = Doctoral degree. *Family income* (monthly per capita): 1 = less than 100 000 HUF; 2 = 100 000–150 000 HUF; 3 = 150 000–200 000 HUF; 4 = 200 000–250 000 HUF; 5 = more than 250 000 HUF. Significant results are written in bold.

Table 4.3.2 summarizes medians and median absolute deviations for all tests at each time point (T0−T2) in the DM-music class and the IM-music class. The tests of reading (DM-music class: *n* = 9, IM-music class: *n* = 14) and phoneme awareness (DM-music class: *n* = 13, IM-music class: *n* = 18) were completed by a subsample at the beginning of schooling. Therefore, descriptive data related to T0 and T1 are based on the performance of this subsample in case of Reading Fluency and Phoneme Deletion.

Table 4.3.2

Medians (MADs) for all measures at the three measurement points in the music classes

Measures	DM-music class			IM-music class		
	T0	T1	T2	T0	T1	T2
Melody Discrimination	7.0 (1.0)	7.5 (1.5)	9.0 (2.0)	6.0 (1.5)	6.5 (0.5)	9.0 (2.0)
Pitch Discrimination	8.5 (3.0)	12.0 (2.0)	14.0 (1.0)	8.5 (2.5)	8.5 (2.5)	14.0 (1.0)
Rhythm Discrimination	8.5 (2.5)	9.0 (2.0)	8.0 (2.0)	8.0 (2.0)	7.0 (3.0)	7.5 (1.5)
Harmony Discrimination	9.0 (1.0)	9.5 (1.5)	10.5 (1.5)	7.0 (2.0)	7.0 (1.0)	11.0 (1.0)
Tempo Discrimination	9.0 (2.0)	9.0 (1.0)	10.0 (1.0)	7.0 (2.0)	7.0 (1.0)	9.5 (2.5)
Melody Connection	5.5 (1.5)	7.5 (1.5)	10.0 (0.0)	4.5 (2.5)	7.5 (1.5)	8.5 (1.5)
Rhythm Connection	2.5 (0.5)	3.0 (1.0)	4.0 (1.0)	2.0 (1.5)	2.0 (1.0)	4.0 (1.0)
Synchronized Tapping	0.11 (0.03)	0.08 (0.02)	0.08 (0.01)	0.08 (0.03)	0.09 (0.02)	0.08 (0.01)
Continuation Tapping	0.10 (0.02)	0.08 (0.01)	0.08 (0.01)	0.09 (0.03)	0.08 (0.02)	0.07 (0.01)
Reading Fluency [a]	1.50 (1.00)	2.45 (0.94)	3.99 (0.95)	0.90 (0.65)	2.92 (0.92)	5.74 (0.86)
Phoneme Deletion [a]	−1.60 (0.57)	−1.79 (0.41)	0.24 (0.42)	−1.79 (0.37)	0.02 (0.74)	0.11 (0.65)
RAN Digits	1.11 (0.18)	1.47 (0.15)	1.82 (0.17)	1.30 (0.22)	1.58 (0.11)	1.95 (0.18)
RAN Pictures	0.86 (0.09)	1.06 (0.09)	1.20 (0.12)	1.07 (0.13)	1.17 (0.09)	1.24 (0.20)
Digit Span	11.0 (1.5)	12.0 (1.5)	14.0 (1.5)	11.5 (1.5)	13.5 (2.0)	14.0 (1.5)
Counting Span	2.33 (0.34)	3.0 (0.33)	2.67 (0.34)	2.33 (0.34)	2.67 (0.34)	2.67 (0.34)
Verbal Fluency	25.5 (5.0)	35.0 (4.0)	41.5 (7.5)	31.0 (3.5)	42.0 (10.0)	48.0 (9.5)
Verbal IQ	23.0 (4.0)	28.0 (4.0)	35.0 (2.5)	26.5 (5.0)	31.5 (5.5)	35.0 (4.5)
Nonverbal IQ	26.0 (4.0)	26.5 (7.0)	32.0 (11.0)	22.0 (4.0)	22.0 (4.5)	33.0 (6.0)

[a] T0 and T1 data are based on the performance of the subsample completing the test at baseline.

Results from the Mann-Whitney tests of baseline group differences are displayed in **Table 4.3.3**. At the beginning of schooling, the classes showed significant differences in the measures of harmony and tempo perception, with the medians indicating the superior performance of the DM-music class compared to the IM-music class in both musical tasks. Additional differences were observed between the classes in nonalphanumeric RAN and verbal IQ, showing that children in the IM-music class performed significantly better than children in the DM-music class. These baseline between-group differences were corroborated by the results of Bayesian data analysis.

Table 4.3.3

Differences between the music classes at baseline in all measures

Measures	***U***	***p***	r_B	BF_{01}
Melody Discrimination	216.5	.620	0.09	2.87
Pitch Discrimination	230.5	.382	0.16	2.84
Rhythm Discrimination	227.0	.436	0.15	2.30
Harmony Discrimination	308.5	**.002**	0.56	0.13
Tempo Discrimination	275.0	**.036**	0.39	0.45
Melody Connection	251.5	.147	0.27	1.21
Rhythm Connection	235.5	.302	0.19	1.92
Synchronized Tapping	217.0	.615	0.10	3.01
Continuation Tapping	205.0	.861	.04	3.14
Reading Fluency [a]	59.0	.825	−0.06	2.50
Phoneme Deletion [a]	135.0	.489	0.15	2.34
RAN Digits	130.0	.066	−0.34	0.85
RAN Pictures	77.0	< **.001**	−0.61	0.08
Digit Span	189.0	.815	−0.05	3.22
Counting Span	202.5	.911	0.02	2.92
Verbal Fluency	135.5	.091	−0.32	1.70
Verbal IQ	116.0	**.026**	−0.41	0.45
Nonverbal IQ	245.5	.196	0.24	2.43

Note. Significant *p*-values below .05 are written in bold.
[a] Results are based on data from participants who completed the test at baseline.

4.3.2.2. Longitudinal results

Table 4.3.4 summarizes the results of the longitudinal analysis examining children's development during the two school years (T0–T2) in all measures. In the following, only significant results are discussed in detail.

Regarding musical abilities, the main effect of Time was significant for all components of music discrimination, Melody: RTE_{T0} = .40, RTE_{T1} = .47, RTE_{T2} = .62; Pitch: RTE_{T0} = .35, RTE_{T1} = .45, RTE_{T2} = .69; Harmony: RTE_{T0} = .37, RTE_{T1} = .48, RTE_{T2} = .63; Tempo: RTE_{T0} = .41, RTE_{T1} = .45, RTE_{T2} = .62, apart from Rhythm Discrimination. Moreover, the main effect of Time was significant for performance in the tasks of Melody Connection, RTE_{T0} = .32, RTE_{T1} = .49, RTE_{T2} = .68, and Rhythm Connection, RTE_{T0} = .39, RTE_{T1} =.44, RTE_{T2} = .66. Together, these effects suggest a general increase from school entry to the end of Grade 2 in tonal and tempo-related music perception as well as in musical audiovisual processing. A significant main effect Group was observed in case of Rhythm, $RTE_{DM\text{-}music}$ = .56, $RTE_{IM\text{-}music}$ = .43, Harmony, $RTE_{DM\text{-}music}$ = .57, $RTE_{IM\text{-}music}$ = .42, and Tempo Discrimination, $RTE_{DM\text{-}music}$ = .57, $RTE_{IM\text{-}music}$ = .42. The relative treatment effects imply that DM-music class demonstrated an overall superior performance in these musical tasks over the 18-month measurement period.

Concerning sensorimotor synchronization ability, the main effect of Time was significant in Synchronized Tapping, RTE_{T0} = .56, RTE_{T1} = .50, RTE_{T2} = .43, and Continuation Tapping, RTE_{T0} = .60, RTE_{T1} = .50, RTE_{T2} = .39. This suggests that participants in both classes showed considerable increases over the two school years in finger tapping accuracy.

As for reading and phoneme awareness, longitudinal data analyses were run using T0 and T1 data of children who performed the shortened tests of Reading and Phoneme Deletion at baseline. A significant main effect of Time was found for both Reading Fluency, RTE_{T0} = .36, RTE_{T1} = .62, and Phoneme Deletion, RTE_{T0} = .32, RTE_{T1} = .69. These time effects indicate significant increases for both classes over the first school year in reading and phoneme awareness. To test group differences at T2 in the more complex tasks of reading and phoneme awareness, additional Mann-Whitney tests were run using data of the whole sample. A significant difference emerged between the classes in Reading Fluency, $U = 120$, $p = .034$, $r = -.39$, showing that the IM-music class (*Mdn* = 5.74, *MAD* = 0.86) scored significantly higher than the DM-music class (*Mdn* = 3.99, *MAD* = 0.95). There was no significant difference between the classes in Phoneme Deletion at T2, $U = 204$, $p = .882$, $r = .03$.

Concerning the tests of RAN, the main effect of Time was significant for both RAN Digits, RTE_{T0} = .24, RTE_{T1} = .53, RTE_{T2} = .75, and RAN Pictures, RTE_{T0} = .35, RTE_{T1} = .53, RTE_{T2} = .65. Longitudinal analysis indicated the significant main effect of Group for both RAN Digits, $RTE_{DM\text{-}music}$ = .45, $RTE_{IM\text{-}music}$ = .57, and RAN Pictures, $RTE_{DM\text{-}music}$ = .42, $RTE_{IM\text{-}music}$ = .60. These group effects suggested the overall higher performance of the IM-music class in rapid naming skills. Furthermore, a significant Group × Time interaction was found specifically in RAN Pictures (see **Figure 4.3.1**), DM-music: RTE_{T0} = .20, RTE_{T1} = .43, RTE_{T2} = .62; IM-music: RTE_{T0} = .50, RTE_{T1} = .62, RTE_{T2} = .69. Post hoc analyses of within-subject effects showed that the IM-music class did not improve significantly between the measurement points (ps $\geq$ .154), while the DM-music class significantly improved between T0 and T1, T = 4.39, p = .0002, RTE = .80, and between T1 and T2, T = 3.01, p = .012, RTE = .73. Pairwise contrast analyses revealed that the IM-music class earned significantly higher scores than the DM-music class at T0, T = 4.18, p = <.001, RTE = .81, and T1, T = 2.62, p = .014, RTE = .73, whereas the performance of the classes did not differ significantly at T2 (p = .324). The lack of group difference at T2 indicated that the DM-music class reached the initially superior performance of the IM-music class by the last measurement point.

With respect to executive functions, significant main effects of Time were detected for all measures, Digit Span, RTE_{T0} = .33, RTE_{T1} = .51, RTE_{T2} = .67, Counting Span, RTE_{T0} = .36, RTE_{T1} = .58, RTE_{T2} = .56, and Verbal Fluency, RTE_{T0} = .29, RTE_{T1} = .56, RTE_{T2} = .67. These time effects suggest that both children in the DM-music class and children in the IM-music class improved considerably in executive functions. Furthermore, a significant main effect of Group was found specifically for Verbal Fluency, $RTE_{DM\text{-}music}$ = .44, $RTE_{IM\text{-}music}$ = .57, with the RTEs showing the superior performance of children in the IM-music class in the fluency measures.

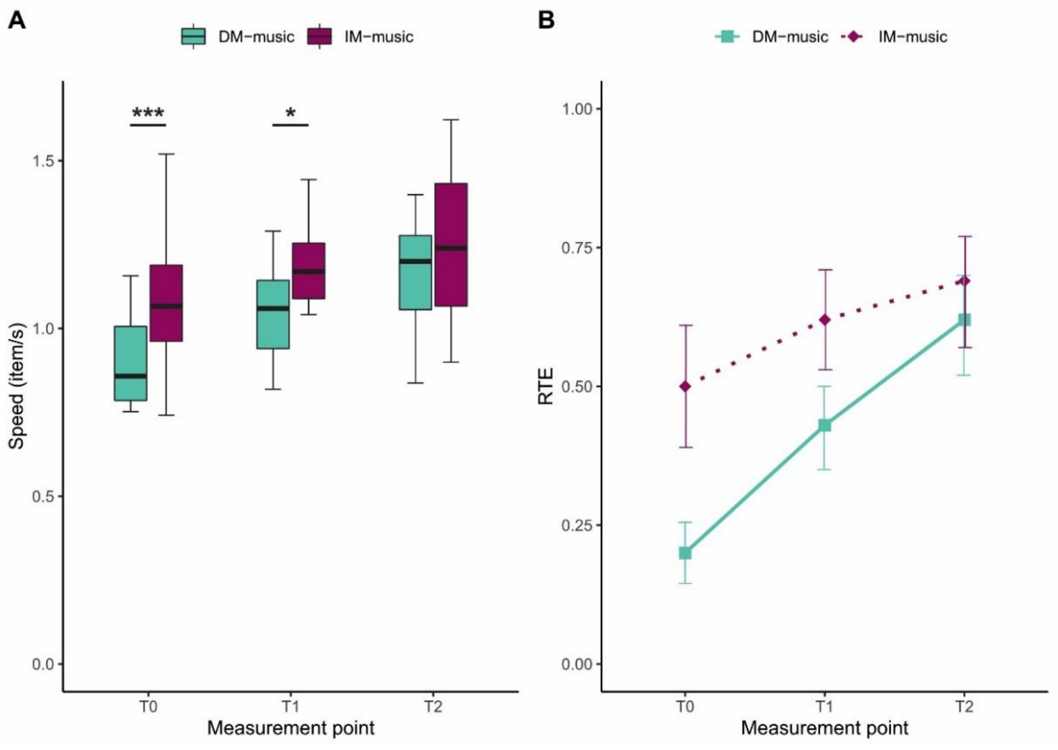
Table 4.3.4
Results of the longitudinal data analysis for the music classes

Measures	**Group effect**		**Time effect**		**Group × Time interaction**	
	***F* (df)**	***p***	***F* (df)**	***p***	***F* (df)**	***p***
Melody Discrimination	2.29 (1)	.130	7.92 (1.63)	**.001**	0.43 (1.63)	.607
Pitch Discrimination	1.56 (1)	.212	39.10 (1.85)	$\mathbf{1.429 \times 10^{-16}}$	1.22 (1.85)	.295
Rhythm Discrimination	4.25 (1)	**.039**	0.71 (1.82)	.481	1.11 (1.82)	.327
Harmony Discrimination	6.08 (1)	**.014**	13.95 (1.88)	$\mathbf{1.676 \times 10^{-6}}$	2.93 (1.88)	.057
Tempo Discrimination	5.87 (1)	**.015**	9.06 (1.99)	**.0001**	0.45 (1.99)	.637
Melody Connection	1.90 (1)	.168	43.16 (1.79)	$\mathbf{1.066 \times 10^{-17}}$	1.25 (1.79)	.285
Rhythm Connection	1.93 (1)	.165	15.94 (1.89)	$\mathbf{2.414 \times 10^{-7}}$	0.65 (1.89)	.513
Synchronized Tapping	0.63 (1)	.429	3.24 (1.99)	**.040**	1.08 (1.99)	.339
Continuation Tapping	1.07 (1)	.301	10.83 (1.95)	$\mathbf{2.451 \times 10^{-5}}$	1.05 (1.95)	.349
Reading Fluency [a]	0.54 (1)	.464	27.53 (1)	$\mathbf{1.549 \times 10^{-7}}$	0.44 (1)	.505
Phoneme Deletion [a]	0.53 (1)	.468	80.05 (1)	$\mathbf{3.654 \times 10^{-19}}$	0.06 (1)	.807
RAN Digits	5.22 (1)	**.022**	170.58 (1.82)	$\mathbf{1.671 \times 10^{-68}}$	0.86 (1.82)	.416
RAN Pictures	8.36 (1)	**.004**	29.16 (1.83)	$\mathbf{1.831 \times 10^{-12}}$	4.51 (1.83)	**.013**
Digit Span	0.002 (1)	.969	49.65 (1.74)	$\mathbf{1.030 \times 10^{-19}}$	0.36 (1.74)	.667
Counting Span	0.08 (1)	.784	13.44 (1.94)	$\mathbf{2.028 \times 10^{-6}}$	1.31 (1.94)	.269
Verbal Fluency	3.97 (1)	**.046**	60.59 (1.93)	$\mathbf{3.416 \times 10^{-26}}$	0.31 (1.93)	.729
Verbal IQ	2.48 (1)	.115	58.81 (1.80)	$\mathbf{6.253 \times 10^{-24}}$	3.83 (1.80)	**.026**
Nonverbal IQ	0.03 (1)	.853	31.60 (1.84)	$\mathbf{1.735 \times 10^{-13}}$	3.05 (1.84)	.052

Note. For all nparLD analyses, the denominator degrees of freedom are set to infinity. Significant *p*-values below .05 are written in bold.
[a] Analysis was conducted using data from T0 and T1 and based on the performance scores of participants who completed the test at baseline.

Figure 4.3.1

Performance on the RAN Pictures task at each measurement point in the music classes

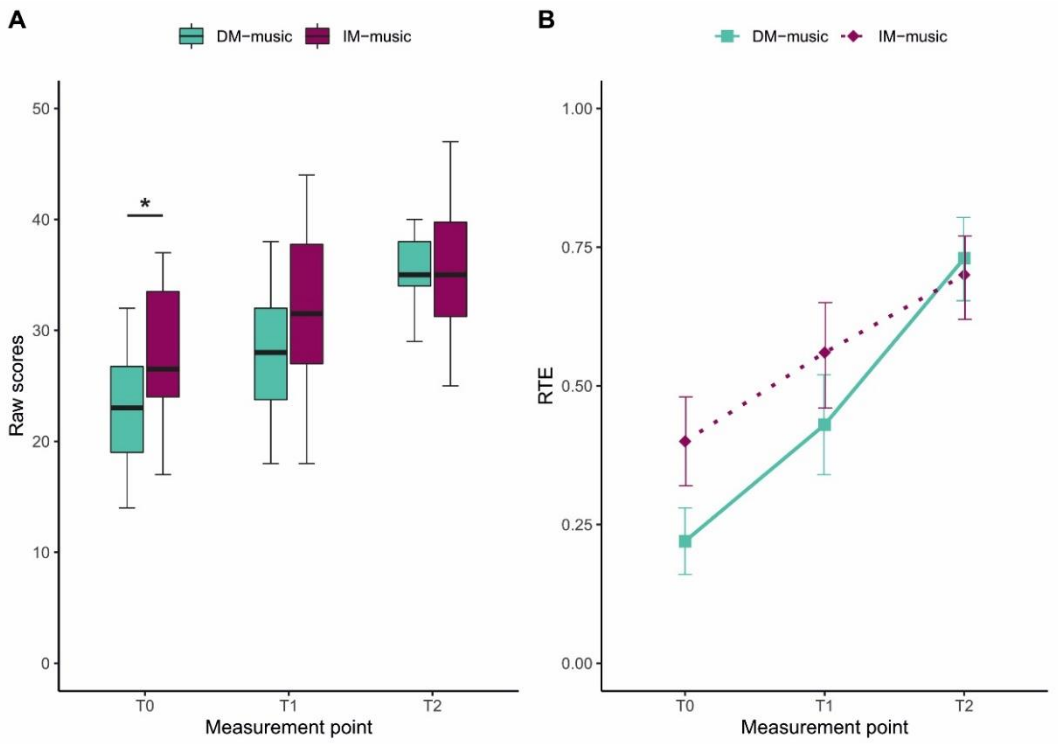


Note. (A) Boxplots showing the changes in performance on the RAN Pictures test from T0 to T2. Asterisks indicate significant differences between the groups. *$p < .05$. ***$p < .001$ (B) Relative treatment effects (RTEs) for each measurement point by groups. Error bars show the 95% confidence intervals for RTEs.

As for tests of general intelligence, there was a significant main effect of Time for Nonverbal IQ, $RTE_{T0} = .38$, $RTE_{T1} = .47$, $RTE_{T2} = .65$. In addition, analysis revealed a significant Group × Time interaction for Verbal IQ (see **Figure 4.3.2**), DM-music: $RTE_{T0} = .22$, $RTE_{T1} = .43$, $RTE_{T2} = .73$; IM-music: $RTE_{T0} = .40$, $RTE_{T1} = .56$, $RTE_{T2} = .70$. The main effect of Time was also significant, $RTE_{T0} = .31$, $RTE_{T1} = .49$, $RTE_{T2} = .72$, indicating general enhancements for both classes in vocabulary. Post hoc analysis concerning within-subjects effects suggested that the IM-music class significantly improved from T0 to T2, $T = 4.30$, $p = .0003$, RTE =.81, but not between T0–T1 and T1–T2 ($ps \geq .168$), whereas the DM-music class showed significant enhancements between T0 and T1, $T = 3.22$, $p = .009$, RTE = .74, as well as between T1 and T2, $T = 5.07$, $p = .0001$, RTE = .84. Pairwise group comparisons demonstrated that the IM-music class significantly outperformed the DM-music class at baseline, $T = 2.46$, $p = .020$, RTE = .71. However, the difference was no more significant between the classes at T1 and T2 ($ps \geq .155$), suggesting that the DM-music class reached but could not score higher than the IM-music class at T2.

Figure 4.3.2

Performance on the Verbal IQ task at each measurement point in the music classes



Note. (A) Boxplots showing the changes in performance on the WISC-IV Vocabulary subtest from T0 to T2. The asterisk displays a significant difference between the groups. *$p < .05$. (B) Relative treatment effects (RTEs) for each measurement point by groups. Error bars show the 95% confidence intervals for RTEs.

4.3.3. Discussion

The results of the present study did not confirm the original hypothesis regarding the greater growth of sensorimotor synchronization and executive functions in the intensive music class with the teacher-directed movement-based music curriculum. Over an 18-month period, children who engaged in Kodály music lessons, either combined with directed movements (DM-music class) or improvised movements (IM-music class), showed comparable improvement in most measured skills.

Children who participated in the movement-based intensive music classes showed general significant improvements in all music discrimination abilities, with the exception of

Rhythm Discrimination. The intensive music classes showed overall improvement in pitch-related music perception, while in Study 2 the science classes showed selective improvement in pitch discrimination. Research has shown that the development of higher-order pitch and rhythm perception abilities (melody, harmony, and tempo perception) follows a more prolonged trajectory compared to basic pitch discrimination (Fancourt et al., 2013; Gembris, 2006; Trainor & Corrigall, 2010). Thus, the current results suggest that the more intense movement-based music curricula may better promote the development of higher-order tonal and temporal processing.

Significant enhancements were observed in performance on both synchronized and continuation tapping tasks after 18 months of intensive music instruction. These results contrast with previous findings (Maróti et al., 2019), showing the relative stagnation in performance on both tapping tasks over eight months of classroom music education using the movement-based programs in first graders. Research on the development of sensorimotor synchronization suggested that tapping ability improves until adolescence (Drake et al., 2000). Therefore, more intense and prolonged implementation of movement-based music lessons may be needed to support further enhancements in sensorimotor synchronization.

Concerning non-musical abilities, children in the music classes showed similar improvements during the first school year in phoneme awareness, which is consistent with the findings of Maróti et al.'s (2019) study. Both classes demonstrated comparable enhancements in reading during the first school year; however, at the end of the second school year, children in the IM-music class significantly outperformed children in the DM-music class. In contrast, children in the DM-music class improved more in rapid naming of pictures compared to their peers in the IM-music class. Since there was a significant difference between the classes at baseline, classroom music instruction could have a larger impact on the development of rapid naming in the class where there was much room for growth. The different developmental patterns in verbal IQ could be similarly explained.

In summary, these developmental patterns do not indicate that the diverse incorporation of body movement into intense classroom music instruction can induce distinct effects on any music-related and non-musical functions during the first two school years. This result is in line with the findings of Maróti and colleagues (2019) , showing the comparable impacts of diverse movement-based music education methods after eight months of classroom music learning. Together these findings suggest that the length of formal music learning, particularly during the first 18 months of schooling, may not have a significant impact on the efficacy of different movement-based music education methods.

4.4 STUDY 4: Longitudinal associations between musical abilities and reading-related competencies in the first school year [5]

In Study 4, the aim was to examine potential longitudinal correlations between musical abilities, phonological processing skills, and word reading specifically in the first school year. The results of Study 1 indicated a highly specific relationship between melody perception and phoneme awareness. As questions were raised about whether the type of tasks influenced the formation of music-reading relations in second-grade children, musical abilities were assessed using a different measurement tool in this study. The study explored whether the relationships between the sub-components of musical abilities and reading-related cognitive abilities remain stable or change during the first six months of reading and music instruction. For this purpose, the patterns of relations were examined at the beginning of schooling and the end of the first school year. Furthermore, the study investigated whether there were parallels between increases in musical abilities and reading-related skills over this specific developmental period. It was hypothesized that there would be specific associations between musical and reading-related abilities (e.g., Forgeard et al., 2008; Ozernov-Palchik et al., 2018; Steinbrink et al., 2019; Hypotheses 4 and 5), which would differ at the beginning and end of first grade (Steinbrink et al., 2019; Hypothesis 6). Moreover, it was expected that selective longitudinal relations would emerge between improvements in musical abilities and improvements in reading-related abilities over the period of the first school year (Forgeard et al., 2008; Hypotheses 7 and 8).

4.4.1. Methods

4.4.1.1. Participants

Children recruited for Studies 2 and 3 were included this study. Children having missing data on a maximum of two measures at either T0 or T1 were chosen from the initial sample. Thus, participants who changed school over the first school year (*n* = 6) or had a considerable amount of missing data due to prolonged illness or technical problems (*n* = 12) were excluded from the pool. Thus, from among 102 children originally recruited, 85 children (45 boys) were included in the final sample, which comprised five bilingual children (Spanish *n* = 2, Russian *n* = 2, English *n* = 1).

[5] This chapter is based on the published paper: Lukács, B., Asztalos, K., Honbolygó, F. (2021). Longitudinal associations between melodic auditory-visual integration and reading precursor skills in beginning readers. *Cognitive Development, 60,* 101095. https://doi.org/10.1016/j.cogdev.2021.101095

4.4.1.2. *Measures and Procedure*

I selected the measures of general intelligence and the tests of musical and reading-related abilities that were administered at T0 and T1 in Studies 2 and 3. Therefore, musical abilities were assessed using the revised online musical test battery, comprising discrimination and auditory-visual connection tasks. The shortened versions of the Phoneme Deletion and Reading subtests from the 3DM-H battery were used to estimate phoneme awareness and reading fluency for high-frequent words. Rapid automatized naming (RAN) skills were measured with the tasks comprising digits and pictures. The Block Desing, Vocabulary, and Digit Span subtests from the WISC-IV were used to evaluate general cognitive abilities. The detailed description of the administration of these tasks is summarized in Section 4.2.1.4 in Study 2. Moreover, Section 3.3 in Chapter 3 provides details on the task scorings.

4.4.1.3. *Data analysis*

Spearman correlation coefficients were calculated to test the relationship between musical and reading-related abilities. To examine the strength of longitudinal relationship between changes in reading-related abilities and changes in musical abilities, repeated measures correlations were calculated using the rmcorr package (Bakdash & Marusich, 2018) in R (Version 4.1.2; R Core Team, 2021). The rmcorr function estimates the common within-participants correlation between two measures performed by each participant at a minimum of two assessments. The estimation is based on a specific version of analysis of covariance (ANCOVA), taking participant as the factor level, one measure as the outcome variable, and the second measure as the covariate to rule out the effect of within-participants variance. The analysis computes individual regression lines with a common slope and varying intercepts showing the longitudinal change in paired measures in the same participant. Ultimately, it defines the best linear fit within participants using multiple regression analysis. The rmcorr coefficient (r_{rm}) ranges from −1 to 1 and indicates the strength of within-participants association between an improvement in one measure and an improvement in another measure (Bland & Altman, 1995). The 95% confidence intervals were calculated for all repeated measures correlations with bootstrapping. Based on the visual inspection of residual plots for each rmcorr model, the normal distribution and homoscedasticity assumptions were met for the analysis.

4.4.2. Results

4.4.2.1. Correlations between general cognitive, musical, and reading-related abilities at T0 and T1

A subgroup of participants performed the measures of Reading (n = 46) and Phoneme Deletion (n = 56) at baseline. Thus, results showing the relations of Reading and Phoneme Deletion to cognitive and musical abilities at T0 are based on data of this subsample in subsequent analyses. Moreover, because of the few missing data found for the RAN and the musical auditory-visual connection tasks, there are slight differences between the number of observations across the subtests.

First, bivariate correlations were performed to test the associations between general cognitive abilities and reading-related and musical abilities. **Table 4.4.1** shows that performance on the Block Design subtest was significantly correlated with several musical abilities at T2, including Harmony Discrimination and both Melody and Rhythm Connection. Vocabulary was significantly associated with Reading, PA, and RAN at T1. In addition, Digit Span was significantly related to PA Accuracy, RAN Digits, and Rhythm Connection at T0, and to PA accuracy and Speed at T1. As Digit Span showed associations with both reading-related and musical abilities, its effect was partialed out in correlation analysis.

Table 4.4.1

Relations of general cognitive abilities to reading-related and musical abilities at T0 and T1

Measures	Block Design		Vocabulary		Digit Span	
	T0	T1	T0	T1	T0	T1
Reading-related tasks						
Reading Fluency	-.19	.12	.02	**.21***	−.02	.21
PA Accuracy	.30*	.21	−.04	**.26***	**.42****	**.31****
PA Speed	.29*	.21	.15	**.25***	.23	**.27***
RAN Digits	.21	.10	.17	**.28***	**.38*****	.16
RAN Pictures	.13	.17	.10	**.29****	.18	.20
Musical tasks						
Melody Discrimination	.23*	.23*	.02	.02	.22*	.08
Pitch Discrimination	.03	.15	.03	−.05	.09	−.03
Rhythm Discrimination	.13	.23*	.08	−.10	.23*	.22*
Harmony Discrimination	.06	**.28***	−.14	.02	-.02	−.02
Tempo Discrimination	.18	.21	−.22*	−.10	.08	.16
Melody Connection	.20	**.39*****	.07	.03	.11	.09
Rhythm Connection	.16	**.37*****	−.03	−.01	**.36*****	.16

Note. Correlations that remained significant after the Benjamini-Hochberg correction are highlighted in boldface.
$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Partial correlations between reading-related and musical abilities at T0 and T1 with Digit Span scores partialed out are presented in **Table 4.4.2**. As for intercorrelations between reading-related measures at T0, PA Speed was significantly correlated with PA Accuracy and RAN Digits. Moreover, there was a significant relationship between the two RAN tasks. Interestingly, Reading Fluency did not show any significant correlations to the measures of PA and RAN. Additional significant partial intercorrelations were found regarding musical abilities. Melody Discrimination was significantly related to Pitch Discrimination. Rhythm Discrimination was associated with Pitch, Harmony, and Tempo Discrimination. Harmony Discrimination showed a significant partial correlation with Pitch and Tempo Discrimination. In addition, one significant cross-domain partial correlation was found between Reading Fluency and Tempo Discrimination when controlling for Digit Span.

Regarding partial correlations at T1, several intercorrelations were found among reading-related and musical abilities. The analysis revealed moderate to strong associations between reading-related measures. Except for the relationship between Rhythm Discrimination and Melody Connection, all partial correlations were found to be significant between the different components of musical abilities. In addition, PA Accuracy showed a weak but significant correlation with Melody Discrimination and a moderate correlation with Rhythm Connection when Digit Span was controlled for.

Table 4.4.2

Partial correlations between measures of reading-related and musical abilities at T0 and T1

Measures		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1.	Reading Fluency [a]	–	−.02	.22	.19	−.11	−.09	.17	.24	.21	**.40****	.06	.21
2.	PA Accuracy [b]	**.43*****	–	**.60*****	.25	.18	−.02	−.27*	−.32*	−.06	−.13	−.04	−.06
3.	PA Speed [b]	**.46*****	**.77*****	–	**.42****	.30**	.04	−.06	.05	−.08	−.08	.18	−.04
4.	RAN Digits	**.57*****	**.42*****	**.42*****	–	**.75*****	.13	.10	.16	−.05	.14	.08	.20
5.	RAN Pictures	**.36*****	**.42*****	**.36*****	**.61*****	–	−.03	−.05	.04	−.11	.07	−.01	.14
6.	Melody Discrimination	.17	**.27***	.16	.05	.10	–	**.40*****	.21	.16	.17	.20	.06
7.	Pitch Discrimination	.23*	−.01	−.06	−.13	−.11	**.48*****	–	**.39*****	**.42*****	.12	.24*	.27*
8.	Rhythm Discrimination	−.05	.07	.05	−.03	.03	**.42*****	**.36*****	–	**.30****	**.34****	.25*	.21
9.	Harmony Discrimination	.18	.15	.13	.06	.06	**.53*****	**.63*****	**.31****	–	**.47*****	.26*	.22*
10.	Tempo Discrimination	.18	−.01	−.17	.04	.01	**.40*****	**.40*****	**.40*****	**.45*****	–	.20	.27*
11.	Melody Connection	.15	.21	.18	.11	.04	**.38*****	**.49*****	.23*	**.52*****	**.36*****	–	**.35****
12.	Rhythm Connection	.10	**.29****	.07	−.03	.05	**.34****	**.32****	**.42*****	**.42*****	**.43*****	**.43***	–

Note. Coefficients for T0 data are presented above the diagonal and coefficients for T1 data are presented below the diagonal. All correlations are controlled for verbal memory (WISC-IV Digit Span). Correlations written in bold survived the corrections for multiple comparisons.
[a] Performed by $n = 46$ at T0 and $n = 85$ at T1. [b] Performed by $n = 56$ at T0 and $n = 83$ at T1.
$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

4.4.2.2. Longitudinal associations between increases in reading-related skills and increases in musical abilities over the first school year (T0−T1)

Table 4.4.3 summarizes the results of repeated measures correlation analysis showing associations between improvements in reading-related abilities and improvements in musical competencies. Significant repeated measures correlations are displayed in **Figure 4.4.1**. Rmcorr plots are special scatterplots which show correlations between two measures collected at multiple assessment points concurrently. Each participant is represented by two dots with the same colour, indicating individual correlations calculated for the two repeated measurement points. A regression line is fitted for each participant with the same colour. All rmcorr lines have the same slope, suggesting the common association between the improvements in the paired measures. The length of regression lines varies as a function of the magnitude of longitudinal change in the individual.

Concerning music discrimination abilities, the only relationship that survived the Benjamini-Hochberg correction was between Pitch Discrimination and RAN Pictures, r_{rm} (84) = .29, 95% CI [0.05, 0.50], p = .006. On the other hand, several significant repeated measures correlations were found regarding the musical auditory-visual connection tasks. Melody Connection was significantly associated with both PA Accuracy, r_{rm} (53) = .58, 95% CI [0.40, 0.72], $p < .0001$, and PA Speed, r_{rm} (53) = .55, 95% CI [0.37, 0.67], $p < .0001$. Furthermore, Melody Connection was also significantly related to both RAN Digits, r_{rm} (81) = .55, 95% CI [0.37, 0.69], $p < .0001$, and RAN Pictures, r_{rm} (82) = .39, 95% CI [0.21, 0.56], p = .0002. Rhythm Connection showed only one significant relation to RAN Pictures, r_{rm} (82) = .34, 95% CI [0.16, 0.53], p = .001.

However, neither the measures of musical discrimination nor the auditory-visual connection tasks correlated with Reading Fluency. Because of the lack of significant repeated measures correlations between reading and musical abilities, no further detailed analyses were run to investigate the extent to which the development of the distinct components of musical abilities is predictive of the development of word reading beyond the development of reading precursors.

Table 4.4.3

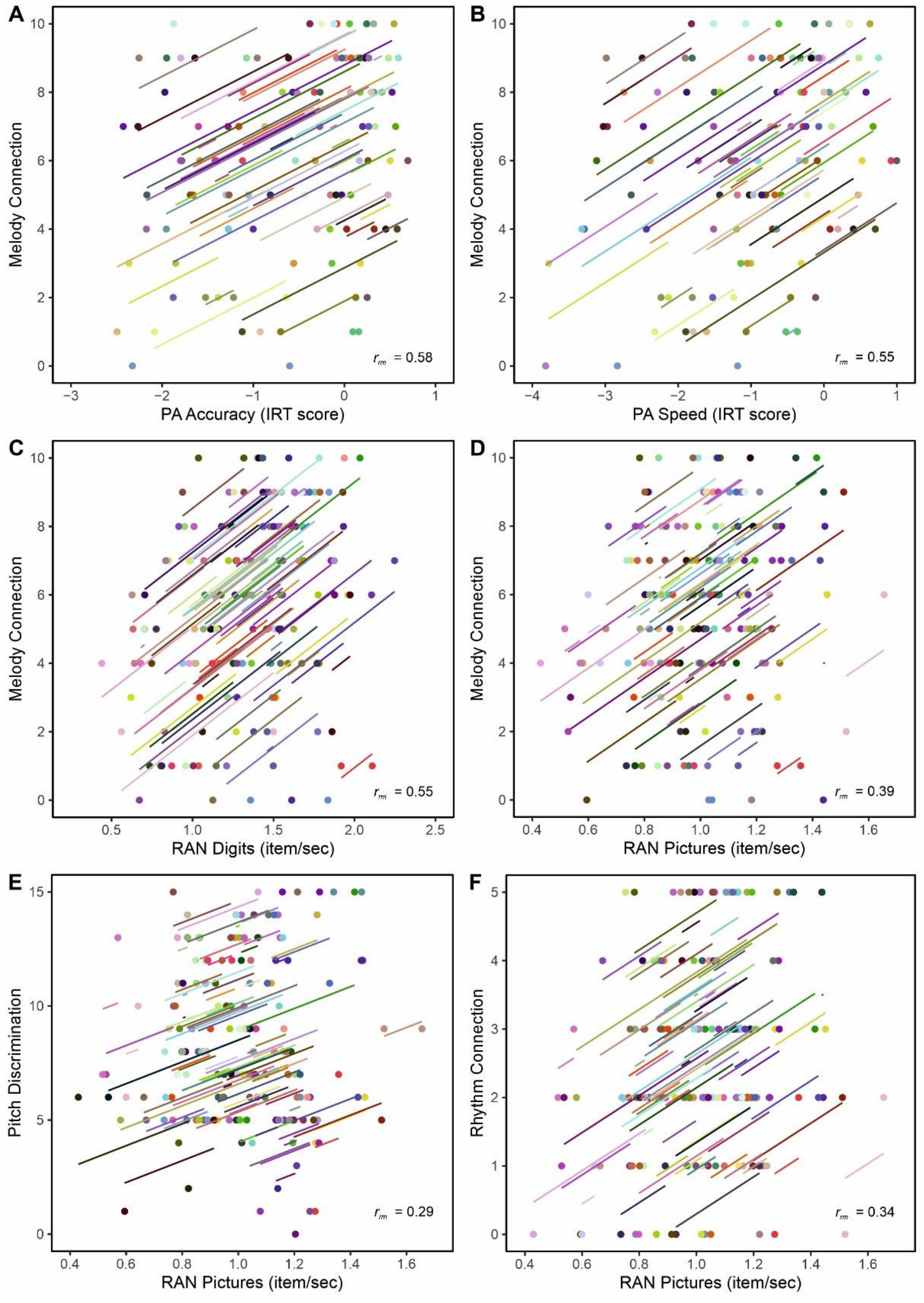
Repeated measures correlations (T0−T1) between reading-related and musical abilities

Measures	**Musical abilities**						
	Discrimination					**Auditory-Visual Connection**	
	Melody	*Pitch*	*Rhythm*	*Harmony*	*Tempo*	*Melody*	*Rhythm*
Reading Fluency [a]	.09	.06	.07	.24	.05	.30*	.22
PA Accuracy [b]	-.01	.19	-.13	.24	.01	**.58*** **	.19
PA Speed [b]	-.13	.17	.05	.09	-.17	**.55*** **	.20
RAN Digits	-.05	.27*	.04	.12	.06	**.55*** **	.26*
RAN Pictures	.08	**.29** **	.11	.21*	.20	**.39*** **	**.34** **

Note. Correlations written in bold survived the correction for multiple comparisons.
[a] Correlations are based on data from $n = 46$.
[b] Correlations are based on data from $n = 56$.
$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Figure 4.4.1

Scatterplots of the significant repeated measures correlations between musical abilities and reading precursor skills in first grade



Note. Panels display the longitudinal relations of Melody Connection to PA Accuracy (A), PA Speed (B), RAN Digits (C), and RAN Pictures (D) as well as the longitudinal relations of RAN Pictures to Pitch Discrimination (E) and Rhythm Connection (F). For the musical measures, the number of correct responses is illustrated.

4.4.3. Discussion

The present findings partially confirmed the predictions concerning cross-sectional correlations between the domains of music and reading. Besides the intercorrelations between musical and reading-related measures, only a few cross-domain correlations emerged at both assessment points. At school entry, a significant association was found between Tempo Discrimination and Reading Fluency when the potential confounding of verbal memory was removed. This corroborates previous results pointing to the association between rhythm-related musical abilities and reading (Douglas & Willats, 1994; Rautenberg, 2015). Unexpectedly, no significant partial relations of musical abilities to phoneme awareness and RAN were found at school entry, which contrasts with prior evidence suggesting links between music perception and phonological processing (e.g., David et al., 2007; Forgeard et al., 2008; Holliman et al., 2010; Janurik et al., 2022; Loui et al., 2011; Moritz et al., 2013; Steinbrink et al., 2019).

At the end of first grade, there was a specific partial correlation between phoneme awareness and Melody Discrimination, supporting the evidence that there is a specific relationship between phonological processing and tonal musical processing (Forgeard, Schlaug, et al., 2008; Loui et al., 2011). Moreover, this result is in line with the findings of Study 1, showing a specific relationship between Tonal Memory and phoneme awareness. It is feasible that phoneme awareness is related to melody perception not only at the higher level of syntactic processing but also at the lower level of auditory processing. Surprisingly, a specific relationship was detected between phoneme awareness and Rhythm Connection, although no associations were expected between phoneme awareness and musical audiovisual processing. I speculate that the unique relation of phoneme awareness to Rhythm Connection suggest a connection between phonological processing and the multimodal processing of musical rhythm.

Even though the patterns of correlations differed at the two assessment points, we cannot conclude that the magnitude of significant correlations found at one assessment point differed significantly from the magnitude of non-significant correlations found at the other assessment point. There are statistical methods, such as the cocor function in R (Diedenhofen & Musch, 2015) that can be used for the comparison between two correlations based on dependent groups. However, these methods cannot handle the comparison of partial correlations using the exact same measures twice in the same participants. Considering that small to moderate partial correlations were found between musical and reading-related abilities, it is likely that the strength of the significant correlations at one assessment point is not significantly different from the strength of non-significant ones measured at the other assessment point. Thus, findings may rather indicate no significant differences in the correlations between musical and reading-related abilities measured at baseline and the end of first grade.

The analysis of longitudinal correlations revealed several significant relations between improvements in phonological processing skills and musical abilities. Concerning the relations of music discrimination abilities, only increases in Pitch Discrimination and RAN Pictures were associated. This repeated measures correlation indicates a close link between the development of pitch perception and the efficacy of accessing phonological representations of everyday non-linguistic visual symbols. However, the lack of connection between increases in phoneme awareness and Pitch/Harmony Discrimination contradicts previous findings (Forgeard, Schlaug, et al., 2008). This suggests a specific longitudinal association between the development of phonological awareness and tonal music perception. Furthermore, the absence of associations between improvements in temporal auditory abilities (Rhythm and Tempo Discrimination) and phonological processing also contradicts prior evidence (e.g., Douglas & Willats, 1994; Moritz et al., 2013), indicating the relevance of rhythmic auditory processing in phonological development.

Surprisingly, no significant associations were detected between improvements in reading and music-related abilities, which contradicts the initial assumptions. This suggests that word reading fluency does not show developmental parallels with music perception abilities or musical audiovisual processing during the first six months of school instruction.

Interestingly, most longitudinal associations emerged between enhancements in phonological processing and enhancements in musical audiovisual processing abilities. Increases in Melody Connection were related to improvements in PA and RAN, but not to improvements in reading. Besides, a specific association was found between increases in Rhythm Connection and rapid naming of pictures. These findings suggest that melodic audiovisual processing may develop in parallel with phonological processing skills, but the development of rhythmic audiovisual processing is specifically associated with the development of nonalphabetic RAN. Furthermore, the patterns of longitudinal relations imply that increases in phonological processing are dominantly associated with increases in melodic, but not rhythmic, audiovisual processing. Overall, these patterns suggest that the tonal and temporal aspects of musical audiovisual processing are dissociable, and these aspects are differently associated with reading-related abilities in the first school year. It is speculated that the formation of these longitudinal associations over the first school year might originate from the emerging efficiency of audiovisual processing in the reading and music domains.

4.5. STUDY 5: Longitudinal correlations between musical abilities and reading-related competencies in the second school year

Study 5 continued to examine the longitudinal relations of musical abilities to reading and its precursor skills specifically focusing on the second grade period. The study compared the patterns of associations between musical and reading-related abilities at the end of the first and second school years. Moreover, an examination was conducted to determine the correlation between changes in phoneme awareness, rapid naming, and reading with changes in music perception and audiovisual processing during the second year of formal instruction. The findings from Study 4 suggest that specific cross-sectional (e.g., Ozernov-Palchik et al., 2018; Steinbrink et al., 2019; Hypotheses 4 and 5) and repeated measures associations (Forgeard et al., 2008; Hypotheses 7 and 8) exist between musical and reading-related abilities in the second school year. Moreover, it was hypothesized that there would be differences in the associations between the development of musical competencies and the development of reading-related abilities in the first and second school years (e.g., Steinbrink et al., 2019; Vaessen & Blomert, 2010; Hypotheses 6 and 9).

4.5.1. Methods

4.5.1.1. Participants

Children who took part in and met the inclusion criteria for Studies 2 and 3 were pooled to form the sample of this study. Thus, after excluding participants from the initial sample who changed school over the two school years (n = 9) or had missing data on a minimum of two measures due to prolonged illness or technical problems at either testing point (n = 13), the final sample comprised 80 children (44 boys). There were five bilingual participants in the sample with Spanish (n = 2), Russian (n = 2), or English (n = 1) as their second language.

4.5.1.2. Measures and Data Analysis

The measures and the method of repeated measures correlation analysis were adapted from Study 4. The detailed description can be read in Section 4.4.1.

To test the extent to which the development of distinct musical abilities could predict the development of reading beyond precursor skills, linear mixed-effects regression analyses were run in R (Version 4.1.2; R Core Team, 2021) using the lme4 package (Bates et al., 2015). These statistical methods enable the analysis of linear mixed models, comprising both random and fixed effects from which the outcome measure could be predicted. Random-intercept regression models were fitted for Reading Fluency (dependent variable), which included the different aspects of musical abilities and the precursors of reading (PA, RAN) separately as fixed effects, allowed the intercept to vary for each level of the random effect (i.e., for each participant), and kept the slope constant among participants. The REML (restricted maximum likelihood) criterion was applied to estimate the parameters in the models. Statistical significance for each model was estimated using Satterthwaite's method from the lmerTest package (Kuznetsova et al., 2017).

4.5.2. Results

4.5.2.1. Correlations between general cognitive, musical, and reading-related abilities at T1 and T2

Results of correlation analysis testing the relationship between general cognitive abilities and reading-related and musical competencies are presented in **Table 4.5.1**. Performance on the Block Design subtest at T1 was significantly associated with several musical tasks, including Melody and Harmony Discrimination, as well as Melody and Rhythm Connection. The Vocabulary subtest was significantly related to all reading-related abilities, except for PA Speed at T1. Moreover, Vocabulary was associated with RAN Pictures at T2. The Digit Span subtest correlated with PA Accuracy at both measurement points and with RAN Digits and Rhythm Connection at T2. Because of its relations to both reading-related and musical abilities, the effect of Digit Span was controlled in the correlation analysis.

Table 4.5.1

Relations of general cognitive abilities to reading-related and musical abilities at T1 and T2

Measures	Block Design		Vocabulary		Digit Span	
	T1	T2	T1	T2	T1	T2
Reading-related tasks						
Reading Fluency	.12	.13	**.23***	.20	.22	.15
PA Accuracy	.26*	.17	**.26***	.24*	**.34****	**.64*****
PA Speed	.13	−.18	.22	.24*	.19	.19
RAN Digits	.13	.14	**.26***	.15	.14	**.30****
RAN Pictures	.17	.22	**.31****	**.33****	.23*	.17
Musical tasks						
Melody Discrimination	**.28***	.02	.06	.12	.09	-.03
Pitch Discrimination	.14	−.09	.01	−.04	−.03	.14
Rhythm Discrimination	.18	.17	−.15	.13	.15	.24*
Harmony Discrimination	**.26***	.06	.07	.11	−.01	.14
Tempo Discrimination	.22*	.18	−.12	.11	.17	.24*
Melody Connection	**.36*****	.04	.08	−.06	.15	-.01
Rhythm Connection	**.38*****	.08	.07	.09	.20	**.35****

Note. Correlations that remained significant after the Benjamini-Hochberg correction are written in bold.
*$p < .05$, **$p < .01$, ***$p < .001$.

Table 4.5.2 summarizes partial correlations between reading-related and musical abilities at T1 and T2 while controlling for Digit Span scores. At T1, moderate to strong interrelationships were found between the measures of reading, PA, and RAN. Similarly, all components of musical abilities correlated significantly with each other, excluding the relationship between Melody Connection and Rhythm Discrimination, which did not reach the level of significance. Besides, the analysis revealed a few significant cross-domain partial correlations at T1. Reading Fluency scores were significantly associated with Pitch Discrimination when partialing out the effect of Digit Span. Moreover, PA Accuracy was significantly related to both Melody Discrimination and Rhythm Connection.

Regarding partial correlations at T2, fewer intercorrelations were found between reading-related abilities. Reading Fluency was significantly related to both RAN tasks. In addition, RAN Digits and RAN Pictures were significantly correlated. However, PA did not correlate with Reading Fluency or RAN. Several significant relationships were found for the distinct components of musical abilities. Melody Discrimination was significantly related to all musical abilities, except for Rhythm Connection. Pitch Discrimination was significantly correlated with Harmony Discrimination and Melody Connection. Rhythm Discrimination was significantly associated with Tempo Discrimination as well as with Melody and Rhythm Connection. Harmony Discrimination was significantly related to Tempo Discrimination and Melody Connection. In addition, there was a significant relationship between Tempo Discrimination and Rhythm Connection. Interestingly, Melody and Rhythm Connection did not correlate significantly. Only one cross-domain correlation emerged between Reading Fluency and Melody Discrimination.

Table 4.5.2

Partial correlations between measures of reading-related and musical abilities at T1 and T2

Measures	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1. Reading Fluency	–	**.41*****	**.38*****	**.56*****	**.37*****	.19	**.27***	−.07	.19	.16	.15	.11
2. PA Accuracy	.15	–	**.74*****	**.34****	**.41*****	**.30****	.04	.04	.13	.00	.24*	**.31****
3. PA Speed	.21	.23*	–	**.38*****	**.30****	.15	−.07	.04	.05	−.21	.09	.04
4. RAN Digits	**.51*****	.17	.04	–	**.61*****	.09	−.04	−.03	.08	.02	.11	.01
5. RAN Pictures	**.46*****	.13	.05	**.55*****	–	.16	−.05	.05	.08	.00	.02	.07
6. Melody Discrimination	**.28***	−.08	−.03	.05	.21	–	**.52*****	**.37*****	**.61*****	**.32****	**.39*****	**.33****
7. Pitch Discrimination	.15	.08	.01	−.15	−.05	**.37*****	–	**.35****	**.67*****	**.41*****	**.53*****	**.30****
8. Rhythm Discrimination	.11	.26*	.20	.02	.00	**.33****	.26*	–	**.33****	**.33****	.16	**.36****
9. Harmony Discrimination	.21	−.03	−.15	−.05	.02	**.35****	**.44*****	.18	–	**.50*****	**.55*****	**.43*****
10. Tempo Discrimination	.23*	−.06	.07	.03	.09	**.28***	.23*	**.29***	**.48*****	–	**.34****	**.41*****
11. Melody Connection	.08	.09	.04	−.01	−.04	**.31****	**.50*****	**.29****	**.44*****	.25*	–	**.44*****
12. Rhythm Connection	.11	.17	.27*	.07	.16	.25*	.19	**.35****	.17	**.48*****	.25*	–

Note. Coefficients for T1 data are presented above the diagonal and coefficients for T2 data are presented below the diagonal. All correlations are controlled for verbal memory (WISC-IV Digit Span). Correlations written in bold survived the corrections for multiple comparisons.
$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

4.5.2.2. Longitudinal associations between increases in reading-related skills and increases in musical abilities over the second school year (T1−T2)

Table 4.5.3 presents the results of repeated measures correlation analysis indicating associations between changes in reading-related abilities and changes in musical competencies over the second school year (T1−T2). Except for Rhythm Discrimination, Reading Fluency showed significant longitudinal relationships with all music discrimination abilities, including Melody, r_{rm} (79) = .28, 95% CI [0.14, 0.51], $p = .012$, Pitch, r_{rm} (79) = .43, 95% CI [0.29, 0.58], $p < .0001$, Harmony, r_{rm} (79) = .28, 95% CI [0.10, 0.45], $p = .010$, and Tempo Discrimination, r_{rm} (79) = .45, 95% CI [0.27, 0.57], $p < .0001$. Reading Fluency was also significantly correlated with Melody Connection, r_{rm} (79) = .47, 95% CI [0.33, 0.61], $p < .0001$, and Rhythm Connection, r_{rm} (79) = .52, 95% CI [0.36, 0.64], $p < .0001$. **Figure 4.5.1** illustrates the significant longitudinal relations of Reading Fluency to the measures of musical discrimination and the auditory-visual connection tasks.

Table 4.5.3

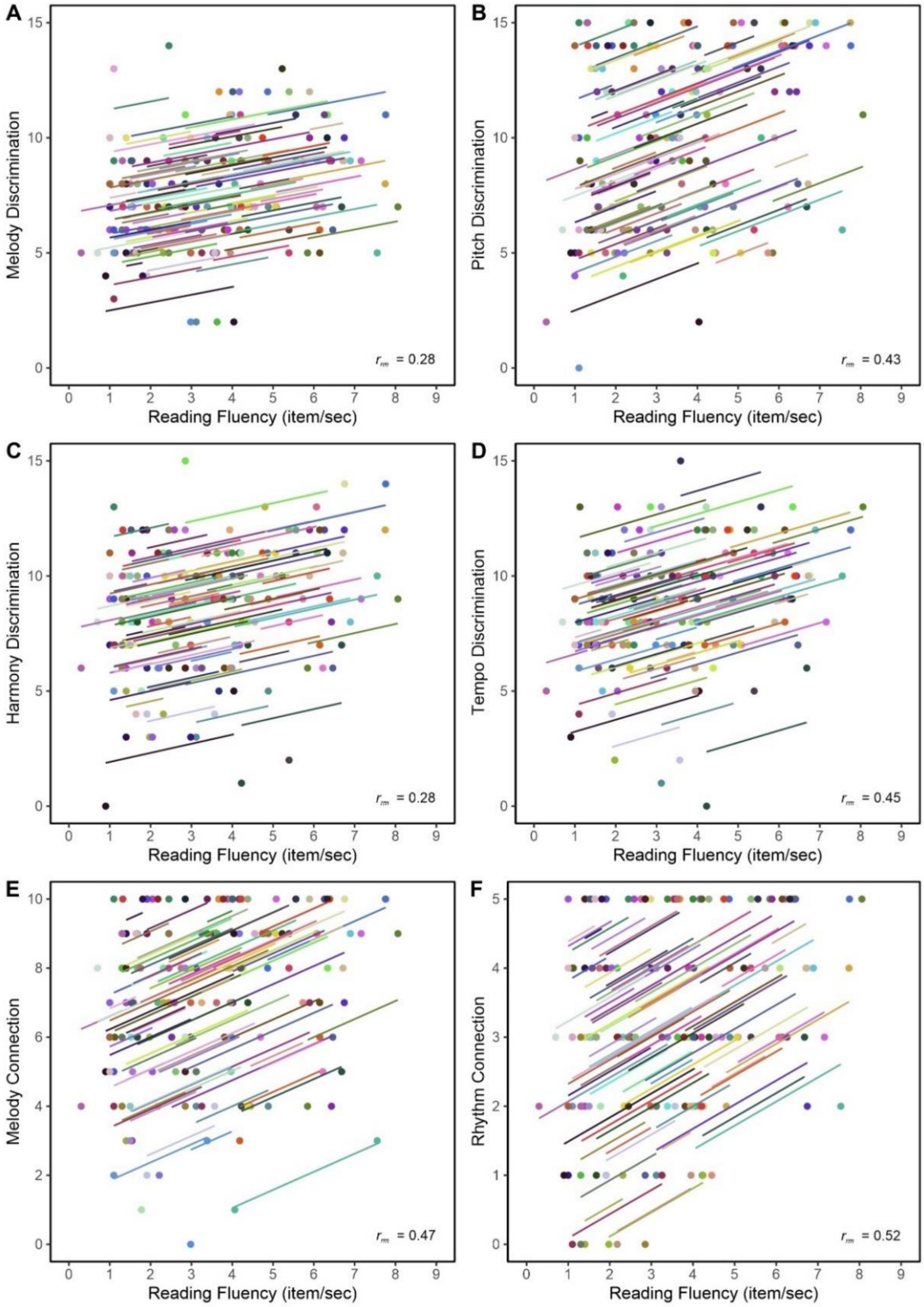
Repeated measures correlations (T1−T2) between reading-related and musical abilities

Measures	Musical abilities						
	Discrimination					Auditory-Visual Connection	
	Melody	*Pitch*	*Rhythm*	*Harmony*	*Tempo*	*Melody*	*Rhythm*
Reading Fluency	**.28***	**.43*****	.23*	**.28***	**.45*****	**.47*****	**.52*****
PA Accuracy	.03	**.38*****	.23*	.10	.10	**.32****	**.27***
PA Speed	.14	.22*	**.26***	−.09	.07	**.35****	**.30****
RAN Digits	.20	**.42*****	**.25***	.17	**.38*****	**.50*****	**.47*****
RAN Pictures	**.35****	.24*	.24*	.16	.24*	.20	**.32****

Note. Correlations written in bold survived the correction for multiple comparisons.
$^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Figure 4.5.1

Scatterplots of the significant repeated measures correlations between musical abilities and reading in second grade



Note. Panels display the significant longitudinal relations of Reading Fluency to Melody (A), Pitch (B), Harmony (C), and Tempo Discrimination (D) as well as to Melody (E) and Rhythm Connection (F). For the musical measures, the number of correct responses is illustrated.

The measures of PA and RAN also showed several significant relationships with musical abilities. PA Accuracy was significantly correlated with Pitch Discrimination, r_{rm} (77) = .38, 95% CI [0.24, 0.54], p = .0006, as well as with Melody Connection, r_{rm} (77) = .32, 95% CI [0.12, 0.49], p = .004, and Rhythm Connection, r_{rm} (77) = .27, 95% CI [0.02, 0.46], p = .015. PA Speed was significantly associated with Rhythm Discrimination, r_{rm} (79) = .26, 95% CI [0.07, 0.42], p = .019, as well as with Melody Connection, r_{rm} (79) = .35, 95% CI [0.17, 0.55], p = .001, and Rhythm Connection, r_{rm} (79) = .30, 95% CI [0.10, 0.49], p = .007. RAN Digits showed significant relations to Pitch, r_{rm} (79) = .42, 95% CI [0.26, 0.52], p < .0001, Rhythm, r_{rm} (79) = .25, 95% CI [0.10, 0.42], p = .022, and Tempo Discrimination, r_{rm} (79) = .38, 95% CI [0.14, 0.59], p = .0004. Besides, RAN Digits was significantly related to Melody Connection, r_{rm} (79) = .50, 95% CI [0.29, 0.62], p < .0001, and Rhythm Connection, r_{rm} (79) = .47, 95% CI [0.32, 0.63], p < .0001. In addition, RAN Pictures was significantly correlated with Melody Discrimination, r_{rm} (79) = .35, 95% CI [0.13, 0.52], p = .001, and Rhythm Connection, r_{rm} (79) = .32, 95% CI [0.10, 0.53], p = .003.

To investigate the extent to which improvements in musical abilities predict the development of reading, a linear mixed-effects regression analysis was conducted. *Model 1* included all measures of musical abilities (discrimination and auditory-visual connection tasks) as fixed effects and Reading Fluency as the dependent variable. Results of the regression analysis are presented in **Table 4.5.4**. Improvements from T1 to T2 in Pitch Discrimination and Rhythm Connection were significant predictors of the development of Reading Fluency. This suggests that over the course of the second school year, increases in both pitch perception and rhythm-based musical audiovisual processing are associated with increases in the fluency of word reading.

Another mixed-effects regression analysis was performed to determine whether improvements in these specific components of musical abilities make significant contributions to reading development beyond improvements in the most important precursors of reading (PA, RAN). Thus, *Model 2* included PA (Accuracy, Speed), RAN (Digits, Pictures), Pitch Discrimination, and Rhythm Connection as fixed effects and Reading Fluency as the dependent variable (see **Table 4.5.4**). From among the precursor skills, PA Speed and RAN Digits significantly predicted Reading Fluency. Moreover, Reading Fluency was also significantly predicted by Pitch Discrimination. This indicates that improvements over the second school year in pitch perception account for a significant unique variance in the development of fluent word reading, over and above PA and RAN.

Table 4.5.4

Results of the linear mixed-effects regression analyses predicting the development of word reading over second grade (T1−T2)

Effect			**95% CI**		***t***	***p***
			LL	***UL***		
Model 1						
Fixed effects	Estimate	*SE*				
Intercept	0.44	0.67	−0.85	1.79	0.66	.514
Melody Discrimination	0.12	0.07	−0.01	0.25	1.75	.082
Pitch Discrimination	0.11	0.05	0.03	0.21	2.18	**.031**
Rhythm Discrimination	−0.10	0.06	−0.23	0.03	−1.60	.113
Harmony Discriminatior	−0.02	0.07	−0.16	0.11	−0.29	.773
Tempo Discrimination	0.12	0.07	−0.02	0.26	1.62	.107
Melody Connection	0.03	0.07	−0.10	0.16	0.42	.677
Rhythm Connection	0.24	0.12	−0.02	0.49	2.03	**.044**
Random effects	Variance	*SD*				
Intercept (participant)	0.86	0.93				
Residual	1.96	1.40				
Model 2						
Fixed effects	Estimate	*SE*				
Intercept	−5.32	1.02	−7.25	−3.30	−5.21	**<.0001**
Pitch Discrimination	0.13	0.03	0.06	0.19	3.98	**.0001**
Rhythm Connection	0.04	0.08	−0.12	0.22	0.52	.602
PA Accuracy	−0.06	0.16	−0.39	0.28	−0.38	.705
PA Speed	0.17	0.06	0.05	0.28	2.83	**.005**
RAN Digits	2.88	0.49	1.89	3.90	5.85	**<.0001**
RAN Pictures	1.16	0.70	−0.19	2.70	1.66	.100
Digit Span	0.08	0.05	−0.02	0.19	1.52	.131
Random effects	Variance	*SD*				
Intercept (participant)	0.65	0.80				
Residual	0.96	0.98				

Note. CI = confidence interval; *LL* = lower limit; *UL* = upper limit.

4.5.3. *Discussion*

The results of the present study confirm the initial hypothesis about the specificity of correlations between musical and reading-related abilities in second grade. Besides partial intercorrelations between musical competencies and reading-related abilities, no significant correlations were found between phoneme awareness and musical abilities at the end of second grade, though phoneme awareness was significantly related to melody perception and rhythmic audiovisual processing at the end of first grade. Reading Fluency showed a unique partial relationship with Melody Discrimination at the end of second grade, although it was specifically related to Pitch Discrimination at the end of first grade. This finding is not entirely consistent with prior results, suggesting a link between rhythmic abilities and reading development in schoolchildren (e.g., David et al., 2007; Douglas & Willats, 1994; Rautenberg, 2015). Moreover, this is not in accordance with the results of the study by Forgeard et al. (2008), who found significant relations of rhythmic and tonal music discrimination only to nonsense word, but not to real word, reading ability. In addition, Study 1 found no significant connections between music perception and reading ability in second graders. It is important to note that prior studies, including Study 1, measured reading ability in terms of accuracy. Thus, these results indicate a possible association between the fluency of word reading and tonal musical processing in the early school years.

Results of repeated measures correlation analyses revealed several associations between increases in musical and phonological processing abilities over the second school year. Concerning music discrimination abilities, increases in rhythm-based music perception were associated with increases in phonological tasks measured in terms of speed. However, rhythm and tempo perception were not related to all timed measures. This suggests that the development of the various components of temporal processing is selectively linked to different aspects of phonological development. The patterns of longitudinal relations indicate a trend towards a general connection between rhythm perception and the speed of phonological processing and a more selective relationship between tempo perception and the efficacy of the retrieval of visual-verbal associations. From among tonal discrimination abilities, Harmony Discrimination did not develop in parallel with any phonological processing skills. However, improvements in Pitch Discrimination were specifically related to improvements in phoneme awareness and numeric RAN, while Melody Discrimination developed in parallel with non-alphanumeric RAN. These longitudinal relations extend prior findings (Forgeard, Schlaug, et al., 2008), implying relations between the development of tonal music perception and the development of both phoneme awareness and the efficiency of visual-verbal information retrieval during the second school year. Moreover, enhancements in Melody and Rhythm Connection were generally associated with enhancements in phoneme awareness and rapid naming. It is not surprising that musical audiovisual connection showed parallel improvements with rapid naming skills due to their potentially shared reliance on the integration of visual and auditory/verbal information. Longitudinal associations with phoneme awareness indicate that improvements in the ability to integrate tonal/rhythmic auditory information with its visual counterparts may be related to improvements in the manipulation of phonemes during this specific developmental period.

Furthermore, Reading Fluency had significant longitudinal relationships with all music discrimination abilities. However, the correlation between Reading Fluency and Rhythm Discrimination did not reach the level of significance. These patterns suggest a relatively global link between the development of reading and music-related abilities during the second school year. These longitudinal links reflect the close relationship between the emerging fluency in reading and the increasing efficiency in differentiating between musical features as well as the ability to integrate auditory and visual musical information. Contrary to the current findings, prior research (Forgeard, Schlaug, et al., 2008) did not reveal any significant associations between the development of real word reading and tonal/temporal music processing over a 14-month period in 6−7-year-old children. Thus, based on the significant repeated measures correlations observed in second grade, it is possible that longitudinal music-reading relations gain strength in a later developmental period.

Investigating the unique contribution of each musical ability to word reading development, results showed that increases in Pitch Discrimination and Rhythm Connection significantly predicted increases in word reading over the second school year. However, only the enhancements in Pitch Discrimination made a significant contribution to reading development beyond the enhancements in phoneme awareness and numeric RAN. These results suggest that over the second school year, the acquisition of fluency in word reading is specifically influenced by the development of pitch perception ability over and above the development of the cognitive precursors of reading.

In summary, highly specific relationships were found between musical and reading-related abilities at the end of the first and second school years. Although there were slight differences in the patterns of relations at the two assessment points, it cannot be concluded that the significant association at one point was significantly different in strength from the non-significant association at the other point. The strength of these generally small correlations cannot be considered different without any statistical comparison. Moreover, compared to the longitudinal correlations found during first grade in Study 4, findings of this study indicate that associations between the development of musical abilities, phonological processing, and reading appear to be less specific over the second school year. At the same time, the results highlight a specific longitudinal relationship between enhancements in word reading fluency and pitch discrimination over this specific developmental period.

5. GENERAL DISCUSSION

The purpose of the current dissertation was to investigate the association between music and cognitive development during the first two primary school years in typically developing children. On the one hand, the patterns of relations of musical abilities to reading-related cognitive functions were examined to better understand the foundations of music learning-induced transfer on reading and its cognitive precursors. Associations were assessed multiple times from the beginning of schooling to the end of the second school year to test the stability of music-reading relationships in young readers and to reveal potential parallels between the development of musical competencies and reading-related abilities in the initial years of formal reading and music instruction. On the other hand, the contribution of music lessons to music-related and non-musical cognitive development was estimated in the school context. More specifically, I aimed to explore and compare the impacts of various classroom music learning programs with or without body movement on cognitive improvements in schoolchildren.

In this chapter, I first summarize the findings of the five studies presented, according to the research questions formulated in Chapter 2, and also highlight the main results as thesis points at the end of each section. Then, I draw conclusions regarding the establishment of music-reading associations and the potential cognitive impacts of classroom music learning in the early school years. Next, I offer alternative frameworks for future research to better conceptualize and evaluate comprehensive music learning-induced changes in music-related and non-musical cognitive competencies. Finally, I discuss the possible limitations of the present studies, and outline questions for future research.

5.1. The role of the amount of classroom music education experience in cognitive development

The relationship between the amount of experience of school music education and cognitive abilities was examined in Study 1. For this purpose, the performance of second-grade children who had received one year of intensive classroom music instruction was compared with that of children who had received regular music instruction on tests of music perception, phoneme awareness, reading, and IQ.

The present results do not support the hypothesis that there is a connection between participation in more intensive music lessons and better music-related and non-musical cognitive abilities after one year of primary school instruction. There were no significant differences in second-grade cognitive performance between children who participated in music classes of varying intensity in the school context. Children who had one year of experience with four-times-a-week music lessons demonstrated similar performance in musical abilities, reading, phonemic awareness, and general intelligence compared to those who had only one music lesson per week for one year. This suggests that participation in classroom music instruction of varying intensity over a one-year period in the early years of schooling is not associated with differences in music-related and non-musical cognitive abilities in second-grade children. Thus, cognitive abilities appear to be independent of the amount of classroom music learning experience in the very first year of primary school.

It is important to note that Study 1 investigated the role of the amount of classroom music education experience using a cross-sectional design, which does not allow for inferences to be drawn about a causal link between participation in more/less intense classroom music lessons and cognitive functioning. Therefore, the current results suggest that children with the same amount of formal musical experience, but with different levels of intensity, have comparable musical, reading-related, and general intellectual competencies. The analysis only considered the length of music instruction, which was identical in both classes, and did not control for the differences in the intensity of music lessons. In future research, it would be desirable to collect data on children's musical experience in terms of the *cumulative duration* of formal music instruction in hours. This could indicate not only the length, but also the frequency of instruction children received. In this way, the combined effects of the intensity and length of music learning could be better estimated and controlled even in correlational studies.

The lack of significant differences between the classes contrasts with the findings of previous studies, which have shown superior musical auditory abilities (Roden, Könen, et al., 2014), reading ability (Hurwitz et al., 1975; Rautenberg, 2015), verbal memory (Roden et al., 2012), working memory (Roden et al., 2012; Roden, Grube, et al., 2014), and nonverbal intelligence (Hurwitz et al., 1975) in primary school children who engaged in school-based music instruction for 7–18 months. However, it should be emphasized that these studies typically compared musically trained children to children with minimal or no music experience. Based on the results of the present study, it is possible that the lack of difference in performance between the classes was due to the fact that children in both classes received music instruction. However, there is a lack of literature comparing different levels of music instruction among children. Thus, in the absence of empirical evidence from longitudinal studies, it is difficult to determine whether different cognitive abilities can be expected as a function of the intensity of music learning in groups of children of the same age. A potential explanation of the present results is that one year of school instruction was not long enough to find significant relations between more intensive music lessons and higher music-related and non-musical cognitive performance. This is speculative, but the instruction's differential effects over a longer developmental period may be established by varying its intensity. Nonetheless, it is clear that longitudinal studies are necessary to establish valid links between participation in music education and cognitive development.

Thesis 1. *Participation in classroom music education with varying intensity for one year is associated with similar levels of musical, reading-related, and general cognitive abilities in second-grade children.*

5.2. Contribution of using body movement in classroom music learning to cognitive development

Studies 2 and 3 investigated the impact of integrating body movement into music education in primary school classrooms on cognitive development during the first two years. Study 2 aimed to determine whether the classroom music program incorporating movement had additional effects on the development of pitch discrimination, phoneme awareness, working memory, and sensorimotor synchronization compared to traditional classroom music instruction without movement. Study 3 aimed to test whether an intensive classroom music program that implemented directed movement could result in greater improvements in sensorimotor synchronization and executive functions compared to an intensive music program that used improvised movement elements. The findings did not support the assumption that incorporating movement into music education or using directed/improvised movement during music lessons would lead to greater improvements in musical and non-musical domains in primary school children. General developmental effects were observed in most measured abilities from the beginning of schooling until the end of first grade.

Contrary to initial expectations based on Maróti et al.'s (2019) findings, no significant improvements were observed in pitch discrimination in children who received music education implementing body movement. However, our results are consistent with previous research (Lewis, 1988), indicating that children's tonal music perception abilities were similar after receiving 12 movement-based or no-movement music lessons. It is important to emphasize that the intensity of music learning differed in the Maróti et al. study and Study 2. While participants in the Maróti et al. study underwent an intensive music learning program, attending four music lessons per week, children in the current study participated in music education with two music lessons per week. Therefore, it may be necessary to apply the movement-based music learning method more intensively to achieve a more significant development in pitch perception. This assumption is supported by the results of participants in the intensive movement-based music learning program, where general developmental effect was identified not only in pitch perception but also in all pitch-based perceptual abilities. Given that the development of higher-order pitch perception, such as melody and harmony perception, follows a longer trajectory (Fancourt et al., 2013; Gembris, 2006; Trainor & Corrigall, 2010), it is possible that intensive movement-based music education may have accelerated the development of higher-order tonal processing.

Although we did not assume that integrating movement into music learning or using directive/improvisational music learning would be more effective in developing rhythm perception, it is surprising that we did not observe a general developmental effect in rhythm processing. Our findings are consistent with those of the Maróti et al. (2019) study, which found no significant changes in rhythm perception when implementing the movement-based music curricula in classroom education with the same intensity for eight months. The results suggest that the incorporation of body movement in classroom music lessons does not lead to further improvements in rhythmic discrimination ability, even within an extended implementation period. Moreover, the present results indicate that various movement-based music programs may promote the development of pitch-related and rhythm discrimination abilities differently during the early primary school years.

Musical audiovisual processing ability showed general enhancements in Study 2 and 3. The developmental trajectories of the tonal and rhythmic aspects of musical audiovisual processing appeared to be comparable among the science classes and the intense music classes. This global and considerable growth might have resulted from the learning of music notation reading and writing, which was an integral part of Kodály music education independent of the implementation of movement. Developmental research suggests that children become capable of connecting musical sounds with visual symbols at around 5 years of age (Miyamoto, 2007) and learn to read music notation at around 6 years (Kenney, 1997). Music notation reading is, however, typically acquired through formal instruction. Thus, general improvements in the performance on the auditory-visual connection tasks may be due to schoolchildren's formal experience with music notation reading.

Despite the initial hypothesis that children who receive music instruction using directed movement would achieve greater gains in sensorimotor synchronization, tapping performance did not improve more in the classes applying the directed movement music education program. This was surprising since the directed movement music curriculum provided explicit opportunities for children in the DM-science class and the DM-music class to practice music-movement coordination. Based on the absence of distinctive advances, it is speculated that in the current studies, music lessons conducted in a classroom setting with 20 to 30 children moving together to music might have better supported the training of social entrainment (Phillips-Silver et al., 2010). In a social setting, children moving to music could follow the movements of other group members during music lessons. The perception of the others' motions might have served as a reference, which helped them to anticipate their partners' movement and better adjust their own movements to the auditory stimuli (Overy & Molnar-Szakacs, 2009). In contrast, during the testing in the present studies, children had to perform sensorimotor synchronization tasks on their own, requiring them to adjust their movements to the metronome sound without any external social reference. It seems probable that tapping tasks were unique and relatively demanding to all participants, regardless of the classroom music program they engaged in. Thus, the present findings indicate that in a classroom context, music lessons following the directed-movement music curricula could not support more pronounced enhancements of sensorimotor entrainment processes.

Another important notion is that children in all groups were trained to clap to complex musical stimuli during listening or singing activities. A recent study by Kertész and Honbolygó (2021) found that first graders tended to tap with less variability when synchronizing with music compared to a metronome. It seems plausible that more distinctive effects of music programs would have been detected if participants were asked to synchronize with musical pieces. All in all, the present results point to the need for further research on the potential impact of learning context and stimulus type in enhancing sensorimotor synchronization skills through movement-based music programs.

Our results indicated that music learning completed with movement does not support the development of phonemic awareness more effectively than the traditional non-movement music learning method. This contradicts our hypothesis formulated based on the results of Maróti et. al. (2019); it is worth noting, however, that in Maróti's study, the development of classes participating in intensive music learning with or without movement was compared. Our findings regarding the phonological development of children in the intensive music classes complemented with directive/improvisational movement are consistent with Maróti's study. Although the intensive music classes with directed/improvised movement showed slight differences in the developmental trajectories of RAN and reading, overall, the results did not indicate that any music curricula had a greater potential to better promote enhancements in reading and its cognitive precursors in the early primary school years. Since phoneme awareness and word reading measures were only assessed at the end of the second school year for the whole sample, it is not possible to draw any firm conclusions regarding the causal links between incorporating body movement into music lessons and the observed specific reading-related benefits in the classes.

The beneficial effects of music learning on the development of reading and its cognitive precursors have been often explained by the fine-tuning of basic auditory processing mechanisms. Prevailing theories (e.g., Besson et al., 2011; Patel, 2011, 2014) postulate that long-term music instruction enhances low-level spectral and temporal sound processing, which may also have beneficial effects on the auditory encoding of speech. The enhancement of speech processing may further advance the establishment of more accurate phonological representations at the cognitive level, leading to the better capability in manipulating speech sounds, i.e., phonological awareness (Moreno & Bidelman, 2014). According to other perspectives (A. T. Tierney & Kraus, 2014), precise auditory timing ability plays a specific role in supporting both rhythmic synchronization and phonological processing. However, it is still not clear whether there is a direct link between auditory processing (specifically temporal processing) and reading ability or the proposed link is driven by phonological awareness in kindergarteners and schoolchildren (Lê et al., 2020; Ozernov-Palchik et al., 2018). Based on the above approaches, it seems plausible that the lack of distinctive improvements of musical abilities among the science classes and the music classes hindered the emergence of clear differences in the developmental courses of reading-related abilities.

Originally, it was predicted that for children who received music lessons combined with teacher-directed movement components would show greater increases in executive functions (EFs). This was based on the hypothesis that movement-based music lessons rely more heavily on a variety of EFs compared to the traditional Kodály curriculum using improvisational movement choreographies or no body movement. However, no significant difference was detected among the science classes and the intense music classes in the development of EFs over the course of one and a half years in Study 2 and 3. Moreover, the results of the present studies indicated that both classes showed comparable improvements in general intelligence. The parallel developmental courses might suggest age-related enhancements of EFs and intelligence in children in their early primary school years, which presumably originate in the onset of formal school instruction (Ceci & Williams, 1997).

It has been suggested that EFs may play an essential role in the emergence of transfer from music lessons to non-musical cognitive competencies. According to some frameworks (Moreno & Bidelman, 2014; Moreno & Farzan, 2015), the extent to which music learning benefits specific and general non-musical abilities depends on the degree to which it enhances EFs. The argument was supported by the authors' findings indicating that music training promotes considerable specific (e.g., verbal) and domain-general cognitive improvements, especially in the inhibitory control dimension of EFs and its neural correlates (e.g., Moreno et al., 2011; Moreno & Bidelman, 2014). Despite the promising findings, it has not yet been directly tested whether EF dimensions play a role in mediating music-induced transfer in relation to the development of phonological processing and reading ability.

Research on the mediatory role of EFs concerning general intelligence has received more attention in research; however, the evidence is inconsistent. For example, Schellenberg's (2011) correlational study with children aged 9 to 11 years old found no strong association between engagement in music training and intelligence driven by EFs, though intelligence and EFs were closely related. By contrast, Degé et al. (2011) confirmed the mediatory role of EFs in the relationship between music training and IQ in the same age group when including music training as a continuous measure (i.e., months of instruction) in the analysis. Therefore, future studies are needed to clarify the role of different EF components in supporting the transfer of music learning to specific and domain-general cognitive functions in schoolchildren. Although speculative, it is possible that, the comparable development of the EF dimensions in Study 2 and 3 might have contributed to the lack of distinct developmental courses for specific (e.g., phonological processing, reading) and general (e.g., intelligence) cognitive abilities in both the science and intense music classes. Based on the above arguments, obvious domain-specific and domain-general music learning-induced transfer could not emerge as the music curricula incorporating directed/improvised body movement or no movement components did not distinctively enhance top-down (control) mechanisms.

Thesis 2. *Classroom music education programs, regardless of the inclusion of movement, lead to similar improvements in both music-related and non-musical cognitive abilities during the first two years of primary school.*

Thesis 3. *Incorporating different types of movement into classroom music education results in similar improvements in music-related and non-musical cognitive abilities during the first two years of primary school.*

5.3. The stability of the patterns of relations between musical and reading-related abilities during the first two years of primary school

In line with the predictions, the findings of Study 1 and Studies 4–5 indicated the selective nature of associations between musical and reading-related abilities in beginning readers. Because of the diverging results of previous correlational studies (e.g., Degé et al., 2015; Douglas & Willats, 1994; Forgeard, Winner, et al., 2008; Janurik et al., 2022; Loui et al., 2011; Moritz et al., 2013; Rautenberg, 2015; Steinbrink et al., 2019), no hypothesis was formulated regarding the exact nature of music-reading relations. The present results suggest that the subcomponents of music-related abilities have diverse associations with PA, RAN, and reading ability across the assessment points.

Phoneme awareness was found to be associated with melody perception at the end of the first and the beginning of the second school year, which corroborates empirical evidence suggesting a relationship between musical pitch-related discrimination abilities and phonological processing in schoolchildren (e.g., Forgeard et al., 2008; Loui et al., 2011). One important notion is that phoneme awareness was solely related to melodic, but not pitch, processing ability in the current studies. This implies that it is pitch pattern processing, rather than the perception of pitch values, that is linked to phoneme awareness. This relationship was confirmed using two different types of melody perception measures. The Tonal Memory task from Bentley's MMA test (Bentley, 1966) requires a series of cognitive mechanisms. These include the segmentation of the melodic sequence into discrete notes, followed by a note-by-note analysis to localize the position of the alteration, and the detection process to determine the specified sound. In contrast, the Melody Discrimination task in the online battery (Asztalos & Csapó, 2017) requires the pitch contour processing of the note sequence. The cognitive processes implicated in the Phoneme Deletion task seem to be similar to those included in the Tonal Memory task. Both require the sound-by-sound analysis of auditory sequences to discriminate and precisely define changes in melodies and pseudowords. As performance on the Phoneme Deletion task was also related to the performance on the Melody Discrimination indicating a global pitch pattern processing mechanism, it appears that the establishment of the relationship between phoneme awareness and melody perception is independent of the cognitive demands of the particular task used. It has been evidenced that the accurate processing of the patterns of frequency changes supports stress location and segmentation processes in speech (Jusczyk, 1999; Morton & Jassem, 1965) as well as syntactic processing of the speech sequence (Ziegler et al., 2012). Thus, this association may suggest the importance of pitch pattern processing that facilitates both the lower-level frequency-driven differentiation of musical notes and speech sounds as well as the higher-order structural processing of sound sequences.

The relations of reading fluency to musical abilities varied considerably across the measurement points. The association found at the commencement of schooling between word reading and tempo perception is only partially consistent with prior studies, which suggested a close relationship between the rhythmic aspects of music perception and reading ability in 6−8-year-old children (David et al., 2007; Douglas & Willats, 1994; Rautenberg, 2015). In fact, the present studies found that rhythm perception did not associate with reading fluency, even when using different types of musical measures (discrimination and memory tasks). Nevertheless, there may be a connection between tempo perception and early reading ability, as both rely on the sensitivity to the temporal structure of sound sequences. On the other hand, reading fluency was found to be related to pitch perception at the end of first grade and to melody perception at the end of second grade, pointing to associations with pitch-related musical auditory abilities as children gain more reading experience. These results differ from the findings of the study by Forgeard et al. (2008), which showed that tonal (and rhythmic) discrimination abilities specifically correlate with nonsense word reading, but not with real word reading. However, previous research focusing on the music-reading relationship exclusively assessed reading accuracy in schoolchildren. Thus, it appears that tonal music perception abilities are also connected to reading ability, particularly in terms of fluency during the first stages of reading acquisition.

Surprisingly, rapid naming skills were not related to music perception abilities at any assessment points. Previous research investigating the relation of non-linguistic auditory processing to RAN have provided inconsistent findings in both kindergarteners and schoolchildren (David et al., 2007; Degé et al., 2015; Ozernov-Palchik et al., 2018). RAN is sometimes considered as another subskill of phonological processing (e.g., Savage et al., 2007; Vaessen et al., 2009), as it is highly dependent on the efficiency of accessing the phonological representations of word pronunciations. Despite the presumed phonological basis of rapid naming, the results of the current studies indicate the relative independence of RAN and musical auditory processing.

Furthermore, neither the performance on the melodic nor rhythmic auditory-visual connection tasks demonstrated significant relations to RAN or word reading ability at any assessment points. This contradicts the initial hypothesis that musical audiovisual processing skills would be linked to both RAN and reading fluency due to the shared multimodal associative learning mechanism (Blomert, 2011; Hodges & Nolker, 2011; Stewart, 2003). It is important to note here that the study did not measure children's ability to read music notation, but rather their ability to match musical auditory and visual information using identification tasks. This task requires the discrimination between visual representations of melodic/rhythmic patterns based on an auditory stimulus. In contrast, reading music involves a visuomotor transcription process, where visual information is converted into a motoric output (Stewart, 2003). Similar visuomotor processes are required in the RAN and oral word reading tasks applied in the present studies. Thus, it is conceivable that performance in music notation reading would have been more closely linked to RAN and word reading in young readers.

Contrary to the initial hypothesis, there was a specific association between performance on the rhythmic auditory-visual connection task and phoneme awareness at the end of the first school year, despite the seemingly different mechanisms underlying the two tasks. This relationship was apparent even when verbal memory was controlled, suggesting that short-term and working memory did not play an essential role in establishing this relation. It is possible that both tasks required an analytic, sound-by-sound processing of sound sequences. Therefore, similar local processing mechanisms may have led to the association between rhythmic audiovisual processing and phoneme awareness measured by a deletion task.

Although there were various patterns of relations between musical and reading-related abilities at the three assessments in the first two school years, the findings do not confirm the initial hypothesis concerning a change in the strength of associations as a result of formal instruction. Changes *per se* from the first to the third assessment in the music-reading associations do not indicate significant differences in the magnitude of their relations. The relative weakness of the relationships found at all time points indicates no considerable change in the strength of cross-domain relations from the beginning of schooling to the end of the second school year.

On the other hand, there were slight variations in music-reading relations across the assessments. PA was related to melody perception specifically at the verge of first and second grades. Reading fluency was related to tempo perception at school entry and to pitch-related music perception at the end of the first and second school years. These differences may indicate shifts in the significance of tonal or temporal musical abilities in reading development. However, the cross-sectional correlational design of the current studies prevented an explicit determination of their exact role.

Thesis 4*. The relationship between musical abilities and reading, as well as its cognitive indicators, is highly specific. The patterns of these relationships differ across all assessments during the first two years of school.*

5.4. The relationship between the development of musical abilities and the development of reading-related skills in the first two years of primary school

Studies 4 and 5 explored whether performance changes in the tests of musical and reading-related abilities were related using repeated measures correlations. This novel statistical approach enabled the estimation of longitudinal associations among the development of musical competencies and reading-related skills based on individual developmental courses by controlling for intra-individual variance. Findings indicated that certain musical abilities develop in parallel with reading and its indicator skills over the early primary school years. Moreover, some differences were found in the patterns of longitudinal associations between the first and the second school year.

During the first school year, phoneme awareness showed no longitudinal links with the aspects of musical auditory processing, which contradicts the initial hypothesis of specific parallel developmental trajectories. However, increases in pitch discrimination and rapid naming of pictures showed a specific relationship. During the second year, relations were found between increases in tonal music discrimination abilities and increases in PA and RAN. Moreover, reading precursor skills implicating time (i.e., PA Speed, RAN tasks) showed selective longitudinal relations to temporal music discrimination abilities. The associations suggest a general relationship between phonological processing speed and rhythm perception, as well as a more specific relationship between the efficacy of retrieving visual-verbal associations and tempo perception. The results partially align with prior findings (Forgeard, Schlaug, et al., 2008), showing that improvements in phoneme awareness over 31 months was specifically predicted by improvements in tonal music perception in 6−7-year-old children.

Contrary to the hypothesis, longitudinal associations were observed between musical auditory-visual connection and phonemic awareness, rather than just rapid naming as predicted. In the first and second school years, improvements in melodic audiovisual connection correlated with improvements in both phoneme awareness and rapid naming skills. In contrast, increases in rhythmic audiovisual processing were specifically linked to improvements in rapid naming of pictures in the first year, but correlated with increases in phoneme awareness and rapid naming in the second year. It appears that melodic audiovisual processing and the indicators of reading have similar developmental trajectories already in an early stage of schooling, whereas temporal audiovisual processing shows longitudinal parallels with PA and RAN later in development. Longitudinal associations between improvements in rapid naming skills and musical audiovisual connection support the initial prediction that they both rely on the integration of visual and auditory/verbal information. Longitudinal relations with phoneme awareness suggest that over the first school years, the ability to integrate tonal/rhythmic auditory information with its visual counterpart develops in parallel with the ability to manipulate speech sounds. These findings are unique to show developmental relations between the cognitive indicators of reading and non-linguistic audiovisual processing abilities in children in their early primary school years.

The most salient difference in the patterns of longitudinal associations between the two school years were detected for word reading. Whereas there were no longitudinal links found between the development of music-related abilities and reading fluency in the first year, music perception and musical audiovisual processing abilities were longitudinally associated with reading in the second year. These findings indicate that music-related abilities develop in parallel with reading fluency, specifically over the second school year.

Longitudinal associations between musical and reading-related improvements were found to be selective over the first six months of schooling, with more general developmental parallels observed between the domains over the second school year. Therefore, it is possible that the connection between the growth of musical abilities, reading, and precursor skills are more pronounced in a later period of school instruction. The decrease in specificity observed in the associations by the second school year may be attributed to the dynamic nature of musical and reading development during this period. It is well-established in the literature on reading development that the significance of cognitive precursors varies throughout the course of reading development. In languages with shallow orthography, such as Hungarian, the influence of phonological awareness on reading fluency decreases within one or two years as decoding skills become more solidified. Conversely, the role of rapid naming abilities either increases or remains constant over time (Vaessen & Blomert, 2010). Although speculative, it is possible that the longitudinal associations between different aspects of music processing and reading may also change with reading experience. During the early stages of formal instruction, the relationship between improvements in musical processing and reading-related abilities is more specific as domain-specific skills may improve first in both domains. This leads to the development of domain-specific representations. However, as children progress through their second year of school, they are presented with more complex tasks that require the simultaneous processing of multiple aspects of information in both domains. Increased exposure to diverse complex cognitive activities may enhance the interplay between the domains of music and reading. It is possible that as representations become stronger and processing becomes more automated in both domains, the developmental relationship between musical and reading-related abilities may also strengthen. However, the research approach applied in the present studies is unable to capture the extent to which the cognitive demands of learning music and reading contribute to a closer developmental relationship.

Furthermore, improvements in reading fluency were particularly predicted by increases in pitch discrimination when controlling for the effects of changes in the cognitive precursors of reading. This implies that besides phoneme awareness and RAN, the development of pitch perception made a unique contribution to reading fluency acquisition during the second school year. The relationship between the development of a perceptual variable, such as pitch discrimination, and the development of a performance variable, such as reading, may be mediated through general non-linguistic learning abilities, particularly implicit learning. Implicit learning refers to the acquisition of knowledge and skills in an incidental manner, without conscious awareness of the learning process (Seger, 1994). Reading has been linked to the capability of passive detection, storage, and utilization of statistical regularities in the learning context (Arciuli & Simpson, 2012; Erickson & Thiessen, 2015). Previous research on reading (Folia et al., 2008; Gombert, 2003; Ziegler & Goswami, 2005) suggests that initial correspondences between graphemes and phonemes are learned explicitly, while subsequent mappings arise from the detection of probabilistic correspondences. Learning these regularities enables the establishment of efficient representations for higher-order associative and rule learning (Pavlidou et al., 2009). This enables children to recognize letter combinations, word structures, and syntactic patterns, which helps them decode written words automatically as they gain more reading experience. Similarly, in music, pitch discrimination relies on the implicit learning of tonal patterns, relationships between tones, and rules (Tillmann et al., 2000). Neural network models for pitch perception (Sano & Jenkins, 1989; Taylor & Greenhough, 1994) argue that invariant acoustic properties of musical sounds are extracted from musical exposure, leading to the formation of abstract sound units that support categorization and memory of feature patterns. This bottom-up learning process driven by psychoacoustic features enables automatic recognition of tonal patterns and intervals in pitch discrimination. Exposure to various tonal musical stimuli during school music lessons may enable children to implicitly learn pitch discrimination rules. This, in turn, may have a positive impact on their ability to learn and recognize rules in non-musical domains, promoting the acquisition of fluency in reading.

The ability of young readers to read prosodically may provide an additional explanation for the prevalence of longitudinal associations between reading-related abilities and tonal musical competencies, as well as the establishment of more longitudinal relations in the second school year when children had gained greater experience in word decoding. The acquisition of reading with prosody has been proposed to mediate the emerging capability of fluent reading. Prosodic reading is the capability of reading aloud with appropriate phrasing, intonation, and expression (Kuhn et al., 2010). The speed and duration of the articulation of syllables/words and the placing of pauses determine the rhythm of oral reading, which supports the organization of the text into syntactically relevant phrases (Cowie et al., 2002; Kuhn et al., 2010). Besides acoustic features like intensity and timbre, pitch changes and the contour of voice define the intonation and expressivity of oral reading, which helps to detect relevant boundaries as well as implicit meaning in the text (Godde et al., 2020). When examining the contribution of the different aspects of prosodic reading to fluent reading development from first to second grade, Miller and Schwanenflugel (2008) revealed that the acquisition of proper pitch contour production, but not the placing of pauses, predicted later fluent reading over and above the development of decoding skills. The results of other studies also pointed to the relevance of the early achievement of pitch-related prosodic reading for later fluent reading development (Clay & Imlach, 1971; Cowie et al., 2002; Schwanenflugel et al., 2004). It has been emphasized that basic word decoding skills should be acquired first to assign cognitive capacities to read texts with appropriate prosody (Schwanenflugel et al., 2004). This suggests that the fundamentals of reading with proper intonation can be acquired early, which may be aided by the implicit learning of pitch patterns during reading.

Thesis 5*. The relationship between the development of musical competencies and reading-related cognitive abilities is selective, with different patterns of association in the first and second school years.*

5.5. Conclusions on the associations between musical and reading-related cognitive development in the early primary school years

5.5.1. The specificity of music-reading relations

The present findings indicate that at each assessment point, specific subcomponents of musical abilities were related to reading and/or its cognitive precursors. At the same time, this specificity does not imply that these relations included only tonal or temporal aspects of music processing. Therefore, results pointed out that although the associations between musical and reading-related abilities are not all-encompassing, both pitch-related and rhythm-related dimensions of music processing might be relevant in forming relations with reading in children with emerging literacy. Dominant theories (e.g., common acoustic processes hypothesis, Besson et al., 2011; top-down control hypothesis, Moreno & Bidelman, 2014; OPERA hypothesis, Patel, 2011, 2014) emphasize the importance of the general sharpening of basic auditory processes in the occurrence of transfer from music learning to the language domain and do not distinguish between the importance of the tonal and temporal processing in the first place. Together with the present results, this implies that studies that exclusively examine the relations of either tonal (e.g., Bolduc & Montésinos-Gelet, 2005; Loui et al., 2011) or temporal (e.g., Moritz et al., 2013; Ozernov-Palchik et al., 2018) music processing to reading-related abilities might not be able to provide a comprehensive picture of the real nature of the music-reading relationship.

However, it is important to note that the use of large test batteries including several tonal and temporal tasks also have drawbacks. In case of the present studies, the batteries comprised single tasks to measure each musical or reading-related ability when exploring the associations between the two domains. This approach is not necessarily beneficial considering that one task cannot fully account for a cognitive ability, and on the other hand, rarely demands a pure process (for a detailed discussion, see also Green et al., 2019; Noack et al., 2014). Accordingly, a certain dimension of musical abilities assessed by a single task cannot entirely explain reading ability, PA, or RAN also measured by a single task. This issue is generally reflected by the results of regression analyses conducted in the field, showing that various subcomponents of music processing can account for approximately 13% of the variance in phonological processing (e.g., Steinbrink et al., 2019) and 2–6% of the variance in early reading ability (e.g., Holliman et al., 2010; Ozernov-Palchik et al., 2018; Steinbrink et al., 2019) in school-aged children. These findings indicate that there are music-related and/or non-musical cognitive competencies other than the measured – or the yet uncovered – ones that could also contribute to reading in the first stages of acquisition. However, enlarging the test batteries to cover a wide range of potential music-related and non-musical cognitive competencies could have detrimental effects on participants' motivation to remain in the study and their cognitive performance (for a discussion, see also Green et al., 2019). Hence, one challenge for further research is to overcome the oversimplified or extremely complex practices of assessments by developing an adequately comprehensive test battery that covers the supposed cognitive mechanisms/constructs underlying the music-reading relationship. Moreover, the use of multiple tasks with somewhat overlapping processing demands might help to eliminate the possibility to unravel task-dependent associations, as well.

There is now growing evidence that other non-linguistic abilities may influence reading achievement. Recent research has identified links between reading-related cognitive abilities and *beat processing* in children. It suggests that basic temporal auditory processing is a shared foundation for music and speech (A. T. Tierney & Kraus, 2013a). A study of kindergarten population conducted by (Ozernov-Palchik et al., 2018) found that beat-based rhythm discrimination was independently linked to early reading ability, even when controlling for non-metrical processing, IQ, auditory working memory, and PA. Moreover, PA partially mediated the relationship between temporal processing and early reading ability. Further research with school-aged children has revealed specific links between *the processing of timing and grammar skills*. In typically developing 6−9-year-old children, rhythm discrimination but not melody discrimination was associated with receptive grammar skills (S. Swaminathan & Schellenberg, 2020). Furthermore, rhythm perception was specifically associated with expressive grammar skills (R. L. Gordon et al., 2014). As children grow older, rhythm discrimination has been shown to better predict syntax processing (Y. S. Lee et al., 2020). The relevance of *beat production ability* in reading acquisition is also highlighted. Studies have shown that tapping performance is linked to phonological processing, word reading, and spelling, in 5−7-year-old children (Bonacina et al., 2018; Kertész & Honbolygó, 2021, 2023; Lundetræ & Thomson, 2018) Moreover, investigating the influence of stimulus modality on the relationship between rhythmic abilities and reading in 7 to 11-year-old children, Tierney et al. (2021) found that reading performance correlated with rhythm reproduction accuracy in auditory and visual conditions but not in the multimodal condition. This suggests that the link between rhythm ability and reading is not limited to the auditory domain but extend to the visual domain. These findings suggest that there may be additional rhythm-related musical abilities that are relevant to the connection between music and reading acquisition in schoolchildren, beyond those measured in the present studies. Specifically, the ability to detect temporal regularities and synchronize with rhythmic patterns seems to play a role.

The ability to integrate auditory and visual information has been rarely investigated as a potential foundation of the relationship between music processing and literacy development in the early school years. This may be because audiovisual processing is specifically implicated in reading processes in the music domain and researchers might not expect to find direct connections between musical and reading-related audiovisual processing in children without experience in music notation reading. Studies examining the relationship between word and music reading are typically conducted with adults having different amounts of formal musical experience. Based on an event-related potential study (Nichols & Grahn, 2016), musical experience indeed appears to influence the audiovisual processing of music, with adults having less musical experience showing similar neural correlates of integration as beginning readers. There is also evidence that the effects of musical expertise might be generalized to some degree to the audiovisual temporal processing of sinewave and natural speech in adults (Lee & Noppeney, 2014), suggesting that the impacts of music learning could be transferred to the language domain. Yet, direct comparisons of musical and reading-related audiovisual processes have not been made in schoolchildren, to the best of my knowledge. In the future, examining children with emerging word and music reading abilities would be fruitful to uncover whether audiovisual processing implicated in word and music reading is already connected and show developmental parallels in the early stage of acquisition.

Overall, the abovementioned findings point out the need for the systematic analysis of the associations between music processing and reading-related abilities in primary school children. In an innovative work with 5−7-year-old children, Cohrdes et al. (2016) comprehensively investigated the relationship between diverse musical and linguistic competencies on different processing levels. Perception and production abilities were organized into five levels based on the size of units involved in cognitive processing, ranging from low-level sound discrimination to the processing of larger units such as texts or songs. Findings indicated that when accounting for potential confounding factors (e.g., the effects of non-verbal IQ, home musical and literacy environment, and EFs), musical and linguistic abilities were more closely related if the size of processing units and involved cognitive mechanisms were similar. This also suggests that musical and reading-related competencies on different processing levels could be loosely associated, making certain correlations hard to be replicated. Furthermore, a specific relationship was detected between lower-level musical auditory processing and higher-level emotion recognition in spoken sentences, which provides some evidence for theories (e.g., Besson et al., 2011; Moreno & Bidelman, 2014) arguing that improved lower-level processing abilities might benefit higher-level processing even in distinct domains. Thus, it seems reasonable to assume that the inconsistencies in the patterns of correlations between musical and reading-related cognitive competencies revealed by prior studies might be originated from the distinct levels of cognitive processing involved in the tasks applied. Hence, it would be advantageous for future research to focus on the differentiation between the various levels of processing in both the music and language domain to better understand within- and cross-domain associations as underpinnings of music learning transfer to reading ability in schoolchildren.

5.5.2. The variability of music-reading associations over time

Findings of the present studies suggest that the patterns of associations between musical and reading-related abilities varied slightly at each assessment point. Towards the end of the second school year, an expanding array of musical abilities showed relations to reading and/or its precursor skills. Moreover, the repeated measures correlations between musical auditory/audiovisual processing and reading-related cognitive abilities indicated several developmental parallels, suggesting a closer relationship in their development over this period.

Accordingly, one might conclude that cross-domain associations may differ at certain stages of music and reading development. Prominent theories have not considered potential developmental changes in the relations between music and reading. Thus, the relations of musical abilities to reading-related abilities have rarely been investigated longitudinally. Nevertheless, previous studies conducted with kindergarteners or school-aged children (e.g., Anvari et al., 2002; Steinbrink et al., 2019) have already examined potential differences in the music-reading relationship using cross-sectional designs in children from different age groups, with findings suggesting modest differences in the patterns of cross-domain relations. However, the age differences of the participating groups hindered the possibility to apply identical linguistic measures in these studies, which presents some difficulty in evaluating the similar and different patterns of cross-domain associations revealed. Therefore, the same tasks were employed in the same individuals over the course of one and a half years in the present studies. It should be mentioned that in case of the measures of PA and reading, the direct comparison of data obtained from completing shortened and more complex subtests may be methodologically questionable. I believe that using the same index for both types of subtests, regardless of their length, helped to overcome this issue. It also provided valuable information about within-participant changes in music-reading associations. This demonstrates that musical and reading-related abilities show more developmental parallels as children gain more experience in music and reading.

Nonetheless, it was not possible to evaluate the influence of reading and music instruction on the development of parallels between the domains. Formal school instruction may have contributed to the emergence of these longitudinal associations. Classroom reading instruction and music learning provided opportunities to practice reading, phonological and musical auditory processing, and musical audiovisual integration, which could lead to explicit reinforcement of all these skills and underlying processes. Therefore, the formation of longitudinal associations between reading-related and musical improvements may have resulted from reading instruction, music learning, or an interaction between the two. However, the current study design did not allow for the disentanglement of their potential effects.

It should be also highlighted that these longitudinal relationships were discovered in a sample where all children received formal music education. Thus, it is possible that the present findings cannot be generalized to the broad population. To draw comprehensive conclusions on the nature of these cross-domain longitudinal associations, it would be necessary to consider participants' cumulative formal musical experience. This will help control for the potential effects of music learning on the formation of music-reading associations. Further examinations over more extensive periods are important to explore if there are dynamic changes in the relations of musical and reading-related improvements as children gain more expertise in these competencies. This would assist researchers in understanding the connection between the two domains during development, and identifying the musical foundations that may influence reading-related abilities in children at different developmental stages.

5.6. Conclusions on the potential of comprehensive music programs to induce cognitive transfer in the early school years

Results from the present studies showed that the different use of body movement in classroom music instruction might not have diverse effects on the development of musical abilities, sensorimotor synchronization, phonological processing, reading, executive functions, and general intelligence over the first two primary school years. Nevertheless, a trend was found towards the more pronounced enhancements of pitch-related discrimination, tempo perception, and continuation tapping abilities by the end of second grade in children receiving movement-based classroom music lessons with higher intensity. These tendencies indicate that during the first 18 months of primary school, the benefits of classroom music lessons incorporating body movement are very modest and limited to domains closely related to music. The lack of broader movement-related cognitive advantages might have resulted from several factors linked to the context, the content of music learning, and the period during which music lessons occurred.

5.6.1. The context of music learning

When estimating the benefits of music learning programs implemented into school music curricula, the context, i.e., the setting in which music education took place should be primarily considered. In music research, the effects of community music instruction have lately been of particular interest, aiming to explore whether providing children with group music lessons for free in naturalistic settings could promote similar cognitive increases as focused music training programs (for a review, see Tervaniemi et al., 2018). Of these, high priority has been given to school-based music programs, which enable wider populations to partake in music lessons during the school hours. The realization of these programs, however, varies considerably across studies. One influential difference in the settings is that in previous studies, 5 to 15 children were typically included in classes who participated in school music education. By contrast, following the Hungarian practice, entire classes of 20 to 30 children received music lessons in their schools in the present studies. Though I intended to explore the effects of large-group music lessons, learning in large groups might have adverse effects on sustained attention and provide less support for individual growth. As prior studies (e.g., Jaschke et al., 2018; Roden et al., 2012; Roden, Grube, et al., 2014) including smaller groups of schoolchildren found specific cognitive benefits over the course of the early school years, it is feasible that the classroom context in which music lessons were held for large groups could not provide the necessary conditions for cross-domain enhancements to emerge. Hence, music instruction in the school context might be more successful in facilitating cognitive enhancements for children in lower grades if music lessons take place in small groups.

Nevertheless, the first school years are typically associated with engagement in systematic instruction even outside the school environment. It is thus possible that *other school-like activities* might have influenced participants' cognitive development. At the commencement of the longitudinal research, parents were asked to provide information about the participants' extra-curricular activities. Responses suggested that most of the children had at least one after-school program, such as movement-related (e.g., sports, dance), extra music (e.g., playing instruments and solfeggio), language-related (e.g., English as a foreign language) and arts (e.g., drama, visual arts) lessons. These data were collected only once at the beginning of schooling. Thus, changes in children's engagement in these activities were not registered throughout the research and their potential impacts on the development of cognitive competencies were not controlled for. It is feasible that extra-curricular activities contributed considerably to the similar developmental trajectories observed among the science classes and the music classes, compensating for possible developmental disadvantages in any groups. To better evaluate the potential of classroom music education in supporting cognitive increases, repeated administration of children's out-of-school activities would be indispensable.

Besides systematic music programs, children can often have access to music in everyday contexts, as well. *Informal music experience* refers to musical activities like singing, music listening, playing musical instruments, dancing to music, which occur in unstructured conditions at home or even in school contexts with no instructional aim (Tervaniemi et al., 2018). Musical activities included at home might be crucial as taking place at children's primary environment. As being easily available, home music activities might provide additional opportunities for practice in a variety of functions. A new line of research indicates that informal music experience indeed has an impact on preschool-aged children's music-related and non-musical cognitive development. Studies have revealed that the greater amount of joint singing and playing musical instruments at home was associated with better music-related auditory processing at the neural level (Putkinen et al., 2013) as well as grammar skills (Politimou et al., 2019), vocabulary, numeracy, and attentional regulation (Williams et al., 2015). Moreover, engagement with spontaneous music activities has been shown to improve children's social skills, such as cooperation, prosocial behaviour (Kirschner & Tomasello, 2009; Williams et al., 2015), and interaction (Ritblatt et al., 2013). In school-aged children, examining the role of involvement in informal music activities is a neglected area, since the effects of long-term structured music learning programs can already be studied in this age group. At the beginning of the longitudinal investigation, some information was collected about the potential exposure to music at home by asking parents to report the amount of music their children listen to and the number of musical instruments at home. Because of the incomplete data, home music experience was not included as a variable in any analyses. In general, our knowledge concerning the role of participation in informal music activities in schoolchildren is still deficient. Thus, the exploration of the features of spontaneous music activities that can contribute to cognitive development in the early school years awaits future research.

Children may also have access to reading in informal settings. The concept of *home literacy environment* includes various literacy-related opportunities and interactions within a family, such as the reading habits of family members, their attitudes towards reading, shared family reading practices, and the quantity of books in the household (Burgess et al., 2002; Niklas et al., 2020). Moreover, there is ample evidence to support the notion that home literacy environment plays a significant role in the development of children's linguistic and literacy competencies (e.g., Burgess et al., 2002; Inoue et al., 2018; Sénéchal & Lefevre, 2014; Silinskas et al., 2020). Research has shown that home literacy environment is associated with reading outcomes in kindergartener children, unlike socioeconomic status (Burgess et al., 2002). It was also found that home reading instruction predicted letter knowledge and word reading fluency at the beginning of schooling and sentence reading fluency at the end of second grade (Silinskas et al., 2020). Furthermore, reading comprehension activities at home were found to specifically predict reading ability from first grade onwards (Georgiou et al., 2021), highlighting the importance of home practice in reading development. Previous research on the transfer effects of music education on reading development has primarily focused on the quantity of books at home, which is often used as a measure of socioeconomic status. However, to more accurately assess the contribution of music education to reading development, it is essential to consider the home literacy environment, especially parental attitudes towards reading, shared reading, and teaching of reading.

5.6.2. The content of music learning

Another important question is how the content of the music program affects the cognitive outcomes. Even though there is still no clear picture on the exact curricular features that are critical in supporting the occurrence of music-related transfer, I propose that the *focus of the applied music program* plays a central role in the occurrence of cognitive transfer in the first primary school years. In previous studies conducted by Roden et al. (Roden et al., 2012; Roden, Grube, et al., 2014; Roden, Könen, et al., 2014) and Jaschke et al. (2018), focused instrumental training was implemented into school-based music programs besides general activities, such as music listening and singing. Instrumental play and music making in general have been suggested to highly demand executive functioning (Okada & Slevc, 2018). Accordingly, findings of these studies corroborated this notion by implying greater increases for groups of children undergoing instrumental training than groups of children receiving visual arts or no specialized training in planning, inhibition (Jaschke et al., 2018), verbal (Roden et al., 2012) and working memory (Roden, Grube, et al., 2014). In the present studies, classroom music programs incorporating body movement might have also demanded executive functions.

However, predetermined and spontaneous movement forms implemented into music listening activities and singing-rhythmic games might have created more playful conditions for children to improve executive functions. It is thus feasible that school music programs including instrument learning might support more significant developments during the first primary school years in selective components of EFs as compared to classroom music programs comprising body movement.

Based on the success of instrumental music learning in promoting considerable improvements in children’s general cognitive abilities like executive functions, one might question the need for designing further non-instrumental music programs with uncertain cognitive outcomes. Initially, with the development of movement-based music learning programs, the main aim was to provide children with multimodal experience through body movements accompanying music listening and production activities. Movement-based music education, either implementing teacher-directed or improvised movement components into musical activities, employed motion in order to strengthen the attention to as well as the perception, analyzation, and understanding of musical qualities through kinaesthetic experience. There is evidence pointing to the relevance of practice for the improvement of fixed and free movement reactions to music. It has been shown that years of formal music training on the temporal organization of perception and actions was positively associated with the precision of timed movements (Janzen et al., 2014; Repp, 2010) Moreover, interventions supporting the investigation of unique and adaptive movement alternatives under different conditions facilitates motor creativity (Orth et al., 2017). It has been also shown that synchronized movement and motor creativity has common cognitive foundations and both demand attentional mechanisms and working memory capacity (de Dreu et al., 2012; Moraru et al., 2016; A. T. Tierney & Kraus, 2013b). Conceivably, because of the complex auditory, sensorimotor, and cognitive requirements of following music listening and music making with body movement, the benefits of movement-based music educational programs might emerge over an extensive period, demanding longer and/or more intense practice to enhance cognitive functions through the coordination of music and movement. Therefore, it would be advantageous to further study the potential impacts of classroom music education using body movement on children’s cognitive development from the commencement of schooling to the late primary school grades.

Another purpose of the implementation of body movement into music education was to make school music learning more enjoyable to children. Empirical evidence corroborates that the outcomes of formal music instruction might also depend on the *participants’ experience* *related to that specific music program*. Ericsson et al. (2009) argued that the potential gains that can be achieved through music education is based on how rewarding and enjoyable musical activities are for children, making them motivated and engaged in that musical activity. Similarly, Lamont (2020) suggested that motivation is vital for musical engagement and thus musical development in childhood. In her view concerning early musical development, musical engagement is best supported in contexts which are challenging, provide opportunities for growth and social interactions, and where children can experience their agency. The newly developed movement-based music programs for schoolchildren in the current studies attempted to initiate and keep participants' motivation by bringing joy, the feeling of responsibility in their groups using bodily experiences. As pointing beyond the scope of the current research, participants' motivation, engagement, and satisfaction with the movement-based music programs were not measured. In addition, children's social development was not tested, either, even if the movement-based music programs allowed for interactions between the group members in the classroom setting. Although speculative, it is also possible that music programs complemented with diverse movement forms better supported musical engagement and the development of socioemotional skills, but not music-related or specific/general cognitive abilities, during the first two years of primary school.

Given the diverging findings in the literature concerning the cognitive outcomes of various music learning programs established in school settings, it would be worth considering whether classroom music education could be regarded as a cognitive training technique, facilitating domain-general cognitive improvements. The term "cognitive training" describes interventions that involve intellectually challenging activities or cognitive tasks with the objective of improving overall cognitive ability (Gobet & Sala, 2023; Jolles & Crone, 2012; Sala & Gobet, 2020). This standard definition is broad, covering both "brain training programs" with a particular focus on enhancing cognitive abilities through systematic practice of cognitive tasks as well as other programs demanding cognitive competencies, such as music learning. However, the question arises whether the same cognitive outcomes can be expected from focused brain training and comprehensive music learning programs. Diamond and Ling (2016) investigated the efficacy of diverse cognitive training programs including musical activities from the perspective of the development of executive functions. The authors suggested that engaging in cognitive challenges and activities that require effortful control and working memory may improve executive functions. They concluded that improvements in cognitive abilities occur only in the specific competence that has been practiced, which does not transfer to other untrained abilities. To achieve broad enhancements, individuals should practice a variety of abilities. Based on the authors' arguments, various learning programs might induce improvements in a certain ability when being directly trained by both programs, but the occurrence of transfer to cognitive competencies being untrained might be rare. Accordingly, the current findings indicating general improvements for most of the measured music-related and non-musical cognitive competencies independent from the inclusion of body movement in music lessons might have resulted from the great potential of the comprehensive music curriculum in supporting widespread development in schoolchildren. Further, specific music-related or non-musical cognitive enhancements might reflect selective areas that might have been specifically trained by a certain music program with or without body movement.

Though a variety of motor abilities were implicated in classroom musical activities, we cannot make firm conclusions on their role in supporting music-related and non-musical cognitive benefits since motor development was not measured over the 18 months of the present studies. It is important to mention that neither of the previous studies (e.g., Lewis, 1988; Maróti et al., 2019; Rohwer, 1998; Yazejian & Peisner-Feinberg, 2009) assessed motor functions when estimating the impacts of combined music and movement programs on children's musical, linguistic, or general cognitive development. Concerning views that emphasize the role of practice in the occurrence of transfer, it would be essential to assess fine and gross motor functions beside all music-related/non-musical auditory and cognitive functions that had been included in the instructional program when evaluating the potential of movement-based comprehensive music education in promoting schoolchildren's musical and cognitive development. This necessitates specifying the variety of functions targeted by the movement-based music curriculum. This would help us to determine whether the trained elements show significant enhancements in the first place, which would help to identify music-related and non-musical competencies that could count as origins, mediators, or moderators of transfer to domain-specific and domain-general cognitive abilities.

5.6.3. The developmental period during which music learning occurs

Finally, it should be kept in mind that the impacts of childhood music learning are not independent from normative development. Evidence from the field of developmental cognitive neuroscience suggest that the effects of formal learning programs depend on the complex interplay between learning and maturation processes (Galván, 2010). During the first school years, children exhibit intense improvements in musical abilities (Gembris, 2006; Gooding & Standley, 2011), phonological skills (Ziegler & Goswami, 2005), and executive functions (Best

& Miller, 2010) of which many competencies (e.g., inhibition accuracy, working memory capacity, set-shifting ability, Best & Miller, 2010; musical preferences, Gembris, 2006; sense of tonality, pitch-matching ability, Kenney, 1997; temporal/tonal discrimination, Miyamoto, 2007; phonological awareness, Ziegler & Goswami, 2005) improve even without any explicit instruction, while others (e.g., rhythm skills, Gembris, 2006; music notation reading, writing, Gooding & Standley, 2011; phoneme awareness, Wimmer et al., 1991) improves as a result of the commencement of schooling. Thus, any structured music education program starting in the early primary school years influences the trajectory of normative development in these domains. It is feasible that music education programs varying in their content, which provide different opportunities to practice diverse abilities, could have diverse effects on age-related improvements. Moreover, there might be differences in how individual learners improve in distinct areas, leading to trajectories deviating from the developmental course of the group (Jolles & Crone, 2012). Results from the present studies indicated that within each class there was great variability between participants in all competencies, implying that the individual's level of functioning at certain assessment points might have associated with the outcomes of instruction. Thus, it seems plausible to assume that the developmental trajectory of a particular domain in a particular individual influences the degree to which domain-specific and domain-general competencies could be modified by formal music education (Holochwost et al., 2021; Jolles & Crone, 2012). Hence, it would be desirable to estimate the benefits of classroom music education grounded in individual learning courses, which could help to clarify how the current normative and individual developmental stage impact the benefits that could be achieved through large-group comprehensive music lessons during the first years of primary school.

5.7. Alternative frameworks for the estimation of music learning transfer

The fundamental aim of research on the impacts of music learning is to evaluate whether and to what extent enhancements can be generalized to untrained functions through musical activities. With respect to cognitive benefits, findings of meta-analyses (e.g., Cooper, 2019; Gordon et al., 2015; Sala & Gobet, 2017, 2020) have indicated that the overall magnitude of the impacts of music lessons on cognitive development tends to be small or minimal during childhood. A general issue in the field of music transfer research is that longitudinal studies dominantly focus on the success of a particular education program in promoting cognitive increases during childhood, at the same time placing little emphasis on exploring *why* the music program was efficient and *which elements* were transferred from music learning to children's cognitive development. However, these deficiencies may also reflect the lack of theoretical background, which could grasp the complexity of the phenomenon and support the better understanding of the factors and conditions necessary for its occurrence.

The evaluation of the outcomes of music learning solely on the grounds of the *distance of transfer* appears to be initially problematic. The taxonomy of transfer distance categorizes transfer effects based on the similarity between the trained and untrained tasks. Thus, near and far transfer is generally determined by the generalization of music-induced cognitive enhancements based on the similarity of the learning and target domain (Sala & Gobet, 2017). According to the traditional “common elements theory” (Thorndike & Woodworth, 1901), transfer is limited to the degree to which two tasks share common elements or similar underlying processes, indicating that transfer is not a general, but rather a task-specific phenomenon. Moreover, the interpretation of far transfer effects is initially complicated by these shared underlying processes, making it difficult to attribute any improvements to the specific cognitive skills targeted by the learning. Based on the assumption of common processes, the question may arise whether the goal of the intervention should be to improve the specific task or the cognitive process or ability underlying that task (McArdle & Prindle, 2008). It seems that the *content* or target domain that should be influenced by the training is needed to be revealed first to estimate the generality of transfer effects in cognitive research (Noack et al., 2014).

Given that music learning provides complex learning conditions, demanding not only cognitive, but also a variety of sensory and motor functions, the evaluation of the generalizability of enhancements across the domains appears to be hard using the unidimensional category of transfer distance. In the music literature, there have been suggestions for *multidimensional models* of the effects of music interventions. For instance, Moreno and Bidelman (2014) proposed a framework in which music-induced cognitive transfer can be examined on a continuum along the orthogonal dimensions of the nature of transfer (near–far) and the level of processing (sensory–cognitive), with the latter representing the impacts ranging from basic perceptual processing to higher-order aspects of cognition. The model posited that the advantages of music learning and thus the generality of transfer from music to untrained functions might be mediated by general cognitive abilities. Based on research evidence (Bialystok & DePape, 2009; Moreno et al., 2011) about the mediatory role of EFs in the transfer of cognitive interventions, Moreno and Farzan (2015) proposed in an augmented model that the transfer of music learning is likely to be supported by the involvement of EFs, and particularly by inhibition control. The authors, however, highlighted the need for future investigations concerning the role of other EF dimensions in the occurrence of music-related transfer. Moreover, systematic analyses are required to clarify whether this model is applicable to interpret the outcomes of various music interventions.

As discussed above thoroughly, there might be contextual and content-related factors that influence the effectiveness of different music education programs. These factors are typically not included in the models of music learning transfer regarding cognitive outcomes. Recently, Holochwost et al. (2021) offered a framework in which *the role of context* was emphasized in understanding of the possible effects of diverse arts education programs on children's socioemotional development. The authors suggested that the immediate (i.e., the setting of instruction, the content and intensity of the program, characteristics of the educator) and broader (i.e., the characteristics of participants, their families and broader societal environment) contextual factors of learning should be all considered when estimating the outcomes of the instruction. Furthermore, the domain of development should be specified to formulate more accurate hypotheses about the effects of the employed program. As a strength of this framework, it suggests that the interpretation of the outcomes of arts programs should consider not solely one factor but the interaction between a set of contextual features. This implies that each arts program might have differential impacts on children's development based on its characteristics. What was included but not sufficiently emphasized in the overview of the proposal is that the characteristics of the arts program determine the outcome of learning in interaction with the characteristics of the learner. This also indicates that arts programs could have highly specific impacts on development in a certain domain, with children gaining different advantages based on their own characteristics.

Although the authors' proposal focused on socioemotional development, this division of contextual factors and the inclusion of their interactions in the understanding of transfer could be adapted to the estimation of the cognitive outcomes of music learning. This framework could shed light on the complex interplay behind the cognitive transfer effects of music lessons in natural settings, which often hinders the possibility to compare the outcomes of prior studies with varying characteristics. I believe that the application of this approach could help us to design future research more deliberately, also promoting the better comparability of later studies in this field. By considering the specific features of the immediate and broad context in which music education occurs in future reserach, we could better understand and interpret why childhood music learning programs with different contextual features lead to distinct advantages on various cognitive outcome measures. Furthermore, it could also help us to examine if individual learners achieve unique cognitive benefits from the same music education program during the early years of primary school. The application of this framework could serve as a novel complementary view to the ones interpreting the mechanisms underlying the transfer of music learning to cognitive development.

5.8. Limitations and future directions

Several conceptual and methodological factors have been already listed in previous sections that can limit the interpretation of the current findings and offered some approaches to counteract these limitations in further research. In this last section, I suggest additional relevant issues and research areas that require clarification in future studies.

One important notion is that *the design of the current longitudinal studies,* where participants were self-selected instead of randomly assigned, may limit the conclusions could be drawn from the results. Even though the random allocation of participants would be preferable to account for potential pre-existing differences in longitudinal studies, it was important not to alter the natural school environment in exploring the effects of classroom music instruction, to maintain the ecological validity of the present studies. The lack of random allocation allowed participants (and their parents) to select the class based on their preferences and motivations. Nevertheless, because of the use of real-life allocations, it was not possible to alter the basic specifications of the school curricula in the classes. As a result, there was no control class with a science-based curriculum receiving classroom music education that incorporated improvised body movement in Study 2 and a control class with an intense music curriculum involving no body movement activities in Study 3. As the impacts of classroom music learning on children's improvements in general cognitive abilities (i.e., EFs, IQ) were of special interest in the studies, their possible confounding was not controlled in relation to the development of musical and reading-related abilities. Accordingly, it is not excludable that self-selection influenced the distinct increases appeared for specific sub-competencies in certain groups. For future studies conducted in naturalistic settings, an *alternative block randomization process* applied by Jaschke et al. (2018) would provide a valuable solution, where each participating school treated as a block is randomly allocated to the treatment or control conditions. This procedure may be adapted to classes in order to control for pre-existing cognitive biases without considerably manipulating the natural school environment.

Furthermore, in the current studies, the enlargement of the classes was not feasible due to the lack of manipulations regarding the learning context in schools, which is responsible for *the relatively small and different sub-sample sizes* remained for the last assessments. However, using a small sample size can critically impact the reliability and generalizability of the study results. One significant limitation is the reduced statistical power, which makes it difficult to detect genuine effects or relationships within the data. Small samples are more prone to random variations, which can lead to less reliable conclusions. Additionally, the risk of Type I and Type II errors increases with small sample size, which can compromise the accuracy of study results and subsequent interpretations. Although the relevance of power analysis was evident at the beginning of the studies, a priori power and sample size estimation were hampered by the exploratory nature of the investigations with no clear expectations concerning the outcomes. Following the above-mentioned block randomization procedure, the selection of a sufficient number of participants for longitudinal studies based on the estimation of power analysis could be achieved. Therefore, it is recommended to expand each music program to include multiple classes of children in future studies. This method aims to achieve an adequate sample size, reducing power-related issues, particularly when investigating transfer effects in uncontrolled contexts. This holds especially when non-parametric statistical methods are used for hypothesis testing. On the other hand, there is a novel approach suggesting *the use of Bayesian hypothesis testing methods* instead of traditional paradigms for specifying an adequate, but not fixed, sample size (e.g., Sequential Bayes Factors; Schönbrodt et al., 2017). One advantage is that they do not require accurate a priori calculations of effect size. Additionally, these methods appear to need a smaller number of participants to achieve the same level of confidence. Hence, these techniques might be especially advantageous for estimating sample size in future longitudinal investigations where the recruitment and the preservation of an overall sufficient number of participants are often critical issues.

In addition, some methodological issues arose concerning *the measures used* in the current studies. First, it is important to note that not all measurement tools used in the studies were validated tests. This compromises their reliability and validity, which in turn affects the theoretical foundations and the conclusions drawn from the studies. In future transfer studies, it would be important to work with a larger sample to enable *measurement invariance analysis*. This would ensure that measurement instruments remain consistent and comparable over time, thereby supporting accurate interpretations of changes in observed variables. Furthermore, the measures of Phoneme Deletion and Reading were only performed by a portion of the participants at the assessments carried out at school entry. Thus, for PA and reading ability, results from the first school year reflect the performance changes of children from this sub-sample. This highlights the importance of creating *adaptive testing methods*. The development of computer-based measures would allow for Computerized Adaptive Testing (CAT) which presents test items adjusted to the individual's estimated ability level. CAT is based on a pool of test items ranging from easy to difficult, allowing for a more personalised assessment. CAT employs an algorithm to select an item from the pool that matches the individual's current estimated ability. This algorithm then recalculates the individual's ability level based on each response and presents another item from the pool, with a 50% chance of an accurate response. After conducting an adequate number of trials, the score is calculated based on the difficulty of accurately completed trials (for a general overview, see Weiss, 2011). Overall, this method might enable the more precise evaluation of the individual's ability in less time. The application of CAT would be beneficial for examining of children with emerging reading and musical abilities, as being able to estimate children with moderately different ability levels on the same scale. Furthermore, by accounting for the individual's ability level, CAT provides a unique approach that centre around individual performance instead of a priori expectations regarding normative performance.

It appears evident from the previous and present results that investigating direct associations between music-related and non-musical cognitive competencies *cannot represent the whole picture on the foundations of music learning transfer*. In research related to this dissertation, I intended to emphasize that functions serving as bases for music learning transfer are not stable but dynamically changing, which should be taken into account when investigating the mechanisms of transfer in schoolchildren. I believe that this longitudinal approach counts as a clear strength of the present studies. Although longitudinal associations between musical and reading-related abilities and their development have been revealed, the design did not allow for *the examination of latent factors* through which the advantages of music learning could be transferred to the reading domain. In future research, *Latent Change Score (LCS) models* might provide statistical solutions for exploring the dynamics of processes over time in relation to music learning. LCS models are grounded in the assumption that development is affected by the constant interplay between all the components in a particular system (Thelen & Smith, 2006). Thus, for music research, multivariate LCS models could capture the short-term dynamics and the long-term developmental trajectories of the music and reading domains as well as the dynamic interrelation between their processes by specifying latent changes and covariances (i.e., external and internal effects) during development (for a summary of the LCS, see Cáncer et al., 2021). Ultimately, LCS models could be well suited to test hypotheses concerning the dynamic nature of music-reading associations. This approach would be useful to study the relations between music and other cognitive abilities, as well.

Another step forward to the better understanding of the effects of diverse music learning programs would be to study *the role of individual performance/growth* in the variability of cognitive outcomes. As individual development may differ from the average developmental course of participants, it would be essential to estimate the efficacy of a particular music program from the perspective of individual learning trajectories. This could help us to identify (the set of) factors related to the person, which can significantly contribute to the extent of advantages one participant could gain from music learning. Instead of common variable-oriented methods relying on the examination of inter-individual differences, person-oriented statistical methods would enable to draw conclusions about individuals and individual patterns of performance (Bergman & Wangby, 2014). From among the several person-oriented methods, for instance, cluster analysis-based methods could be used for longitudinal data to explore patterns of variables at multiple assessments and explore potential within-individual and structural changes in their classification over time (Bergman et al., 2003). Alternatively, individual developmental patterns obtained from repeated measurements could be also treated using mixed models (for a summary, see Detry & Ma, 2016). Apart from comparing sub-samples, these statistical methods can also be utilized to describe the patterns of individual improvements. Moreover, the models are especially valuable in longitudinal analyses when the progression of a specific outcome for an individual in a study is affected by variables that are expected to be consistent across the participants (e.g., influence of an instructional program) as well as factors that might significantly differ among participants (e.g., initial performance).

Even though the examination of participants' cognitive improvements over the course of the learning program is essential to determine the immediate benefits of music instruction, it would be also important to *conduct follow-up studies* to explore if music learning programs could have long-lasting effects. We have little knowledge about the nature of longitudinal changes after childhood music programs had been terminated and whether individual development during the instruction determines later cognitive changes. As being more accessible to children, the future investigation of the long-term effects of taking part in school-based music learning programs should be of special interest.

5.9. Summary

Findings of the dissertation indicates that one year of participation in intense comprehensive music lessons is not associated with higher performance in music perception, phoneme awareness, reading, or general intelligence in second graders. Further, classroom music learning programs incorporating different body movement elements support similar improvements over the first two primary school years in music-related abilities, early literacy skills, executive functions, and general intelligence, though the trajectories of specific aspects of music-related or non-musical cognitive abilities appeared to be diverging among the science classes and the intense music classes. Concerning the lack of between-group differences at the last measurements, these differential patterns does not indicate the superior potential of any music learning program applied.

When examining the relations of musical competencies specifically to reading and its indicators, their highly specific and somewhat varying nature can be seen over the first 18-month period in primary school. Moreover, musical abilities and reading-related skills appear to develop in parallel, with the second school year being associated with more extensive longitudinal associations between the domains. This raises the possibility that there are moderate changes in the patterns of cross-domain associations during the early years of formal reading and music acquisition, which might influence the role music plays in supporting early reading acquisition.

Despite the promising results regarding the relations of music to children's specific and general cognitive development, neither the previous nor the present studies can truly address the questions concerning the general real-life cognitive benefits of music education in the school setting. On the one hand, the influence of school music learning on academic achievement and domain-general cognitive competencies (e.g., problem solving, critical, analytical, and creative thinking) might not be appropriately explained until we have no clear understanding of its behavioural impacts either on abilities which are directly implicated in musical activities. On the other hand, the real-life implications for cognitive development might rather be considered as "habits of mind" (Perkins et al., 1993), reflecting patterns of thinking and behaviour that are essential to solving problems, making decisions, and creating new knowledge. As practice appears to be crucial for cognitive transfer to emerge, the teaching of this way of thinking during classroom music lessons might be essential to achieve such general cognitive improvements. Nonetheless, concerning its possible cognitive benefits, not to mention the pleasure it brings to children, the importance of music learning in the primary school environment is indisputable.

6. REFERENCES

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[1]ADATLAP
a doktori értekezés nyilvánosságra hozatalához

I. A doktori értekezés adatai

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II. Nyilatkozatok

1. A doktori értekezés szerzőjeként[3]

a) hozzájárulok, hogy a doktori fokozat megszerzését követően a doktori értekezésem és a tézisek nyilvánosságra kerüljenek az ELTE Digitális Intézményi Tudástárban. Felhatalmazom az ELTE PPK Doktori Iskola hivatalának ügyintézőjét, Barna Ildikót, hogy az értekezést és a téziseket feltöltse az ELTE Digitális Intézményi Tudástárba, és ennek során kitöltse a feltöltéshez szükséges nyilatkozatokat.

b) kérem, hogy a mellékelt kérelemben részletezett szabadalmi, illetőleg oltalmi bejelentés közzétételéig a doktori értekezést ne bocsássák nyilvánosságra az Egyetemi Könyvtárban és az ELTE Digitális Intézményi Tudástárban;[4]

c) kérem, hogy a nemzetbiztonsági okból minősített adatot tartalmazó doktori értekezést a minősítés (dátum)-ig tartó időtartama alatt ne bocsássák nyilvánosságra az Egyetemi Könyvtárban és az ELTE Digitális Intézményi Tudástárban;[5]

d) kérem, hogy a mű kiadására vonatkozó mellékelt kiadó szerződésre tekintettel a doktori értekezést a könyv megjelenéséig ne bocsássák nyilvánosságra az Egyetemi Könyvtárban, és az ELTE Digitális Intézményi Tudástárban csak a könyv bibliográfiai adatait tegyék közzé. Ha a könyv a fokozatszerzést követőn egy évig nem jelenik meg, hozzájárulok, hogy a doktori értekezésem és a tézisek nyilvánosságra kerüljenek az Egyetemi Könyvtárban és az ELTE Digitális Intézményi Tudástárban.[6]

2. A doktori értekezés szerzőjeként kijelentem, hogy

a) az ELTE Digitális Intézményi Tudástárba feltöltendő doktori értekezés és a tézisek saját eredeti, önálló szellemi munkám és legjobb tudomásom szerint nem sértem vele senki szerzői jogait;

[1] Beiktatta az Egyetemi Doktori Szabályzat módosításáról szóló CXXXIX/2014. (VI. 30.) Szen. sz. határozat. Hatályos: 2014. VII.1. napjától.
[2] A kari hivatal ügyintézője tölti ki.
[3] A megfelelő szöveg aláhúzandó.
[4] A doktori értekezés benyújtásával egyidejűleg be kell adni a tudományági doktori tanácshoz a szabadalmi, illetőleg oltalmi bejelentést tanúsító okiratot és a nyilvánosságra hozatal elhalasztása iránti kérelmet.
[5] A doktori értekezés benyújtásával egyidejűleg be kell nyújtani a minősített adatra vonatkozó közokiratot.
[6] A doktori értekezés benyújtásával egyidejűleg be kell nyújtani a mű kiadásáról szóló kiadói szerződést.

b) a doktori értekezés és a tézisek nyomtatott változatai és az elektronikus adathordozón benyújtott tartalmak (szöveg és ábrák) mindenben megegyeznek.

3. A doktori értekezés szerzőjeként hozzájárulok a doktori értekezés és a tézisek szövegének plágiumkereső adatbázisba helyezéséhez és plágiumellenőrző vizsgálatok lefuttatásához.

Kelt: Budapest, 2024. március 13.

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a doktori értekezés szerzőjének aláírása