The Effects of Musical Engagement on Numerical Cognition in Early Childhood

A thesis submitted in partial fulfilment of the requirements for the

Degree of Master of Science in Psychology

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Abstract

Music and mathematics have been associated since Pythagoras, but there is limited evidence on whether musical engagement promotes the acquisition of cognitive skills in young children that support later learning of mathematics. The goal of the present study was to test if numerical cognition and working memory was enhanced in pre-schoolers who were actively engaged in music. The performance of two groups of children (aged 3 to 5) in numeracy, numerosity, subitizing, and memory tasks were compared. The children in the music group (n = 28) had participated in weekly 30-minute music classes for at least 6 months prior to the study. The control group (n = 28) were children attending regular preschools without any additional music classes. Older children (>= 4 years) performed significantly better than younger children (< 4 years) on most measures. A series of ANCOVAs with music group and age as factors and socioeconomic deprivation (NZDep) as a continuous covariate showed that the music group performed significantly better on several measures related to numerical cognition, including numerosity discrimination and subitizing with canonical (symmetrical) displays. Overall, these results provide evidence that musical engagement helps preschool children develop numerical cognition skills.

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Glossary

Number Sense - the ability to be able to manipulate and interpret large numerical quantities

Implicit computation - unconscious influences of knowledge on a person's ability to identify quantities and mathematical concepts, even though there is no conscious awareness of those influences

Subitizing - the ability to identify a specific quantity of things accurately just by quickly looking at them without counting

Approximate Number System (ANS) - a cognitive system that helps us estimate a magnitude of a group without needing to rely on language or symbols.

Numerosity - the ability to intuitively gauge quantities and relationships of numbers. Connected to the approximate number system (ANS).

Numeracy - the ability to grasp mathematical concepts and apply them to diverse situations.

Cognition - the process of obtaining understanding and knowledge through thoughts, senses and experiences.

Working Memory - a system within ones cognition that has an ability to old some information temporarily. It is involved in processes such as decision making and problem solving.

Chapter I

Introduction

Music refers to the combination of expressive and mathematical structures, which seem to impact human beings on both an emotional and physical level. Humans appear to have an innate psychological response to what is described as music. Responses vary, but can include visible and measurable behaviours such as dancing, singing and expressing enjoyment, in other words, actively engaging with the music in any way possible. In this paper musical engagement is understood to describe the utilization of instruments, and/or one's body or voice, to actively make music, or facilitate musical expression using the rhythm and melody of any given music.

There have been countless attempts to explain and the existence of music and why it plays such a vital role within people's lives. Cultures across the world utilize music to tell stories, calm children, and memorize both, patterns and words among other things. Everyone has been exposed to music or musical structures in some way, be that on the radio, background music in an elevator, cultural songs, or even playing an instrument. All these ways of experiencing music are based on the structure found behind what is called music.

Music works within an established foundational framework, similar to language. This specified framework consists of rhythm, tempo, pitch, melodies, and notation. Trainor & Marsh-Rollo (2019) found that things such as tempo and rhythm pave the way for other developmental milestones, and are used in other important parts of cognition, including speech and auditory understanding. It is proposed that tempo and rhythm are being used to predict essential information (Trainor & Marsh-Rollo, 2019) indicating that early development of an understanding of music is a crucial aid in the development of other important cognitive functions. This supports the idea of tempo and rhythm indicating rules related to an implicitly acquired framework of music, as suggested by Politimou et al. (2021), saying humans possess an ability to implicitly learn and acquire rules related to the aforementioned musical framework.

The concept of an implicit musical understanding leads to a sequence of interesting questions regarding the causes of the human response to music, and the brain functions associated with it. Music perception may hereby be important to mention, as it would provide a basic explanation for the innate need for exposure to music, and thus the origins of a need for the development of an implicit musical understanding – like the perception of language being able to satisfy an implicit need for communication and understanding. Koelsch et al. (2019) refer to music perception as a way of “continuously satisfying our need to resolve uncertainty” (p. 63). This idea provides an interesting point regarding music being able to provide stability and a sense of certainty due to its given structure. It leads to the argument that the expressed structure of music (i.e. tempo and rhythm) is based on mathematical concepts such as symmetry, patterns and time because of their nature of predictability and structure. Those factors provide a foundation that gives the human brain the ability to resolve uncertainty (Koelsch et al., 2019), as music utilizes repetition of a present pattern to enhance the sense of ability to predict what is coming next.

Music involves predictable patterns that brains are able to distinguish. These patterns are based on rhythm, tempo and other specified frameworks. Humans seem to also be able to universally perceive tone, pitch, harmonies and other components of music (Foran, 2009). Because of this, it can be assumed that human brains and cognition are wired in a way that enables people to naturally identify music as something comprised of a specified set of items, make predictions based on those items, and remember and work with the patterns that are provided within the established musical framework.

The temporal effects and symmetry found in music might hereby relate to the enhancing effects of music on working, as well as short- and long-term memory (Talamini et al., 2017). Symmetry is a core feature in mathematics, and can be found frequently, and consistently in music and musical structures. Research suggests that the feature of symmetry aids in consolidation of memory by enhancing continuous attractors of stable memory states leading to the facilitation of related information (Chaudhuri & Fiete, 2016). This suggests that the symmetry found in music is an important contributor to the effects found in short and long-term memory.

The rhythmic component of music has been associated with areas of the brain such as the cerebellar hemispheres, insular cortex, and cingulate gyrus (Jerde et al., 2011). These areas have been connected to the ability of rhythm to be processed uniquely, and within the area of working memory. A study by Jerde et al. (2011) identified differences in brain activity between passively listening to rhythm, and the activation of working memory when judging a target rhythm or melody, to see whether that rhythm or melody was identical to a series of other rhythms and melodies. This study showed that listening to music by itself does not engage the same brain areas as pairing the audible experience of music with a music-related task (musical engagement); this can range from identifying structures and differences in the musical piece to learning an instrument.

Learning a musical instrument is both motivating and rewarding and necessitates the development of skills in multiple areas such as fine motor skills, feedback and evaluation of behaviour, sensory perception, cognition, planning movements, and learning and memory (Weinberger, 1998). Perhaps the combination of such components and the ability to connect information to a wider range of components in order to consolidate the input provided, is what differentiates music from solving mathematical equations. Being exposed to music activates the motor cortex and its functioning, as well as auditory aspects, specifically those focused around pitch (Weinberger, 1998). These outcomes of music connect to major aspects associated with enhanced learning and working memory (Hansen et al., 2012), which will be discussed later.

Engagement with music provides the opportunity for the brain to identify the mathematical roots of music, and make use of them in ways that interact not only with working memory, but also with both short and long-term memory (Talamini et al., 2017). The use and facilitation of these building blocks of music could lead to an overall increase of implicit mathematical understanding of the world, that is, the understanding of symmetry, patterns, correlations, and number systems used within different established frameworks and in different situations.

Music and Its Effects on Memory, Language, Cognition and Mathematics

The development of the ability to apply musical concepts for the development and enhancement of other cognitive areas seems to be especially evident in early years of development (Brodsky et al., 2020), yet some studies identified no significant effects of musical engagement. Mehr et al. (2013) compared a group of 4-year-old children before and after participation in a music class for 6 weeks. No significant differences were found for several areas of cognition including visual form analysis, numerical discrimination, spatial navigation reasoning and receptive vocabulary. Schellenberg & Weiss (2013) compared musical aptitude (a cognitive predisposition to gain musical understanding and become musically skilled in the future) to several other cognitive areas including mathematics, language and general intelligence. Schellenberg & Weiss (2013) found that there is a link between linguistic ability and music aptitude, yet mathematical abilities in the academic sense seem to have no empirical support, further confirming results from Mehr et al. (2013). Although no specific effects were identified in those studies, research suggests there seems to be a more general association of music related to outcomes in cognitive functioning, especially in early childhood (Schellenberg & Weiss, 2013; Kaviani et al., 2014;Kraus et al., 2014; McDonel, 2015; Dumont et al., 2017).

Although Schellenberg & Weiss (2013) did not seem to confirm any positive effects of musical aptitude on mathematical abilities, more recent literature suggests that musicians excel in many areas and abilities compared to non-musicians related to cognitive skills, including mathematical abilities, language, visuospatial cognition and memory, and auditory tasks such as temporal and frequency discrimination, and understanding and perceiving prosody of speech (Talamini et al., 2017). The evidence regarding musical influence in early childhood throughout the more recent studies, and the differences in Schellenberg & Weiss's (2013) results, could be explained by differences related to the way musical effects had been measured and defined. The differences and inconsistencies in measurement, as well as definitions used when looking at musical engagement/aptitude between the studies could lead to inconclusive results when trying to look at the effects of music on cognition.

As the above-mentioned cognitive abilities all seem to have a causal relationship with musical ability, music must have a core foundational aspect relating all individual cognitive factors together. When looking at the cognitive skills listed above, and considering musicianship (that is, playing an instrument and having a deep foundational understanding of music as opposed to just listening to music on the radio and feeling a sense of enjoyment/having an emotional reaction), the identification and use of universal patterns appears to be underlying for each related skill.

Though a meta-analysis by Sala & Gobet (2017) only shows a small overall effect when considering the far-transfer of cognitive skills, which in turn proposes that there is no sufficient evidence to suggest a link between cognitive abilities and music skill, a closer look into further research implies some effect related to musical engagement compared to musical skill, which will be elaborated on further. Additionally, Sala & Gobet (2017) also found a slightly larger effect in transfer to skills such as intelligence and working memory.

Memory

Gupta et al., (2018) found enhanced short-term cognition following exposure to music, including an increase in global and pre-frontal lobe neural efficiency, and an increase in sustained attention. Additionally, enhanced short-term memory in musicians was shown to improve their ability to reproduce sequences of number, letters and words (Talamini et al., 2017). An influence of music on long-term and working memory has also been shown by the same meta-analysis from Talamini et al., (2017). These effects include storing and manipulating verbal information and the ability to recall information while completing a second task in working memory and verbal learning. Effects have also been found concerning long-term memory recall for both numbers and words.

Although music spans a wide range of effects on memory, there are associated developmental differences between these effects. Across all ages, short-term memory related to the reproduction of number and word sequences seems to be enhanced for musicians (Cohen et al., 2011). Musical children present with better long-term memory regarding verbal learning and recall compared to non-musical children (Chan et al., 1998), whereas adults and seniors seem to benefit from being musicians and having a musical background in the reproduction of visual and spatial sequences (working memory) (Suárez et al., 2016). These findings suggest interesting differences in the effects of music on memory in the developing and developed brain, and point towards a developmental effect regarding the influence of music on memory and cognition.

The temporal notions and the symmetry of music might hereby relate to the enhancement of working, as well as short- and long-term memory. As mentioned previously, symmetry is a core feature in mathematics and can be found frequently and consistently in music and musical structure. Research suggests that the feature of symmetry aids in consolidation of memory by enhancing continuous attractors of stable memory states, which leads to the facilitation of related information (Chaudhuri & Fiete, 2016). This suggests that the symmetry found in music is an important contributor to the effects found in short- and long-term memory. Symmetry and memory have been also found to be crucial for language development and the processing of such (Archibald, 2017; Chartier & Rey, 2020), which leads to suspect an existing link between music and language.

Language

Fiveash & Pammer (2014) have found a difference between the processing of language in musicians compared to non-musicians. Their findings suggest music and language share several resource networks including syntactic working memory, the working memory used to discriminate syntax. Musicians seem to have the highest accuracy recall in every research condition for word lists, and the lowest accuracy recall for sentences, but non-musicians had no difference between either. This may be due to differences in attention and memory related to sequences for musicians, which adds to the idea of connectivity and transfer of skills related to musicianship and cognition, possibly mediated by the effects of music on memory.

General Intelligence and Numerical Cognition

Considering the impact of music on the range of cognitive skills mentioned previously, music could be a facilitator for people's ability to learn and recognize patterns and symmetry, and consequently, their understanding of the fundamentals of mathematics (Devlin, 1994), including numerosity, numeracy and subitizing. Research has identified two major systems related to implicit mathematical understanding: the approximate number system and subitizing. The approximate number system (ANS) refers to making a reliable approximate determination of quantities; subitizing can be explained by one's ability to calculate several items accurately and rapidly.

Results from Park et al. (2016) have shown that numerosity and the ability to approximate numbers relies on innate neural mechanisms. Numerosity is hereby referred to as the ability to intuitively assess quantities and relationships of numbers (Haist et al., 2015).

A study by Wynn (1992) showed that even infants were able to distinguish specific sets of numerical values. These results support a number sense theory stating that there are biological processes related to the innate and sub-conscious ability to differentiate between numerical values and patterns, and to identify basic change in numerical values (addition and subtraction). Research has used an approximate number system (ANS) to describe this phenomenon of numerosity. Zhu et al. (2017) found, that automatic non-symbolic numerical processing begins around age 3 to 4. Ma et al. (2021) showed that students with significant hearing loss did worse on an ANS task than students with normal hearing capability. Although their finding was insignificant and the conclusion displayed that there was cognitive transfer to other areas such as visual working memory related to the outcome of ANS function, it points toward an effect of auditory availability on the outcomes of mathematical understanding related to the utilization of approximate number sense.

It is worth mentioning here that grouping and convex hull of the displayed quantities potentially have an effect on the precision of responses when utilizing the ANS (Libertus, 2019). This is similar to the ability to make sense of musical patterns and identify the symmetry defining musical structures as mentioned previously.

Another area of implicit computation and numerosity that has been differentiated from the ANS is subitizing. Subitizing has been found to activate the bilateral posterior temporo-parietal area, which suggests activation for task guidance and attention in the frontal areas and maintenance of numerical representations and spatial attention in the parietal areas (Vuokko et al., 2013). The ability to subitize has been shown to present in young children as early as 2 years old as well as in infants (Starkey & Cooper, 1995). This suggests that subitizing is an implicit skill that develops early in life. Subitizing transfers to the auditory realm, yet seems to be applied slightly differently. McLachlan et al. (2012) have found that during enumeration of harmonics and tonal quantities, one pitch could be identified and enumerated reliably. This shows that the working brain is utilising the same concept regarding ability to subitize not just for the visible, but also for the audible qualities found in music. The overlap in perception of musical structure and quantity assessment could suggest a positive effect of furthering musical engagement and understanding in relation to ANS, and subitizing abilities during initial stages of development.

McMullen et al. (2015) also showed that early numerical skills predict future mathematical performance in school later on. Mathematical abilities have also been positively correlated with working memory capacity (Bull et al., 2008). This demonstrates that it is likely for a correlation to exist between subitizing and mathematical performance, as well as changes between subitizing and enhanced working memory, which has been touched on in previous pages. This effect further supports the idea of musical effects and cognitive overlap, due to the effects of musical engagement on several areas of memory.

The human brain seems to possess a unique ability to be effectively wired and re-wired throughout a lifetime. Neurons start to connect within the first 2 to 3 years of life and then start to manifest and strengthen (Eagleman, 2015). This is important when looking at cognitive overlap, and one's ability to use structures and concepts across different cognitive and functional areas. The next section will go into more detail regarding neuroscientific evidence concerning the development of musical understanding and its connection to, and overlap with, implicit mathematics.

Neuroscientific Evidence for Cognitive Overlap, Numerical Cognition, and Musical Understanding

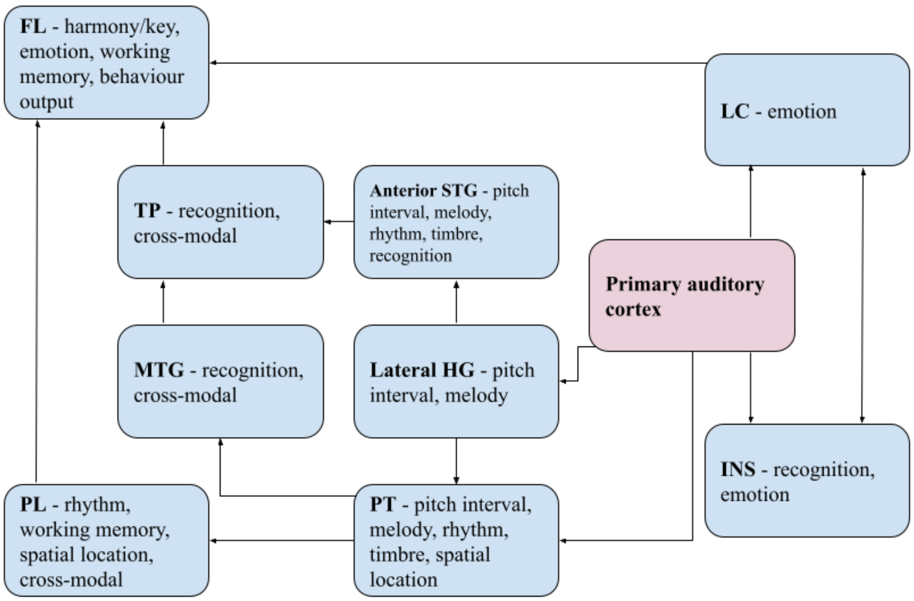
The findings expressed in previous sections related to the overlap between music and other cognitive areas have also been found within the field of neuroscience. Kühlmann et al. (2018) found that listening to music not only significantly enhanced neurogenesis and neuroplasticity in rodents, but also improved their spatial and auditory learning. The effect of music on neuroplasticity becomes important when considering the developing child. Children seem to develop an understanding for music and its constructs early in life. Corrigall & Trainor (2014) found that 4-year-old children had a neurophysiological sensitivity to key membership and harmony. The same study also showed no behavioural evidence for the same participants, which leads to the conclusion that there is some knowledge about musical properties that develops before that knowledge can be expressed explicitly. This sort of implicit, early developed knowledge about musical properties could suggest some sort of effect on other implicit cognitive structures such as number sense.

Politimou et al. (2021) looked at 5- and 6-year-olds and found that implicit musical learning may be influenced by the amount of casual musical exposure in the environment surrounding the child. Children seem to have formed robust melodic expectations at 5 years old and are able to use those internalized regularities and other domain general mechanisms (such as statistical learning) to make predictions about the music they are exposed to, which provides further evidence for the previously mentioned cognitive overlap and the role of implicit cognitive factors in such.

The understanding and processing of music is reliant on several different structures and circuits in our brains (Warren et al., 2008) which have been outlined in Figure 1. Those include connections between the primary auditory cortex, the frontal lobe, parietal lobe, limbic circuit and other areas who were primarily identified to be serving different functions, yet seem to play together in order to create the unique experience that comes with creating and consuming music. The most common overlapping functions include identification of parts of the musical framework, working memory, recognition and emotion, leading to suggest a system that is able to identify musical patterns, recognize and store them, in order to help us react to what has been identified. Figure 1 expands on the areas of music that each part takes over and how they would interlink to create said experience.

Figure 1

Brain Regions Related to Processing of Music and their Functions (after Warren et al., 2008).



Note. FL = frontal lobe; HG = Heschl's gyrus (site of primary auditory cortex); INS = insula; LC = limbic circuit; MTG = middle temporal gyrus; PL = parietal lobe; PT = planum temporale; STG = superior temporal gyrus; TP = temporal pole.

Studies related to the relevant brain areas connected to music, number sense and memory are listed in comparison below in Table 1. Chen et al. (2008) found that listening to musical rhythms activates the premotor cortex for tapping available rhythms and the cerebellum for anticipation. The dorsal part of the premotor cortex has shown to be activated for the selection of actions related to higher order rules of temporal organization. Musical rhythm has also been found to influence the encoding of visual targets into memory when played in the background. This was found by identifying an enhanced memory for targets that were in synchrony compared to out of synchrony (Johndro et al., 2019). This shows neural relations to memory as well as language and the identification of rhythm and rhythmical patterns. Additionally, evenly divisible groups of *n* tones seem to be automatically subdivided into equal groups of 2 or 3 by the brain

(Repp, 2007), which seems to be utilizing ANS and subitizing when looking at numeric quantities. This proves a human ability to transfer concepts between number sense and musical structures as well as an ability to audibly subitize.

Table 1

Compiled literature showing relevant brain areas to musical and numerical cognition as well as working memory, sorted by year.

Author	**Year**	**Outlined Cognitive Area**	**Related Brain Area**	**Comments**
Ferreri et al.	2019, 2021	Working Memory	Dopamine modulation	Dopamine controls the reward experiences elicited by music. Can enhance memory formation through musical reward (2021).
Arjmand et al.	2017	Music	Frontal Lobe	Peak frontal asymmetry response (EEG) in adults was found to co-occur with key musical events related to change within the music.
Blum et al.	2017	Music	Dopaminergic Transmission	Listening to music changes mesolimbic structures (Nucleus Accumbens) responsible for reward – dopaminergic recruitment elicited by music.
Constantinidis & Klingberg	2016	Working Memory	Prefrontal and Parietal Cortex, Dopaminergic Transmission	Working memory can be trained, training increases activity of prefrontal neurons, strength of connectivity in prefrontal cortex and between prefrontal and parietal cortex. Seems to show role of facilitation of dopaminergic transmission. Main parts in brain: Posterior superior frontal gyrus, intraparietal and superior parietal cortex; middle frontal gyrus for visuospatial WM tasks.
Haist et al.	2015	Number Sense	Parietal Cortex, Intraparietal Sulcus	Precision in parietal cortex and intraparietal sulcus with significant positive developmental trend for improved numerosity.
Vuokko et al.	2013	Number Sense	Frontal and Parietal Regions	Counting related cortical areas – frontal and parietal regions. Subitizing activation peak around 250 ms in bilateral posterior temporo-parietal area (ventral visual stream). Activation in parietal areas and then frontal areas (indicates maintenance of numerical representations and spatial attention as well as task guidance and attention).
Warren	2008	Music	Parietal Lobe, Frontal Lobe	Parietal Lobe: Working memory, rhythm, spatial location. Frontal lobe: Key, emotion, working memory, harmony.
Piazza et al.	2007	Number Sense	Intraparietal Sulcus	Activation of horizontal segment of intraparietal sulcus for number processing tasks (symbolic and non-symbolic) – suggests abstract coding of approximate number displays. Shows that symbols acquire meaning by linking neural populations which code symbol shapes to those carrying non-symbolic representations of quantity.
Popescu et al.	2004	Music	Frontal Areas	Music listening: activity in motor related areas (correlated with rhythmicity of music). Frontal areas respond with slow time constants to music – shows integrative approach of frontal areas.

Based on the research provided in Table 1, there are two main brain areas that seem to span function within all three cognitive areas: the parietal and the frontal lobes. Although these areas are quite unspecific, there does seem to be a more specific overlap related to working memory, temporal understanding, spatial reasoning, counting and perception of rhythm within those areas.

Additionally, there seems to be a connection of dopaminergic transmission between music and working memory. This may be the foundation of the findings supporting memory enhancement through several diverse ways of musical application mentioned at the beginning of this paper but more research needs to be done to find supportive effects. Although this provides some evidence for neural overlap in the processing of music, mathematics and memory, there is still a lot of research to be done in order to understand the ways these areas may or may not work together. Paucity of research in this field is also demonstrated by the lack of search "hits", concerning key words both ways, separately and together. Ideas that could be developed in the future include identifying possible connections and looking at possibilities for future interventions regarding the use of music and cognition-related conditions.

Conclusion

Music, like language, has a structure that enables humans to make sense of it, to predict and interact with what we hear. This structure is based on mathematical concepts which suggest some sort of cognitive overlap regarding implicit mathematical understanding, including pattern recognition and understanding of symmetry. There are two primary areas in previous research related to implicit numerical cognition: subitizing and the use of the approximate number system, both of which seem to mature during initial stages of development. The connection between an early understanding of musical concepts, as well as implicit mathematics, further underline a possible connection.

The previous pages have identified a range of scientific papers connected to music, mathematics, and the connection between them. Although literature points towards some type of overlap of music and several cognitive functions, there seems to be a lack of literature concerning the effects of musical engagement on the development of numerical cognition.

The Current Study

The aim of the current study was to test if active musical engagement increases number sense performance in pre-school children. Specifically, we aimed to identify relationships between musical engagement, and numerical cognition and working memory. We included several different variables related to numerical cognition, including subitizing (Leibovich-Raveh et al., 2018), the approximate number system (i.e., numerosity discrimination; Halberda & Feigenson, 2008), and numeracy (Van Der Heyden et al., 2006). An overall numerical cognition measure will be created by averaging Z scores from each measure. We hoped to be able to identify which aspects of numerical cognition were might be related to musical engagement. Additionally, a working memory task (Roman et al., 2014) was also included because previous research suggests that working memory performance can be enhanced by musical training (George & Coch, 2011).

The age range of 3 to 5 years was chosen to ensure as little knowledge about academic/school mathematics in order to assess number sense development prior to the influence of formal learning in primary school. Half of the participants regularly attended music classes (the music group), and the other half of the children were exposed to music only within the context of their pre-school programme and did not participate in classes specific to musical engagement (control). The control group was age-matched, and gender-matched as well as possible to the music group. Participants for the music group were recruited from music classes around Christchurch, New Zealand that had fulfilled the criteria for musical engagement of the child. These criteria were: participation in weekly class time of at least 30 minutes for at least 6 months, the child's engagement during that time in singing and dancing, and use of musical instruments and props. Controls were recruited primarily from two different local community preschools located in two different areas around Christchurch, New Zealand.

Chapter II

Methods

Participants

Participants were children recruited from several preschools and music groups around Christchurch, New Zealand. The final number of participants included 56 children, with 28 children in the music group (14m, 14f) and 28 for the control (14m, 14f). The age of participants was between three and five years old and groups were age matched to the best extent possible. Originally, age matching was done in 6-month age intervals. It was planned that equal numbers under and over 4 years of age would be represented in each group. This was achieved for the music group, as this group was primarily tested earlier in the year where the issues related to COVID19 were minimal in New Zealand/Aotearoa. Because of an unexpected COVID-19 lockdown, and the distress and disruption related to the virus, some parents who had younger children in the control group decided to withdraw participation. To have equal numbers across groups, relatively more children were recruited for the control group who were over 4 years of age. Thus, we planned to include age in the analysis as a factor/covariate.

Ethical approvement was obtained from the Human Research Ethics committee of the University of Canterbury as well as consent from parents and the children's assent (HEC Ref: 2021/66).

Measures

Music@Home Questionnaire

At home musical engagement was measured with the Music@Home questionnaire (Politimou et al. 2018). This questionnaire has been created specifically for children in the preschool age and has been validated for measuring children's musical behaviour (r = .49), and active musical engagement (r = .40). This survey was given to the parents with the information sheet and consent form and filled out in their own time. A 7-point Likert scale was used for all items, fluctuating from Completely Disagree (1) to Completely Agree (7). Item scores for negatively worded items were coded inversely meaning that the score for Completely Disagree (1) corresponded to the score for Completely Agree (7).

This measure has been used by other studies looking at exposure to, and engagement with early music in preschoolers with ASD (autism spectrum disorder) (Boorom et al., 2020). The study utilized the parental views in order to assess differences in engagement of children with ASD who were regularly exposed to music, and children with ASD who were not regularly exposed to music.

Final measures for statistical analyses were created using the conversion table in Excel attached by Politimou et al. (2018) in their original study (Appendix A).

Individual Subitizing Range (ISR) Measure

Children were presented with a computer program displaying frogs (between 1 and 8, either random or canonical (symmetrical)) in order to test subitizing range. This was derived from Leibovich-Raveh et al. (2018). The game was originally presented in OpenSesame software but unfortunately did not work with the current accessible version of OpenSesame. This meant that it had to be recoded in order to be used for this study. This was done in PsychoPy3 using Python. The game was recreated as to the best extent possible, however it was not possible to create a useful voice control option leading us to use keyboard response only. Children were asked to reply with the amount of frogs they saw on the screen as quickly and as precisely as possible. There was a test round provided for the child to practice the task.

In the experimental task the trial started with a red fixation point in the middle of the screen for 1,000 ms. 500 ms after the fixation point has disappeared, a target emerged for 350 ms, followed by a 100 ms mask. A slide with a text saying “how many?” appeared after that. This slide stayed until the child provided a response. The child was instructed prior to the experiment to respond as soon as they could and have a guess if they are not sure about the actual number of frogs displayed. The key response was input by the experimenter to assure a consistent delay of reaction time after the vocal response has taken place. Each participant completed four blocks of 36 trials each with breaks in between, taking up about 15-20 minutes of time.

The final subitizing range was computed using a MATLAB code which read the numerosity displays output by the program. The original code provided by Leibovich-Raveh et al., (2018) had to also be updated based on the current version of MATLAB. The final output included average reaction time as well as subitizing range based on the reaction time and a Sigmoid Fit.

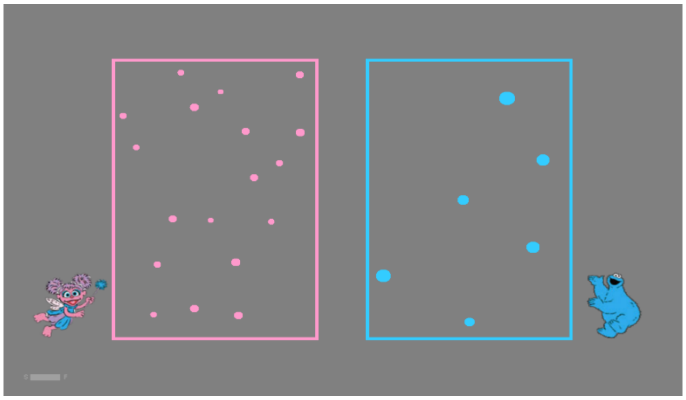
Additionally, correct rates for random and canonical responses were created using Excel in order to draw conclusions based on accuracy of symmetry within the measure, and to have an additional measurement related to subitizing range using accuracy instead of reaction time, as the way it has been created might not be as suitable for the age of the participants in this study.

Panamath – Numerosity

Numerosity and number sense were measured using Panamath (www.panamath.org), collecting correct percentage and reaction time (RT) data for ANS functioning. Panamath has previously shown to work with children as young as 3 years old (Halberda & Feigenson, 2008). Children were shown two arrays of spatially separated blue and pink dots (Figure 2).

Figure 2

Set up of Panamath Numerosity Measure.



The two arrays were simultaneously and briefly presented. Children aged 3 and 4 had the ‘super easy’ setting and children aged 5 were tested on the ‘easy’ setting. The children were then asked to click either pink or blue depending on what they perceived to be the bigger number of dots. This measure took approximately 5 to 10 minutes. The original dataset from this measure presented with reaction time, percent correct and the Weber fractions. This study used percent correct as the primary measure for numerosity due to large variability and some infinite Weber fractions, possibly due to discrepancies in responses when used with the younger children.

Working Memory - Missing Scan Task

The Missing scan task (MST) (Roman et al. 2014) was used to assess working memory in this study as Roman et al., (2014) have validated this version of the missing scan task for preschool children.

Thirty-six wooden animal toys were used as test stimuli. Animal examples in the test set included turtle, dolphin, lion, elephant, etc. The child was asked to provide a name for each animal which would be used for the remaining time of the task, in order to prevent the child from having to learn new vocabulary, providing the child used this name consistently and had separate names for each animal in the test set. If the child was not able to provide a name for the animal, the animal was not involved in the test set.

For the test set, the child sat across from the researcher where a box containing all the test animals was placed in front of the child without the child being able to see inside. The researcher explained to the child what was going to happen and that they were going to play a game involving memory. The researcher presented two randomly selected animals and placed them on the table for the child to see. This set of two was used as the practice set for each child, thus assessing the child’s ability to proceed with the game. The child was asked to name the two animals aloud and to remember the animals because they were going back where the child would not be able to see them. 10 seconds were given for the child to look at the given memory set and name them aloud before they were taken away. When the animals appeared again, one of the animals would stay behind. 2 to 3 seconds later, one animal would be presented again (chosen at random), and the child was asked to say which one was missing. The child had to then show understanding of the instructions before carrying on with the task. If the child were unable to show an understanding for the task, he/she would not continue and results will score 0. Each child would get a second trial of two animals if they did not show understanding in the first practice round. The children who successfully completed the memory set of two animals proceeded to the test sets. The memory set size increased by one animal every time the child responds correctly with the missing animal.

The child was required to scan the contents and verbally tell the experimenter the right name of the missing animal from the memory set to successfully complete the trial. The memory set size increased by one item every time an animal was correctly identified. If the child named the missing animal incorrectly, the same memory set size was trialled again with a new set of animals. In both training and test trials, the child was shown the missing animal after each trial disregarding exactness of the answer. The task finished as soon as the child failed to accurately name the missing animal after running through two trials of the same memory set size or once the correctly completed a set size of 10.

Preschool Numeracy Measure

Numeracy was tested using probes developed by Van Der Heyden et al. (2006). These were individually administered. The number sense measure includes 4 different probes shown to predict mathematics skills.

Measures include a number probe, count objects probe, free count probe, and discrimination probe. Each probe will be described in the following paragraphs. Items for each probe were arranged on laminated cards as instructed by the original experiment. There were no materials needed for the free count probe.

The following descriptions of the probes have been adjusted from the methods in Van Der Heyden et al. (2006).

Free count probe: The child was told: “I want to see how high you can count. When I say ‘go,’ count as high as you can. Ready? go.” The experimenter started timing after saying, “go,” and stopped timing once the child reached 30 or missed a number. This probe was noted down as total numbers correctly named divided by the total time to respond in seconds. Alternate form correlation for this probe was $r = .71$ (Van Der Heyden et al., 2006).

Choose number probe: The child was presented with four separate numbers equally spaced in a row on a laminated card, roughly A5 in size. The experimenter asked the child to point to a particular number. This probe was scored as correct once the child pointed to the right number. The very first number the child pointed to was noted down. This probe had 10 items, with answers of 1 to 10. Cards were randomized for each participant. This probe was scored as number of items correct divided by total time to respond (in seconds) across all test items. Alternate form correlation for choose number scores was $r = .83$ by Van Der Heyden et al. (2006).

Count objects probe: The researcher showed the child black and white pictures that were printed on a card. The experimenter asked the child to count the pictures on the card (e.g., “Count the crabs.”), and started timing as soon as the instructions were given. Correct responses consisted of the child counting the correct number of objects displayed. This probe had 10 items, with possible answers of 1 to 10. Prior to beginning the probe, the cards were shuffled. This probe was scored as total number of correct responses divided by the total time to respond (in seconds) across all items. The alternate form correlation for scores on the Count Objects probe was $r = .87$ (Van Der Heyden et al. 2006)

Discrimination probe: For this task, the experimenter showed the child four objects displayed on a laminated card (i.e., numbers, letters, shapes) and said, “I want you to choose the one that is different or does not belong.” There were 30 items in this probe and it was run for 1 minute. This probe was recorded as number correctly identified per minute. Alternate form correlation for the Discrimination probe was $r = .88$ (Van Der Heyden et al., 2006).

Baglici et al. (2010) performed a test of early numeracy containing several measures including the measures used in this study. These span a range of probes needed to assess early numeracy and will accurately represent numeracy in young children. All probes were combined in a numeracy composite score as the average of the Z scores for each probe. Similar approaches have been used in prior studies with measures such as attention, memory and children’s behaviours (Huston, 2006; Lim, 2016; Gilmore, 2017). The Z score variable ‘NumeracyZ’ will be used to determine effects on numeracy; however, results for each probe will also be presented.

A final overall numerical cognition variable was also created. Z scores for Numeracy, Panamath, ISR and both correct subitizing measures averaged to create a composite numerical cognition Z score (NumCogZ).

Socioeconomic Factor - NZDep18

Socioeconomic status was assessed using NZDep (Salmon & Crampton, 2012), describing the estimate of relative deprivation based on residential location. The scale ranges from 1 = least to 10 = most deprived. NZDep scores was derived from home addresses, home suburbs and school addresses/suburbs where available, with no data for $N = 4$.

Procedure

Parents were asked to fill out the consent form as well as the questionnaire before commencement of the games with the child. Initially our plan was to allow parents the option for home or school testing, but restrictions due to COVID-19 lockdowns posed challenges, and we endeavoured to equate the overall number of children tested at each location for both groups.

Children who were part of the music group were tested at their homes, or before or after their allocated music class, as most children went to different preschools. Testing the children in an adjacent room to where the music classes are run will provide a similar environment to the children in the control group, who were tested in a separate area at their preschools. The separate areas were used to reduce distractions as much as possible, and make surroundings between the music and control group as similar as possible in regards to distractions.

Testing sessions were limited to 30 minutes, to ensure engagement and attention of the child, and children required two separate sessions. Each child was rewarded with a sticker after completion of each game. A child who appeared to lose either attention or motivation was offered encouragement, a reward for continuing (a sticker) or the option of taking a break.

There were 16 possible testing orders when allowing for one computer based and one interaction-based game in each session. Each child was randomly assigned to one of the testing orders. The assignment of session to game allocations was as follows, and was reflected in the last digit/s of the child's identification number (Table 2).

Table 2

Session and Game Allocations and the matching Identification (ID) number

Session to game allocation	ID Number	Session to game allocation	ID Number
AC BD	1	BD AC	9
CA BD	2	BD CA	10
CA DB	3	DB CA	11
AC DB	4	DB AC	12
AD BC	5	BC AD	13
AD CB	6	CB AD	14
DA CB	7	CB DA	15
DA BC	8	BC DA	16

Note. Panamath (A), ISR (B), Numeracy (C) , Working memory (D)

At the end of both sessions, a $20 grocery voucher was given to each family to thank them for their participation.

Data analysis

Data were analysed using SPSS 27. After descriptive analyses and basic correlations, a *t* test was conducted for each measure to compare music and control groups. These comparisons were repeated with a series of analyses of covariance (ANCOVAs) which used group as a factor and socioeconomic deprivation (NZDep) as a continuous covariate.

Outlier screening was conducted by calculating Z scores for each measure and identifying potential outliers as $Z > 2.0$. Due to incomplete results for some participants in the ISR measure, 5 data sets had to be excluded from the analysis, reducing the number of participants for the ISR measure to 51.

Chapter III

Results

No outliers were identified. Analyses showed no significant effects of testing at home or school and so results presented below are pooled across locations. One child (m) in the music group completed half of the measures and was only included in the appropriate analyses.

Descriptive statistics for both groups are presented in Table 3. As expected, the general factor of the Music@Home measure was significantly greater for the music (M = 101.18) compared to control group (M = 92.46), $t(54) = 2.898$, $p < .01$, $d = .78$. However, socioeconomic status (NZDep) was significantly lower for the control group (Ms = 6.69 and 4.63), $t(54) = -3.408$, $p = .001$, $d = -.913$. This shows that children enrolled in music programmes also had a richer musical environment at home. Perhaps not unexpectedly, the music group also had lower levels of socioeconomic deprivation.

Descriptive statistics for study variables are shown in Table 3 separately for music and control groups. t tests and effect sizes are also included. Table 3 shows that for measures related to numerical cognition and working memory, average scores were always greater for the music group (with the exception of CountObj, where averages were equal), but not significantly so. The general trend for scores related to numeracy to be overall greater for the music group was demonstrated by the NumeracyZ score, where the means were 1.16 and 1.02, $d = .269$, but the difference was not significant ($p = .33$).

Table 3

Means, standard deviations and sample sizes for numerical cognition, working memory (WM) and music measures divided by groups.

	Music			Control			t	Effect size (d)
	M	SD	N	M	SD	N		
NZDep	4.63	2.54	30	6.69	1.87	26	-3.341*	-.913
WM	3.11	1.71	28	2.75	1.92	28	0.736	.197
General Factor (Music@Home)	101.18	11.61	28	92.46	10.9	28	2.898*	.775
Numerosity %corr	82.86	14.73	28	77.6	16.00	28	1.28	.342
ISR	2.76	1.89	25	2.19	1.36	26	1.244	.349
ISR Correct random	29.48	7.44	25	27.58	5.95	26	1.011	.283
ISR Correct canonical	35.72	10.21	25	31.88	9.39	26	1.397	.391
Choose NR	0.16	0.11	27	0.13	0.10	28	0.95	.256
Count Obj	0.13	0.05	27	0.13	0.05	28	0.52	.140
Free Count	2.30	1.21	27	1.09	0.59	28	0.768	.207
Discr	0.10	0.07	27	0.07	0.08	28	1.184	.319
Numeracy Z	1.16	0.48	27	1.02	0.54	28	0.999	.269

Note. * p <.05

As noted in the Method, the music group had the same number of children >= 4 years of age and < 4 years (*ns* = 14), whereas the control group had more children >=4 years (*n* = 20) than < 4 years (*n* = 8). Although this difference was not significant, χ^2 (1, *N* = 56) = 2.695, *p* = .101, it represents a potential confound in the group comparisons, along with the previously noted differences in socioeconomic deprivation (NZDep).

Table 4 shows correlations of age group (< 4 years = 0, >= 4 years = 1) and NZDep with measures of working memory and numerical cognition. Age was significantly correlated with working memory, NumeracyZ, numerosity (%correct), random and canonical correct measures (subitizing), showing that older children performed better. By contrast, NZDep was not significantly related to any measure, although most correlations were negative, suggesting that higher deprivation was associated with lower scores on working memory and numerical cognition.

Table 4

Correlations of Age group (< 4 years, >= 4 years) and NZDep with variables related to numerical cognition and working memory.

	Age Group	NZDep	N
	r	r	
WM	.210	.000	56
NumeracyZ	.240	-.068	56
Numerosity %corr	.492**	-.233	56
ISR	.044	-.188	51
Correct ran	.381**	-.054	51
Correct can	.407**	-.060	51

Note. † p = .05, * *p* < .05, ** *p* < .01, *** *p* < .001. WM = Working memory, NumeracyZ = Numeracy, NumCogZ = Numerical cognition, Numerosity %corr = Percent correct (Panamath), ISR = Individual Subitizing Measure, Correct can = correct canonical (ISR), Correct ran = correct random (ISR).

Next, a series of univariate ANCOVAs was run to compare performance on measures of working memory and numerical cognition between the music and control groups. Age group was included as a factor and NZDep as a continuous covariate. Means for music and control groups adjusted for NZDep are shown in Figure 3.

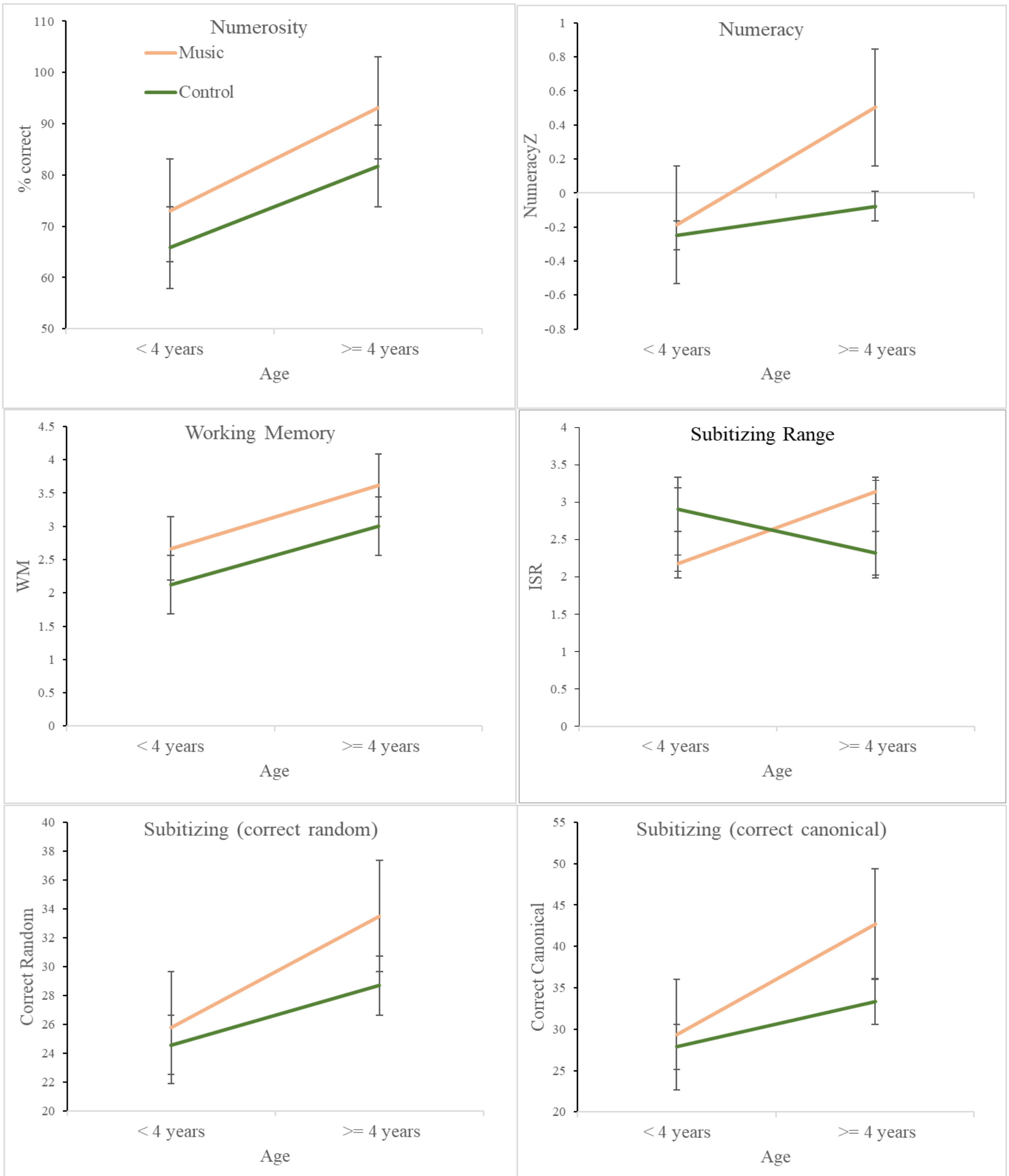
Figure 3 (upper left panel) shows Numerosity (Panamath % Correct) scores. Overall, Panamath %Correct scores were greater for the music group and for older children. This observation was confirmed by an ANCOVA which found significant effects of music ($F(4, 1) = 4.733$, $p = .035$, $\eta p2 = .091$) and age ($F(4, 1) = 21.046$, $p < .001$, $\eta p2 = .309$). Neither the group x age interaction or the effect of NZDep (covariate) was significant (*ps* = .597 and .494).

Figure 3 (upper right panel) shows NumeracyZ scores. Average scores were greater for older children and for the music group, but the effect of age only approached significance ($F(4, 1) = 3.698$, $p = .061$, $\eta p2 = .074$), while the effects of music group, the interaction and the covariate NZDep were not significant (*ps* = .256, .228 and .970 respectively).

Working memory (Figure 3, center left panel) scores were greater for the music group and older children, but the effects of age, music/control and the interaction were not significant (*p*s = .095, 501, and .932, respectively). NZDep was also not significantly related to working memory ($p = .733$).

Figure 3

Adjusted means for music and control groups from ANCOVA with NZDep as a covariate.



Note. Error Bars: 95% CI

Subitizing range is shown in the center right panel of Figure 3. Subitizing range did not vary systematically across groups or age – none of the effects in the ANCOVA were significant (*p*s for music, age, the interaction and NZDep were .933, .727, .152 and .293 respectively).

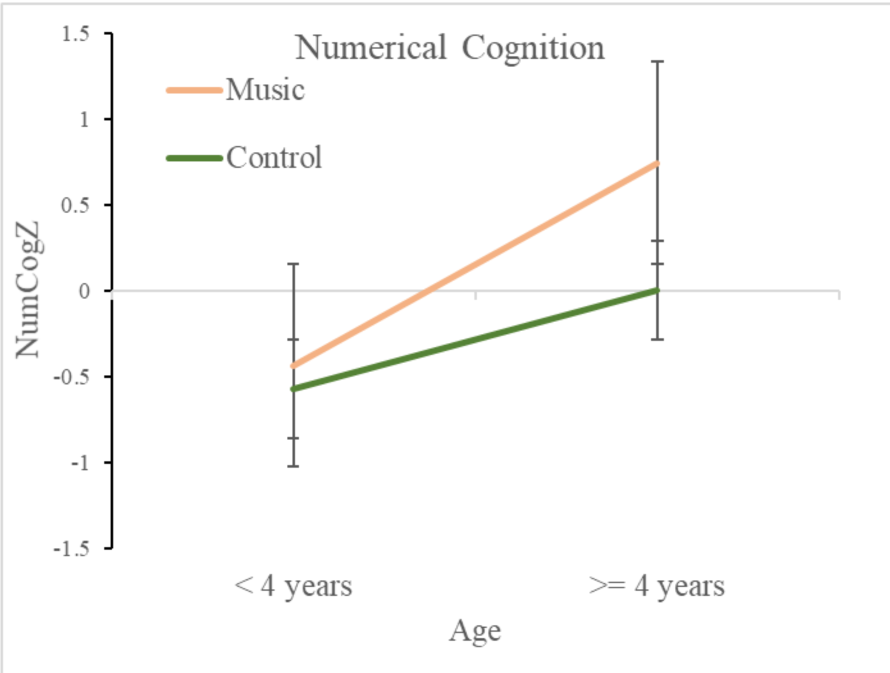
Correct random identifications (Figure 3, bottom left) of numbers during the subitizing task were significantly greater for older children, age ($F(4, 1) = 9.049$, $p = .004$, $\eta p2 = .177$), but the effect of music group was not significant, $F(4, 1) = 2.768$, $p = .104$, $\eta p2 = .062$. Both the interaction and covariate (NZDep) were not significant, *ps* = .384 and .673, respectively.

Correct canonical identifications in the subitizing test are shown in the Figure 3, lower right panel. Overall, scores were greater for the music group and for older children. The ANCOVA confirmed this observation with significant effects for music group ($F(4, 1) = 5.851$, $p = .020$, $\eta p2 = .122$) and age ($F(4, 1) = 15.203$, $p < .001$, $\eta p2 = .266$). Neither the group x age interaction or the effect of NZDep were significant (*ps* = .257 and .484).

Overall numerical cognition (NumCogZ) scores are presented in Figure 4. Scores were greater for the music group and for older children, and confirmed by an ANCOVA which found significant effects of music group ($F(4, 1) = 4.759$, $p = .034$, $\eta p2 = .094$) and age ($F(4, 1) = 16.321$, $p < .001$, $\eta p2 = .262$). The interaction and covariate (NZDep) effects were not significant (*ps* = .143 and .784).

Figure 4

Adjusted means for music and control groups for NumCogZ scores by age, with NZDep as a covariate.



Generally, results in Figures 3 and 4 show that scores for number sense (Panamath) and correct canonical variables in the subitizing test, as well as the overall numerical cognition Z score were significantly greater for the music group and for older children. These effects were independent, as none of the interactions were significant, and unrelated to differences in socioeconomic deprivation. This suggests a positive effect of musical engagement on the development of numerical cognition, especially numerosity/the approximate number sense and accuracy for identifying canonical/symmetrical quantities below eight.

Table 5 displays a summary of the effect sizes presented in the analyses run above for music group and age. Significant effects were found for age and group factors for Numerosity (percent correct), correct canonical subitizing and the final numerical cognition measure. The effect of age was also significant for correct random subitizing. Overall, effect sizes were greater for age than music group, although the significant effects for music group were still medium to large in terms of conventional interpretations. Overall Table 5 suggests that there was a very large developmental effect on some study measures, and medium to large effects of music group.

Table 5

Effect size ($\eta_p 2$) and significance (p) of age and group effects in ANCOVAs for each variable.

	Music Group		Age (< 4; >= 4)	
	ηp2	*p*	*ηp2*	*p*
Numerosity %corr	.091	.035*	.309	<.001***
NumeracyZ	.028	.256	.074	.061
WM	.010	.501	.058	.095
ISR	.000	.933	.003	.727
Correct Ran	.026	.104	.177	.004**
Correct Can	.122	.020*	.266	<.001***
NumCog Z	.094	.034*	.262	<.001***

To examine relationships between measures of numerical cognition and working memory, Table 6 shows partial correlations controlling for age group. Measures related to numeracy (except free count), working memory and numerosity (percent correct) were positively correlated as well as correct canonical subitizing (p = .05). Numerosity (percent correct) also seems to be correlated to the majority of numeracy measures, as well as both correct random and correct canonical arrangement for subitizing. Overall, results in Table 6 suggest that with the exceptions of ISR and free count, measures of numerical cognition and working memory were correlated after controlling for age group.

Table 6

Partial correlations (age group) between measures of working memory and numerical cognition.

	WM	Choose Nr	Count Object	Free Count	Discr.	Numerosity %corr	ISR	Correct Ran
WM								
Choose Nr	.252							
Count Obj	.360**	.615***						
Free Count	.163	.151	.118					
Discr.	.197	.626***	.613***	.172				
Numerosity %corr	.305*	.565***	.501***	.094	.389**			
ISR	.098	.117	.181	.066	.101	.206		
Correct Ran	.244	.493***	.472***	.145	.272†	.452***	.237	
Correct Can	.277†	.641***	.490***	.071	.430**	.570***	.204	.624***

Note. † p = .05, * p > .05, ** p > .01, *** p > .001

Chapter IV

Discussion

This project assessed the effects of musical engagement on the development of numeracy skills and numerical cognition between children who attended musical engagement classes for at least 6 months, and children who attended regular preschool without any extracurricular musical activities. Our major question was whether children in the musical engagement group would show greater proficiency at measures related to numeracy and numerical cognition, suggesting that childhood musical training might facilitate the development of cognitive skills necessary for mathematics learning.

Overall, results showed that the musical engagement group had higher scores on several measures related to numeracy and numerical cognition after controlling for effects of age and socioeconomic deprivation. Results specifically showed significance between groups and numerosity, as well symmetrically displayed quantities below eight, showing the largest effect sizes for both Numerosity %correct and correct identification of canonical (i.e., symmetrical) displays. Results for random displays, although not significant, were overall similar to those for canonical arrangements. The effects of musical engagement on abilities related to pattern recognition and symmetry and their established influence on each of the implicit computational panes (Gilmore et al., 2018) may explain these results. Identification of small exact quantities seem to be enhanced by musical engagement, but the subitizing range did not seem to be affected. While subitizing is related to understanding of numbers and focused on the correct identification of small quantities, the approximate number system only considers familiar patterns and the idea of symmetry in order to identify the correct quantity. This concept is more likely to be found within music when compared to the concept of subitizing, potentially due to the rhythmical aspect found in music. While ANS and subitizing share cognitive functions, the results found in this study show that there might be different developmental processes involved in shaping each area individually. It could also mean that the skill of identification of patterns and pattern recognition does not transfer between ANS and subitizing within the first few years of development, and that these are two distinct areas that develop independently in the first few years of life. However, the connection between both areas is supported by the significant positive correlation between ISR and numerosity discrimination (Panamath) which indicates some general combined functioning early on and further confirms the idea of symmetry and patterns being involved in our processing of quantities (Chaudhuri & Fiete, 2016, Koelsch et al., 2019).

Working memory performance did not differ significantly between music and control groups ($\eta_p^2 = .01$), contrary to expectations based on previous research which suggests that musical engagement supports working memory (Talamini et al., 2017). This result could have been affected by the age tested in this study. As this is the first study looking at the effects of musical engagement on working memory at an age this young, one might suppose that the effects of musical engagement/musicality on working memory need to be strengthened by time, repetition and exposure throughout several years, before showing any overlapping function or effects. The study by Talamini et al. (2017) mentioned that there is a stronger effect of music on long-term memory in children, which suggests a need for further research regarding the effects of musical engagement on long-term memory and the connections between long-term and working memory. Additionally, the working memory task used in this study required more verbal interaction by the children, whereas the measures resulting in the largest effects of music group (numerosity % correct and correct canonical) did not have a high number of verbal requirements. This could suggest that musical engagement enhances performance related to more non-verbal tasks compared to tasks with a higher verbal load that early in development, with verbal tasks and related cognitive overlap developing slightly later.

The results of the present study regarding working memory and number sense provide evidence for cognitive overlap and transfer of skills, and may also be correlated to the previously highlighted symmetry and pattern recognition (Pieroni et al., 2014).

Numerosity and approximation as mentioned at the beginning have been found to activate areas in the intraparietal sulcus. Research demonstrates impairment in this area for people with developmental dyscalculia (Szucs et al., 2013). Developmental dyscalculia also comes with an impairment in pattern recognition (Gilmore et al., 2018). Both of these aspects are also connected to our processing of music and rhythm. Music has shown to partially affect parietal regions as well (Warren, 2008). This, combined with the significant behavioural effects presented in this study related to musical engagement and approximate number sense specifically, provides a foundation for possibilities concerning the utilisation of musical training in order to help children with developmental dyscalculia. For children who have difficulties with learning maths, music may help to activate processing in the parietal regions, and transfer pattern recognition skills to activate numerical cognition.

Limitations

Some limitations to this study include the confounding variables related to between group design. As this study was conducted with pre-schoolers, there are several confounding variables between groups. These include parental presence, attention span and motivation as well as testing location and age. Testing location, and with that, parental presence, as well as age did not seem to affect the data as there was no significance detected, yet there was no measure to ensure attention did not interfere with data collection. Attention could have affected the collection of data during the subitizing measure, as the measure required the child to be doing a repetitive computer-based task for at least 15 minutes. Additionally, the lack of measures found in the present literature related to the current sample age limited the ability to choose accurate and valid measures, especially related to musical engagement and subitizing. There was no correlation between ISR and any of the variables nor the free count probe and any other variables. This could be due to the limitations that come with using this measure on young children and the lack of reliability in their response time, possibly due to lack of attention or ease of distraction in that age group. To mitigate this, the correctness for random and canonical objects were used as well as the original measure. A follow-up study could look at developing a way of utilizing the ISR measurement setup and adjusting the analysis to use accuracy instead of reaction time. The Music@Home scale posed several issues related to measurement of the present variable of musical engagement. Although it covers a range of areas and has been chosen due to the ability of preschool aged measurement, it could use some refining related to their confirmatory analysis and external validity of the scale.

The sample size was limited due to the time restraint on this project which could restrict detection of significance and effect sizes. Additionally, because the distinct difference between groups was an (at least 6 months) attendance to a musical play class, and our measure for socioeconomic factor showed significance between groups, it is important to note that there could still be a confound of socioeconomic status or other variables connected to that, as the music classes required paid entry and a more reliable measure of socioeconomic status (e.g. household income) had not actively been recorded for this study. This confound was accounted for as accurately as possible, given the data provided in this study, however more accurate measures could influence these results and should be explored in future research. Parental involvement and the investment in the child's life regarding the child's education and attention toward the child could have also factored into the results found in this study due to the creation of a richer environment, regardless of their socioeconomic status.

Even though running a study with preschoolers includes a lot of limitations, this kind of work is crucial for identifying and building on areas of cognition during all stages of development. This is because of the significance in positive outcomes when using early interventions in several different areas of deficits presenting early on, including autism and anxiety (Mifsud & Rapee 2005, Estes et al., 2015). These early intervention programmes can only be developed and justified with existing knowledge about early development of cognitive areas including numerical cognition and number sense.

Future Directions

This study has expanded insight into the processes considering the development and processes of numerical cognition and its correlation to musical engagement, as well as working memory. To further explore this area of research, future studies should explore the effects and significance of convex hull and symmetry on one's ability to utilize implicit mathematical concepts. Symmetry, and the identification of, could be a significant part involved in cognitive functioning and related issues that may arise such as dyscalculia and possibly even dyslexia. Although language has not been a primary variable in this study, research suggests an even stronger link between language and musical engagement (Papadimitriou et al., 2021). The significance of patterns and symmetry in numerical cognition and working memory could explain the previously identified correlation of language and music and therefore may open opportunities for the use of music during early interventions related to dyslexia.

Additionally, the differences and similarities between subitizing and the ANS would provide more precise understanding of cognitive processes during developmental stages, and further understanding could help create a more precise understanding related to cognitive overlap and functions. This would help create treatment and intervention plans reaching into areas related to dyscalculia, dyslexia, and other learning difficulties.

Further research related to the effects of musical engagement on mathematical understanding could be explored with a slightly older age group such as 5 to 7 and/or a larger pool of participants in order to clarify the significance of patterns and symmetry on cognitive transfer of skills and the effects of musical arrangements on other areas of cognition. Additionally, fMRI (functional magnetic resonance imaging) could be used to identify the brain processes involved in the overlap of mathematical and musical cognition, and development.

Conclusion

The present study found that musical engagement in preschool children is associated with improved performance on some aspects of numerical cognition – specifically approximate number sense and subitizing. To our knowledge, this is the first evidence that engagement with music might promote ‘number sense’ and related cognitive skills that scaffold the later learning of mathematics in preschool children (Dehaene, 2011). Effects were found in children as young as three years old, which demonstrates a relationship between early development of basic numerical cognition and musical understanding. Although working memory was correlated with measures of numerical cognition, it was not related to musical engagement.

This study examined cognitive performance during early stages of development and provided support for early musical engagement to enhance children's development of numerical cognition skills. The benefit of early musical engagement may be that it promotes an understanding of pattern and symmetry, which is relevant for cognitive processing. Future research should continue to explore whether musical engagement increases early development of numerical cognition and related skills.

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Appendix A

Music@Home scale items and questions from Politimou et al. (2018).

	Parental beliefs	**1=positive/0=negative**
1	I believe that children should learn to play an instrument	1
2	I believe that music is part of a well-rounded education	1
3	My child was deliberately sung to/exposed to music whilst in the womb	1
4	I believe music has an impact on my child's intelligence	1
5	I think musical activities are important for learning to communicate	1
	Child's active engagement	**1=positive/0=negative**
6	My child enjoys making sounds/interacting with musical instruments (including toy ones)	1
7	My child rarely makes music	0
8	My child does not use objects to intentionally produce sounds	0
9	My child enjoys toys with musical features	1
	Parent initiation of musical behavior	**1=positive/0=negative**
10	I sing in playful contexts to/with my child at least once a day	1
11	I sing to/with my child in many different situations (e.g. during playtime, with friends and fami	1
14	I make music with my child (including toy instruments) almost everyday	1
15	I do not make music with my child (including toy instruments) more than once or twice per w	0
	Breadth of musical exposure	**1=positive/0=negative**
16	My child is exposed to a broad range of musical styles at home (e.g. pop, rap, dance, classical	1
17	I sing all different types of songs to my child (e.g. adult songs, traditional folk songs)	1
18	I would only expose my child to "children's music"	0
19	I sing mostly children's songs or lullabies to or with my child	0
	General Factor - Music at Home	**1=positive/0=negative**
1	I believe that children should learn to play an instrument	1
2	I believe that music is part of a well-rounded education	1
3	My child was deliberately sung to/exposed to music whilst in the womb	1
4	I believe music has an impact on my child's intelligence	1
5	I think musical activities are important for learning to communicate	1
6	My child enjoys making sounds/interacting with musical instruments (including toy ones)	1
7	My child rarely makes music	0
8	My child does not use objects to intentionally produce sounds	0
9	My child enjoys toys with musical features	1
10	I sing in playful contexts to/with my child at least once a day	1
11	I sing to/with my child in many different situations (e.g. during playtime, with friends and fami	1
14	I make music with my child (including toy instruments) almost everyday	1
15	I do not make music with my child (including toy instruments) more than once or twice per w	0
16	My child is exposed to a broad range of musical styles at home (e.g. pop, rap, dance, classical	1
17	I sing all different types of songs to my child (e.g. adult songs, traditional folk songs)	1
18	I would only expose my child to "children's music"	0
5	I sing mostly children's songs or lullabies to or with my child	0