

Scaling early music: longitudinal evaluation of music perception skills in a large cohort of 5-year-olds

Manon Couvignou^{1*}, Julie Pereira^{2*}, Jonathan Bolduc^{3,4}, Nicholas E.V. Foster³, Isabelle Peretz³

*Equally contributed to the work

¹URL 4072 – PSITEC – *Psychologie: Interactions, Temps, Émotions, Cognition*, Université de Lille, Lille, France

²Centre de Recherche sur les Inégalités Sociales (CRIS), Institut d'études politiques de Paris, Paris, France

³International Laboratory of Brain, Music and Sound Research (BRAMS), University of Montreal, Montreal, Canada

⁴Faculty of Music, Canada Research Chair in Music and Learning, University Laval, Quebec, Canada

Author Note

Manon Couvignou <https://orcid.org/0000-0002-6652-5286>

Julie Pereira <https://orcid.org/0009-0006-0060-1764>

Jonathan Bolduc <http://orcid.org/0000-0001-9737-6175>

Nicholas E.V. Foster <https://orcid.org/0000-0002-5406-3109>

Isabelle Peretz <http://orcid.org/0000-0003-3572-0262>

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Correspondence concerning this article should be addressed to Isabelle Peretz, International Laboratory of Brain, Music and Sound Research (BRAMS), Université de Montréal, Département de psychologie, C.P. 6128, succ. Centre-ville Montréal, QC H3C 3J7. Email: Isabelle.Peretz@umontreal.ca

Abstract

Despite widespread interest in the developmental benefits of music education, few objective tools are available to assess musical abilities in children under six. We developed a child-friendly tablet version of the Montreal Battery of Evaluation of Musical Abilities (MBEMA), comprising tests of melody discrimination, rhythm discrimination, and musical memory, lasting about 15 minutes. In Study 1, 191 children aged 5–6 years from Canada and Belgium completed the battery twice. The MBEMA showed good sensitivity to individual differences, acceptable test-retest reliability, age-related improvements, and significant associations with musical training, particularly for rhythm processing. In Study 2, the battery was administered longitudinally to 1,817 preschoolers from socioeconomically disadvantaged schools in France participating in an early violin education program. Despite near-chance baseline performance in many children, the assessment proved feasible for large-scale field testing, captured substantial individual variability, and was sensitive to changes over 18 months. Children receiving violin training did not improve more than those in the comparison group, suggesting that broad perceptual musical abilities may not be the earliest or most sensitive outcomes of instrumental training. Overall, the tablet MBEMA provides a reliable, engaging, and scalable tool for assessing musical abilities in preschoolers. It is freely available for future research.

Keywords: music perception, music memory, test battery, preschool children, tablet-based assessment

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The belief that music is good for brains and cognitive abilities (“makes you smarter”) has become folk wisdom. Consequently, policy makers and educators frequently ask when children should begin formal music instruction to maximize long-term benefits, including academic success. Recommendations often emphasize the preschool years, a period of rapid brain maturation and heightened developmental plasticity during which experience can have long-lasting effects on the organization of sensory, motor, and higher-order brain networks (Brown & Jernigan, 2012; Penhune, 2021). Consistent with this view, a recent meta-analysis of 22 studies (1,734 children) concluded that music training led to greater improvements in attentional control than other structured activities, including sports, visual arts and drama (Jamey et al., 2024).

Yet, as emphasized in a recent critical review by Schellenberg and Lima (2024), the evidence that music training causes cognitive benefits remains limited. Much of the literature relies on correlational or exploratory findings that cannot disentangle the effects of training from pre-existing individual differences in cognitive ability, personality, or musical aptitude. Moreover, existing accounts of transfer remain largely descriptive rather than theory-driven, offering few testable mechanisms through which engagement with music could transfer to domains such as language acquisition, reading and calculating. Without such mechanistic accounts, the literature remains vulnerable to biased interpretations and selective emphasis on positive findings, and it is difficult to identify when, why, and for whom transfer effects should be expected.

Addressing these limitations requires measurement of musical progress and above all, of musical skills prior to training. Such measures can help to distinguish the contribution of pre-existing musical aptitude from those more plausibly attributable to training (Schellenberg & Lima, 2024). In addition, measuring different components of musical ability can help identify which aspects are most predictive of non-musical cognitive improvements and academic outcomes.

Children are not equally musical from the start. Access to music education remains uneven, and children differ markedly in the extent to which they engage with and benefit from musical training (Mak & Fancourt, 2021). Multiple sources, including genetic factors, cognitive abilities, practice, and the educational environment, may contribute to these individual differences (Hambrick & Tucker-Drob, 2015; Wesseldijk et al., 2019). Moreover, progress in music is unlikely to be uniform across core components such as melody processing, rhythm processing, and musical memory. Indeed, evidence suggests that different musical skills are shaped by partly distinct developmental trajectories and are differentially influenced by factors such as age of training onset, cognitive abilities, and practice (Ireland et al., 2019). Characterizing this variability early in development is essential for identifying which components of music training might plausibly drive downstream benefits for learning and for constraining claims of transfer to non-musical abilities.

Achieving these aims depends on validated, objective tools that can quantify musical abilities in preschool children, that is, below 6 years of age. Although several studies have successfully assessed musical abilities in preschool-aged children using age-appropriate experimental tasks (e.g., Anvari et al., 2002; Degé et al., 2015; Christiner & Reiterer, 2018; Ozernov-Palchik et al., 2018; Politimou et al., 2019; Hutchins, 2018), these tasks are generally tailored to the aims of individual studies rather than developed as standardized assessment instruments for broader use. Consequently, they typically focus on a limited subset of musical abilities, such as melody perception

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or singing, and their psychometric properties have rarely been the primary focus of investigation. Moreover, the diversity of paradigms used across studies makes comparisons between findings difficult.

Recent efforts have led to the development of standardized screening instruments, such as the Child Musicality Screening (CHIMUS), a brief parent- or teacher-report questionnaire for children aged 3–10 years (Buren et al., 2025). While such tools provide valuable information about children's overall musicality, they rely on informant reports rather than direct assessment of musical performance. As a result, validated objective, performance-based measures specifically designed for preschool-aged children remain scarce.

Here we introduce a child-friendly tablet-based assessment designed for this purpose. The tool is a simplified adaptation of the Montreal Battery of Evaluation of Musical Abilities (MBEMA), a standardized test developed to assess musical abilities in children, typically aged 6–8 years (Peretz et al., 2013). Children judge whether two successive short melodies are the same or different, and then complete a recognition task in which they indicate whether they have heard each melody previously. The tablet adaptation preserves the core logic of the original battery while reducing task demands to accommodate younger participants.

A major advantage of building on the MBEMA framework is continuity with an instrument whose psychometric properties are well documented and whose design is closely related to more elaborate versions (e.g., the MBEA; Peretz et al., 2003) and to online adaptations (Peretz & Vuvan, 2017), that is largely used across laboratories and across continents, including Western Europe, North America and China. The resemblance across Montreal batteries supports longitudinal designs spanning early childhood into the school years, facilitating the study of developmental trajectories and training-related change with comparable metrics across time.

The tablet version of the MBEMA also builds on its established use with special populations. The MBEMA has proved useful for identifying musical disorders such as congenital amusia (Lebrun et al., 2012; Mignault Goulet et al., 2012) and for characterizing musical abilities in children with other neurodevelopmental conditions, such as developmental dyslexia, developmental language disorder, developmental cerebellar disorders, and autism (e.g., Clément et al., 2015; Couvignou & Kolinsky, 2021; Couvignou et al., 2023; Guinamard et al., 2022; Sharda et al., 2018).

The MBEMA has also been used in intervention studies to characterize training-related changes in musical abilities in deaf children with cochlear implants (Good et al., 2017). Related measures have also been used in music-education programs for school-aged children from socioeconomically disadvantaged backgrounds to assess changes in musical abilities alongside broader cognitive outcomes. After 18 months of orchestral training, Barbaroux et al. (2019) reported pre-to-post improvements on the melodic and rhythmic tests of the MBEMA, as well as in general intelligence, processing speed, concentration, and reading accuracy. Although performance was standardized against age-based norms, the absence of a control group limits the extent to which these improvements, particularly those in music perception, can be attributed to the intervention. Gutiérrez Cisneros et al. (2023) found no specific improvement on abbreviated melodic and rhythmic tasks adapted from the MBEA following a 10-month school-based singing intervention, although improvements were reported in singing performance, processing speed and reading.

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Here, we address the validation and longitudinal application of the new tablet MBEMA in preschool children. Study 1 evaluates the reliability and validity of the tablet MBEMA in preschool children from Canada and Belgium. Study 2 illustrates the applicability of the battery to large-scale longitudinal research within the socioeconomically disadvantaged preschool cohort studied by Pereira and Coulangeon (2026).

The MBEMA on tablet

The MBEMA on tablet was developed to assess musical abilities before the age of six. The battery is very similar to the older MBEMA (Peretz et al. 2013) and includes three tests presented in the following order: a *melody* discrimination test, then a *rhythm* discrimination test, and finally a *memory* test.

In the *melody* test, the child is invited to tell if two short melodies are the same or different by pressing either a button with two bees for the “same” response or a button with one bee and a beetle for the “different” response (see Figure 1A). In the subsequent *rhythm* test, the background changes. The child has to choose between two rockets for “same” or one rocket and a plane for “different” (Figure 1B). The third and final test assesses recognition *memory*. After each melody, the child is invited to press a teddy bear for “yes, I have heard that melody before” or a frog for the “no” response (Figure 1C). Completion of the battery takes about 15 minutes.

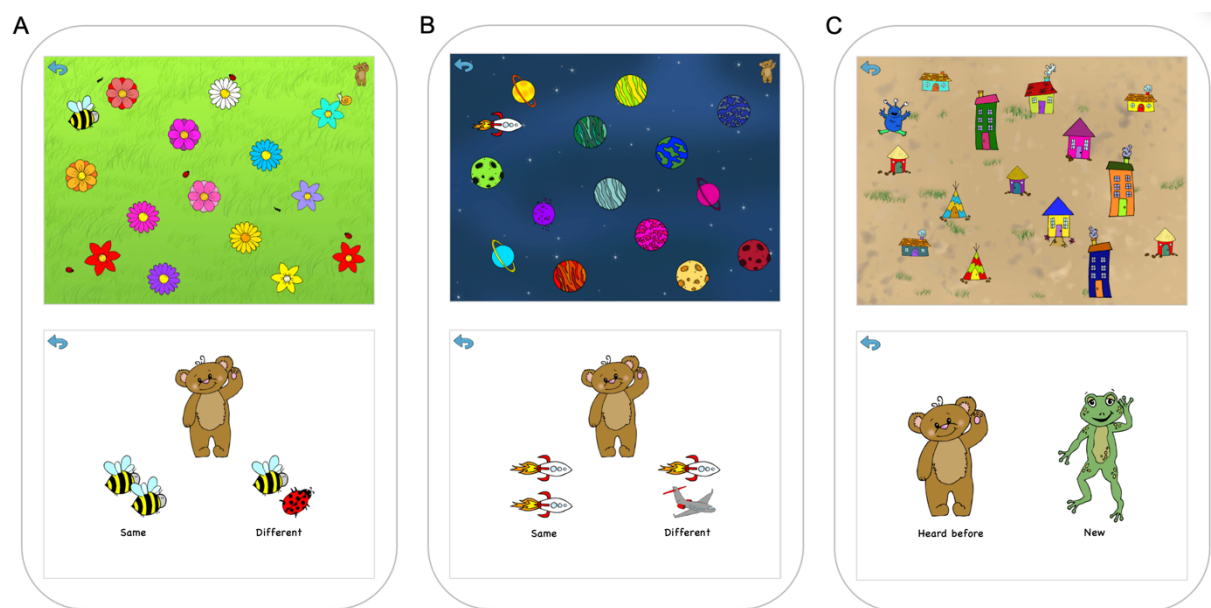


Figure 1. Illustration of a trial in the (A) *melody*, (B) *rhythm*, and (C) *memory* test. For each test, the upper panel shows the screen that allows the child to listen to the melodies and the lower panel shows the response choice.

All tests use the same set of 18 computer-generated melodies that are taken from the MBEMA (Peretz et al., 2013). They contain 5-9 notes and last 3-4 seconds.

In the *melody* and *rhythm* test, each trial consists of one standard melody followed by a comparison melody after a 1.5-sec silent interval. Each test comprises two practice trials and 12 test trials (6 same and 6 different). In any given trial, the stimuli are presented with the same timbre, whereas the timbre changes from one trial to the next.

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Ten different timbres (e.g., piano, marimba, guitar, flute) are used to make the tests as engaging as possible. The trials are presented in a fixed order with no more than three successive trials of either same or differing stimuli.

In the *melody* test, three types of changes are applied to six differing melodies. Two comparison melodies are different by one out-of-key note while retaining the original melodic contour (i.e., a scale violating change; Figure 2A); two comparison melodies have one changed note that alters the pitch direction of the surrounding intervals while maintaining the original key (i.e., a contour-violating change; Figure 2B); two comparison melodies have one changed note that alters two intervals while preserving the original contour and key (i.e., an interval-violating change; see Figure 2C). The serial position of the modified note varies across melodies and never occurs in the first and last position. Average pitch interval changes are equivalent across the three types of pitch changes, with a mean of 1.5 (range: -1 to +2), 4 (-4 to +4) and 4 (-4 to +4) semitones from the original pitch for *scale-violating*, *contour-violating*, and *interval-violating* changes, respectively.

In the *rhythm* test, the manipulation consists of changing the duration of two adjacent tones so as to alter the rhythmic grouping of notes while retaining the number of notes and original meter. This is accomplished by changing two quarter notes to a dotted quarter and an eighth note (in 4 trials; Figure 2D), or by reversing the order of two successive duration values (in two trials; Figure 2E). The serial position of these changes varies across melodies.

Figure 2 illustrates five examples of musical stimuli (A-E) showing changes in melody or rhythm. Each example consists of an original melody and a modified version, with a 1.5-second delay indicated between them. The changes are highlighted with red boxes.

- A (Scale-violating change):** Original melody (3/4, J=150) is compared to a modified version where the third note (F#) is changed from F. The change is framed in red.
- B (Contour-violating change):** Original melody (3/4, J=150) is compared to a modified version where the fourth note (B) is changed from A. The change is framed in red.
- C (Interval-violating change):** Original melody (2/4, J=120) is compared to a modified version where the second note (B) is changed from A. The change is framed in red.
- D (Duration interval change):** Original melody (3/4, J=150) is compared to a modified version where the second and third notes (B and A) are changed to a dotted quarter and an eighth note. The change is framed in red.
- E (Duration order change):** Original melody (6/8, J=90) is compared to a modified version where the second and third notes (A and B) are changed to a dotted quarter and an eighth note. The change is framed in red.

Figure 2. Example of stimuli: The three types of changes in the *melody* test are (A) scale, (B) contour, and (C) interval; the two types of changes in the *rhythm* test are (D) duration interval and (E) duration order. Changes are framed in red. The example can be heard at <https://peretzlab.ca/online-test-material/material/mbema-young-children>

For the *memory* test, six standard melodies that has been presented at least twice in the same format in the *melody* or *rhythm* test are selected. In addition to these old melodies, there are six foils or new melodies. The new melodies are constructed in the same manner as the old melodies but differ in their exact temporal and pitch patterns.

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Study 1: Preschool children from advantaged background

Data were acquired first in Quebec City, Canada, then in Brussels, Belgium. On each site, the three tests were presented to each child individually in a quiet room of their school or at home twice: three months apart for Canadian children (January and March 2017), and approximately nine months apart for Belgian children (June 2018/2019 and March 2019/2020).

Participants

The Canadian sample (CA) consisted of 89 children aged 5 to 6 attending the Ecole de la Passerelle in Chambly, Quebec. This is a public school ranked 1-3 on a socio-economic scale from 1 to 10, with rank 1 considered the least disadvantaged and rank 10 the most disadvantaged (Gouvernement du Québec, 2024).

The Belgian sample (BE) consisted of 102 children, also aged 5 to 6, who were recruited from public schools in Brussels with an average socio-economic status (SES) of 67.2 (Genoud, 2011), close to an index of 68–80 corresponding to upper middle class. Thirty-three children were enrolled in a school with a pedagogical project focused on music from the age of three. These children received two weekly music sessions, complemented by a “tutti” session held every two weeks involving the entire kindergarten section. The curriculum at this stage emphasises early musical development, such as singing, movement, and rhythm. In primary school, they participated weekly in a full-group choral singing session, a half-group session dedicated to musical training and culture, and a half-group session focused on musical creativity. In addition, the ones who were learning an instrument were offered the opportunity to rehearse weekly in a school orchestra. Musical engagement was further encouraged beyond school hours through enrolment in local music schools located within the school premises. An additional ten children attending the other participating schools received extracurricular instrumental lessons, either in local music schools or through private tuition.

Exclusion criteria included brain injury, hearing impairments, and developmental disorders such as oral speech impairment, attention and hyperactivity disorder, or autism as reported by parents. All were native French speakers except two Canadian children who were English-speaking. The characteristics of the two groups in terms of age and sex ratio are presented in Table 1.

Table 1. Characteristics of participants at the CA (Canada) and BE (Belgium) sites at the first timepoint (T1). %F indicates the percent of female participants.

Site	N	%F	Age in years			
			Mean	SD	Min	Max
CA	89	53.9	5.6	0.28	5.09	6.06
BE	102	46.1	5.9	0.28	5.43	6.45
Pooled	191	49.7	5.8	0.34	5.09	6.45

The tests were presented through a *Samsung Galaxy A10* tablet and *Sennheiser HD206* headphones at a comfortable volume. Children were free to request breaks between tests, and each child received a “diploma” as a reward for their time and participation.

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Ethical approval was granted by the local Ethics Committees (Université Laval in Canada, agreement number: 2016-194; Université libre de Bruxelles in Belgium, agreement number: 034/2017). Written informed consent was obtained from the parents of each child, as well as oral agreement from each participant.

Results and comments

Sensitivity

Children's global score, computed across the three tests, ranged from 13 to 33 at T1, with 18 representing chance performance and 36 a perfect score (Table 2). As can be seen in Figure 3, the distribution of global scores did not violate normality [$W_{(191)} = .991$, $p = .261$ by Shapiro-Wilk test; skewness = -0.01; kurtosis = 2.87]. Scores on individual tests violated normality ($W_{(191)} \leq .962$, all $p < .001$) but nonetheless exhibited acceptable values of skewness (-0.02 to -0.45).

Table 2. Mean scores in the pooled CA/BE sample at T1. The Global score has a maximum value of 36, whereas the individual test scores have a maximum score of 12.

Score	Mean	SD	% Chance score	% Perfect score	Score percentiles		
					25	50	75
Global	23.4	3.91	8.9%	0.0%	21.00	23.00	26.00
Melody	6.9	1.67	39.8%	0.0%	6.00	7.00	8.00
Rhythm	8.0	2.02	24.1%	1.6%	7.00	8.00	9.50
Memory	8.5	1.75	15.7%	3.1%	7.00	9.00	10.00

The global score was sensitive to individual variability with less than 10% of the children scoring at chance (with a score at or below 18, representing 50% accuracy). Mean scores differed across the three tests, as indicated by a mixed-effects model, $F(2,380.0) = 50.30$, $p < .001$, $\varepsilon_p^2 = .21$. All pairwise comparisons were significant after Holm-Bonferroni correction (all $p \leq .001$). Because the tests were administered in the same order, these differences may reflect increasing familiarity with the testing situation rather than differences in the musical components assessed.

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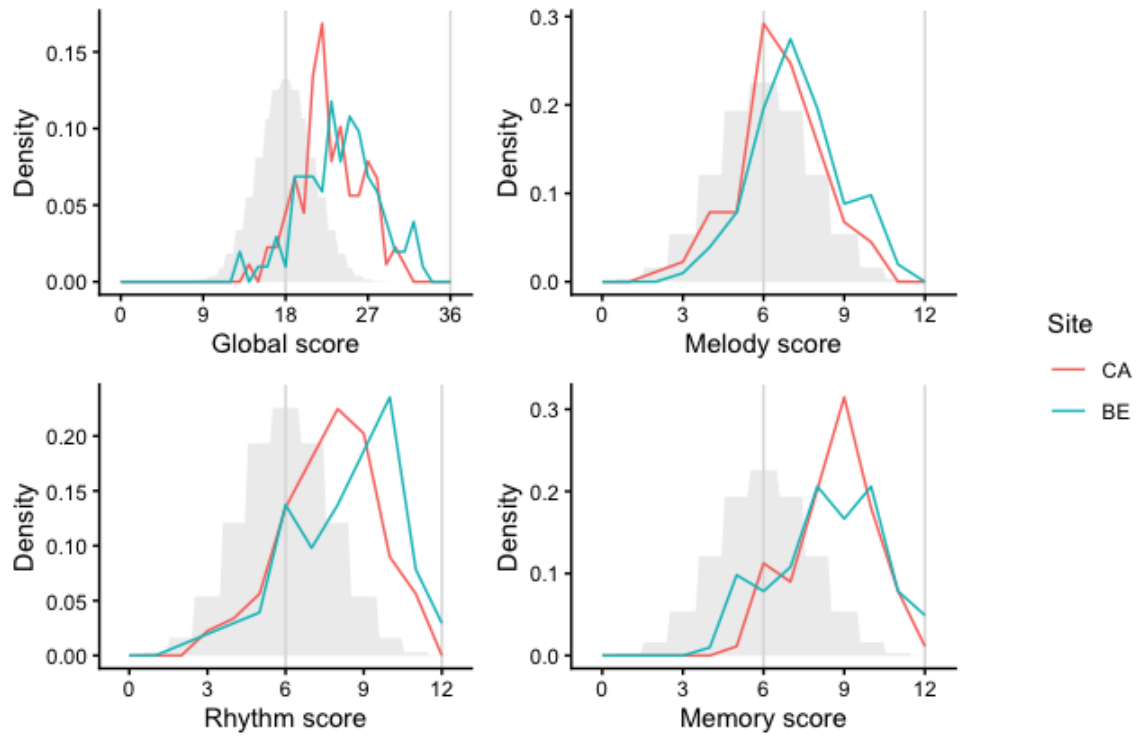


Figure 3. Distribution of scores at T1 in CA and BE. Chance and perfect scores are indicated by gray vertical lines. The expected distribution of scores at chance (random guessing) is represented by the gray filled region.

Test-retest reliability

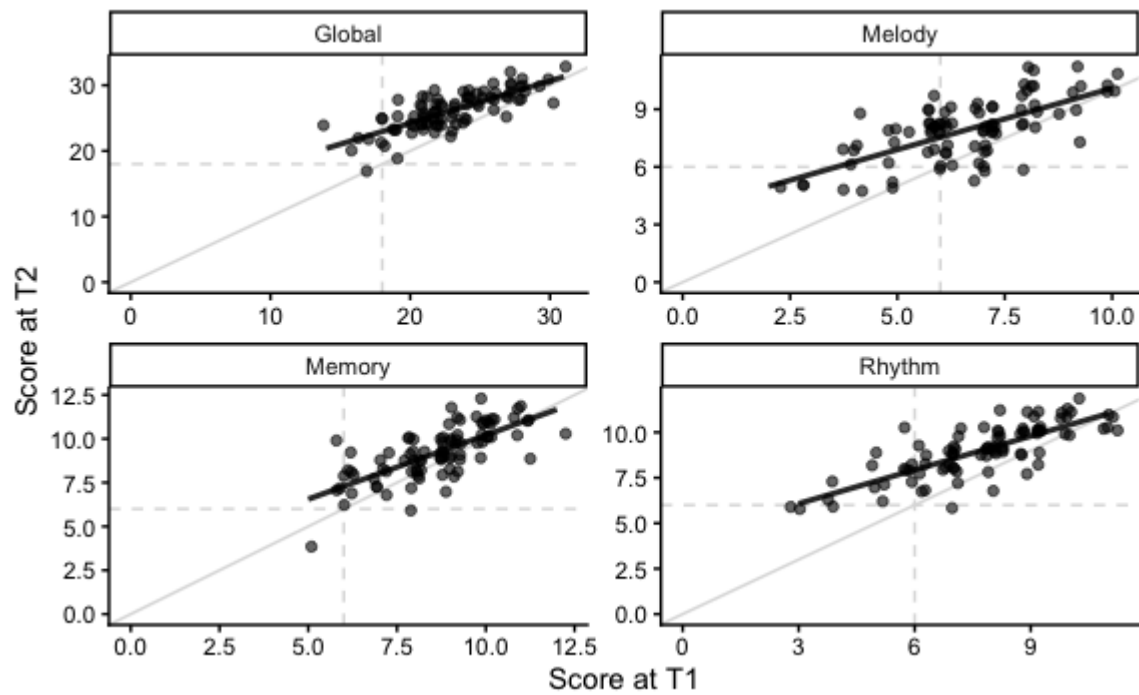
Test-retest reliability was evaluated by calculating the Pearson correlation between scores at timepoints T1 and T2. Because the interval between test and retest was shorter in CA (mean 3 months) than in BE (mean 9 months), reliability was calculated separately by site.

In the CA sample (Figure 4A), performance at Test (T1) predicted performance at retest (T2) both for global performance [$r_{(87)} = .76, p < .001$] and for each individual test [$r_{(87)} = .66, p < .001, r_{(87)} = .79, p < .001, r_{(87)} = .71, p < .001$, for *melody, rhythm, and memory*, respectively], hence showing good reliability.

In the BE sample (Figure 4B), test-retest reliability was slightly lower but significant, with $r_{(100)} = .47 (p < .001)$ for the Global score, $r_{(100)} = .37 (p < .001)$ for Melody, $r_{(100)} = .26 (p = .009)$ for Rhythm, and $r_{(100)} = .20 (p = .048)$ for Memory. The lower reliability in the Belgian group might be due to the longer delay between test and retest.

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(A)



(B)

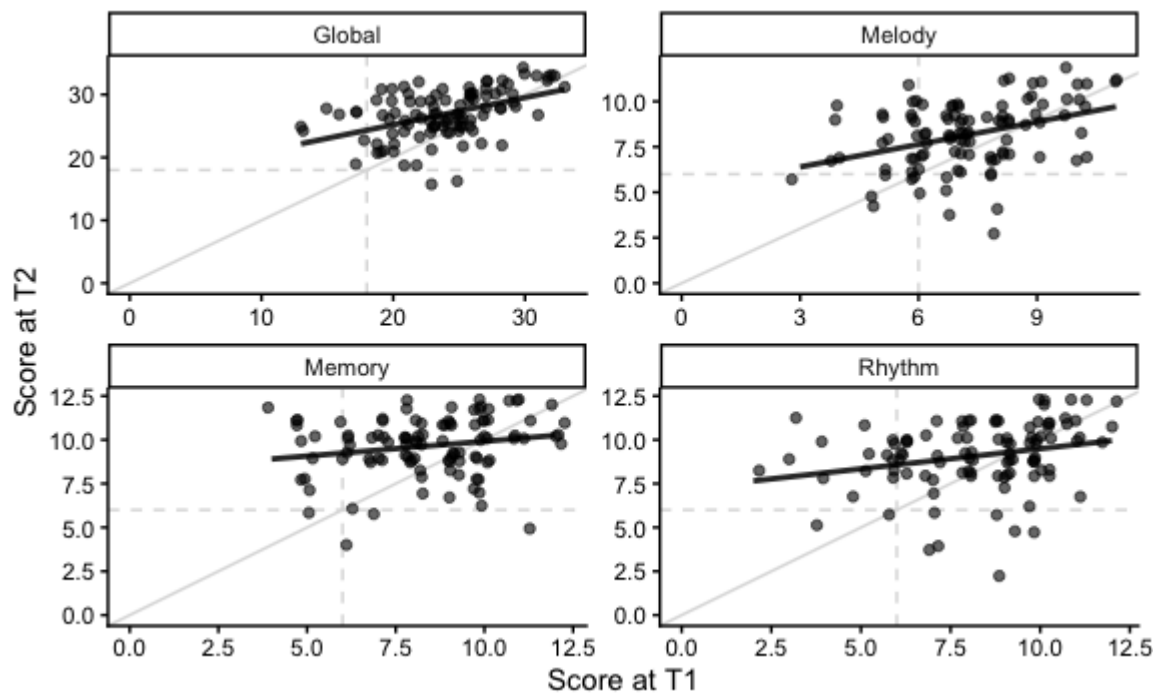


Figure 4. Comparison of scores between T1 and T2 for CA (panel A) and BE (panel B). The gray diagonal line indicates identical scores at T1 and T2; participants whose point lies above this line had higher scores at T2 than T1. The gray dashed lines indicate the score at chance level.

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Global score improvement (i.e., positive non-zero difference score) between T1 and T2 was seen in both CA ($M = 3.20$ points out of 36, 95% CI [2.73, 3.68], $t(88) = 13.35$, $p < .001$) and BE ($M = 2.99$, 95% CI [2.17, 3.81], $t(101) = 7.23$, $p < .001$). Improvement was confirmed for all tests in both sites (all $p < .001$).

Music training

Participants in the BE sample varied in musical training, whereas participants in CA did not have any musical training. Accordingly, the effect of musical training was tested only for BE.

At T1, most children (58%) had no musical training, 7% had 12 months, 31% had 24 months, whereas 4% had training between or beyond those values. At T2, 53% had no musical training, 11% had 6-12 months, 8% had 20-24 months, 26% had 32 months, and 2% had more than 32 months. Given this discontinuous distribution, we split the participants into two groups for analysis: those with limited training ("Non-musician", $n = 122$ observations, mean = 0.4 months training), and those with 12 months or more of musical training ("Musician", $n = 82$ observations, mean = 26.5 months). Timepoint and a group $\times$ timepoint interaction were included in the linear model.

At T1, the children in the Musician group had higher *global* scores than the Non-musicians (+2.2 points out of maximum 36, $F(1, 100) = 10.99$, $p = .001$; $\epsilon^2_p = .04$, Figure 5). There was no interaction between group and timepoint, indicating that the effect of musical training on scores remained the same at T2 ($F(1,100) < 0.01$, $p = .98$, $\epsilon^2_p < .01$). As found in the test-retest analyses, global score increased at T2 (+3.0 points, $F(1,100) = 51.73$, $p < .001$, $\epsilon^2_p = .33$). An analysis across the three tests (testing for effects of group, timepoint, test, and all interactions) revealed that the musical training effect varied across tests ($F(2,500) = 4.90$, $p = .008$, $\epsilon^2_p = .002$), with the greatest effect seen in the *Rhythm* test (+1.2 points out of 12) and the smallest in the *Memory* test (+0.2 points).

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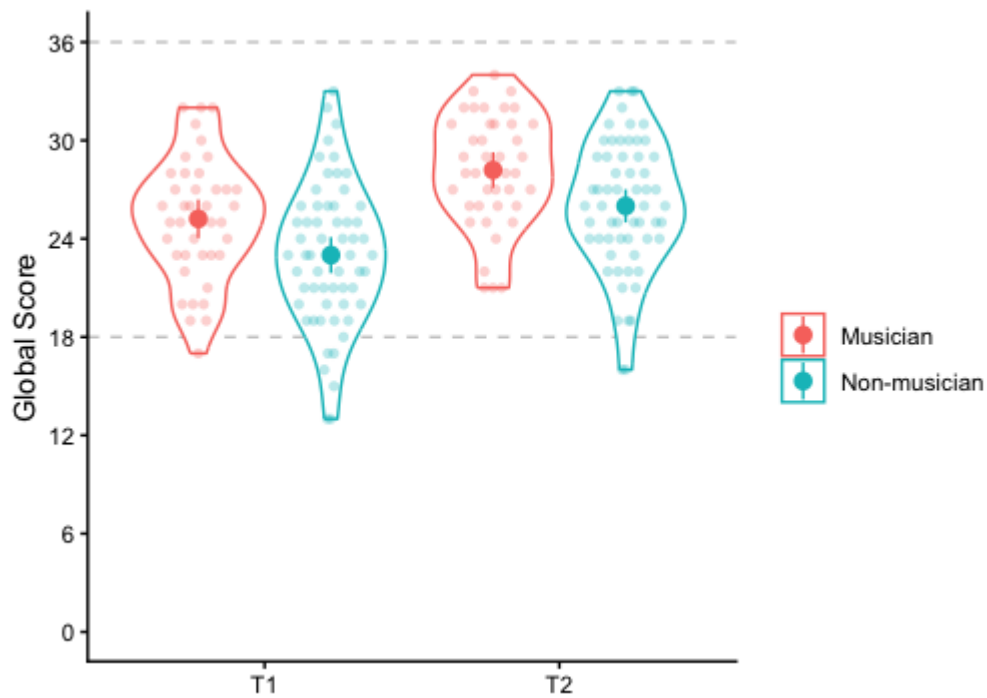


Figure 5. Global scores by musical training group at T1 and T2. Heavy points and vertical lines indicate the mean and its 95% confidence interval. Dashed gray lines indicate chance and perfect performance.

Age and sex

Children were older overall in BE than CA at T1 (BE mean = 5.94, CA mean = 5.56 years, difference = 0.38, $t(185.72) = 9.22$, $p < .001$) while the sex balance did not differ between sites ($\chi^2 = 0.88$, $p = .3$; Adjusted Cramer's $v = 0.03$). In order to avoid the age confound, mean-centered age values were considered separately by site prior to analysis, yielding a linear model containing centered age, sex, and site, without interaction terms. There was no sex difference in scores ($F(1, 187) = 0.48$, $p = .5$; $\epsilon^2_p < .001$). There was an increase in Global scores with age, with 2.2 points per year, $F(1, 187) = 5.01$, $p = .03$; $\epsilon^2_p = .02$.

Overall, in Study 1, the tablet version of the MBEMA appeared adequate for testing 5-year-old children, with a broad distribution of scores and relatively few children performing at chance. Performance increased with age and was higher in children with musical training, while longitudinal stability varied across sites. The tablet version thus provides a welcome addition to the original MBEMA, which was too long for children younger than six years.

Study 2: Large cohort of children from disadvantaged background

The data analyzed in this article come from a quasi-experimental study conducted between 2020 and 2024 in 57 schools in disadvantaged areas of Val d'Oise in the Northern suburbs of Paris. Of these schools, 39 agreed to participate in a music

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education program, while 18 served as control schools. All belonged to the French priority education network¹.

Once a school enrolled in the music program, called *Un violon dans mon école*, participation was mandatory, from the middle section of kindergarten through second grade. It integrates two to three weekly violin lessons into the regular school curriculum over a four-year period. The first year serves as an introductory phase, during which children participate in one 45-minute group lesson (with 12 children) and one 30-minute small-group session (with 4 to 6 children) each week. In the following three years, the structure remains the same, with an additional 30-minute small-group session added, resulting in a total of three classes per week—amounting to 1 hour and 45 minutes of instruction. The violin lessons are taught by professional violinists.

Each child was tested individually in a quiet room of their school twice (T1: beginning of Kindergarten, T2: end of Kindergarten) using the tablet version of the MBEMA. The tests were presented through a *Samsung Galaxy A10* tablet and headphones were set at a comfortable volume. Tests were conducted by the author J.P. and a team of trained research assistants. A subset of children was re-evaluated a year later (T3: end of Grade 1), albeit under different conditions: At T3, the entire class took the test simultaneously in pencil-and-paper form, with the teacher playing the stimuli using a slide show. Figure 6 illustrates the data collection timeline.

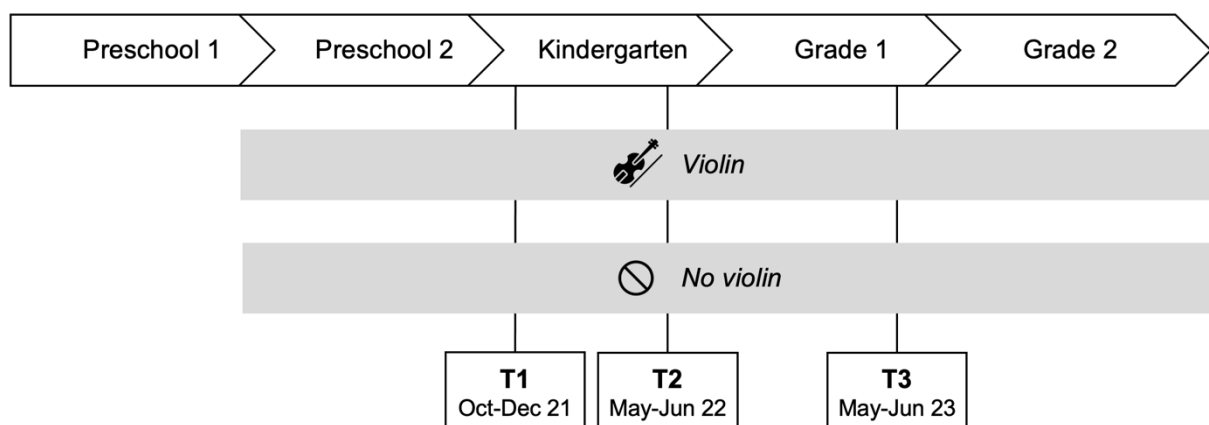


Figure 6. Data Collection Timeline: T1 (halfway through the final year of preschool), T2 (end of preschool), T3 (end of Grade 1).

Participants

The 1817 participating children attended schools with high proportions of socioeconomically disadvantaged households and families with migration backgrounds. Their socioeconomic status (SES) was measured using the social position index (SPI), which is derived from the parents' socio-professional category, and captures the children's social, economic, and cultural background. This index was originally standardized to a mean of 100 and a standard deviation of 30 (Rocher, 2016, 2023). The average SPI of the participants was 86.6 (based on 1789 available data),

¹ The priority education network resulted from a series of French public policies designed to address social and territorial inequalities by providing additional resources to schools serving disadvantaged populations.

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which is substantially lower than the French national average of 105.2. In addition, 55% of the 1514 children with available information were born to parents who had immigrated to France (see Pereira, 2025, for more details). Their characteristics are presented in Table 3.

Table 3. Characteristics of participants at the FR (France) site. %F is the percent of female participants, and SES is the Social Position Index.

Group	N	%F	Age in years				SES	
			Mean	SD	Min	Max	Mean	SD
T1								
Violin	1124	48.7	5.29	0.30	4.44	6.29	86.80	31.92
No-violin	693	49.5	5.27	0.29	4.71	5.89	96.04	33.99
Pooled	1817	49.0	5.28	0.30	4.44	6.29	90.40	33.04
T2								
Violin	1096	48.4	5.94	0.29	5.37	6.92	86.92	31.80
No-violin	664	50.5	5.92	0.28	5.40	6.47	96.44	34.32
Pooled	1760	49.2	5.93	0.29	5.37	6.92	90.63	33.12
T3								
Violin	590	51.5	6.92	0.29	6.41	7.89	85.61	31.88
No-violin	314	49.4	6.91	0.30	6.41	8.25	96.00	33.88
Pooled	904	50.8	6.91	0.30	6.41	8.25	89.95	33.10

The study was conducted with the approval of the Ethics Committee of the Institut d'études politiques de Paris (agreement number: 2021-027) and was performed in accordance with the principles stated in the Declaration of Helsinki. A tacit consent procedure was followed: parents were given the option to opt-out, and verbal consent was obtained from each child prior to the study participation. In the context of the COVID-19 pandemic, necessary precautions have been taken to avoid contaminations including appropriate protection measures (hand and material disinfection, safety interpersonal distance, facemask wearing for adults, and regular ventilation).

Results

Sensitivity

As can be seen in Table 4 and in Figure 7, more than 40% of children performed at chance at T1, whether they had received violin lessons or not. Global scores exhibited acceptable values of skewness (-0.53 to 0.81) and kurtosis (2.55 to 4.76) across all three timepoints, although given the large sample size the score distributions were not normally distributed per Shapiro-Wilk test ($W \geq 0.95$, $p < .001$).

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Table 4. Mean Global scores in the FR sample at each timepoint for the Violin and No-violin group. The Global score has a maximum value of 36. %C is percent of participants at chance, and %P is percent attaining a perfect score. Scores for individual subtests (Melody, Rhythm, Memory) are included in Supplemental Table 1.

Timepoint	Violin				No-violin			
	Mean	SD	%C	%P	Mean	SD	%C	%P
T1	19.59	3.51	41.5%	0.0%	19.59	3.17	41.3%	0.0%
T2	21.76	4.86	29.1%	0.3%	21.84	4.77	28.5%	0.3%
T3	26.22	5.54	10.5%	1.0%	26.86	5.29	9.2%	0.3%

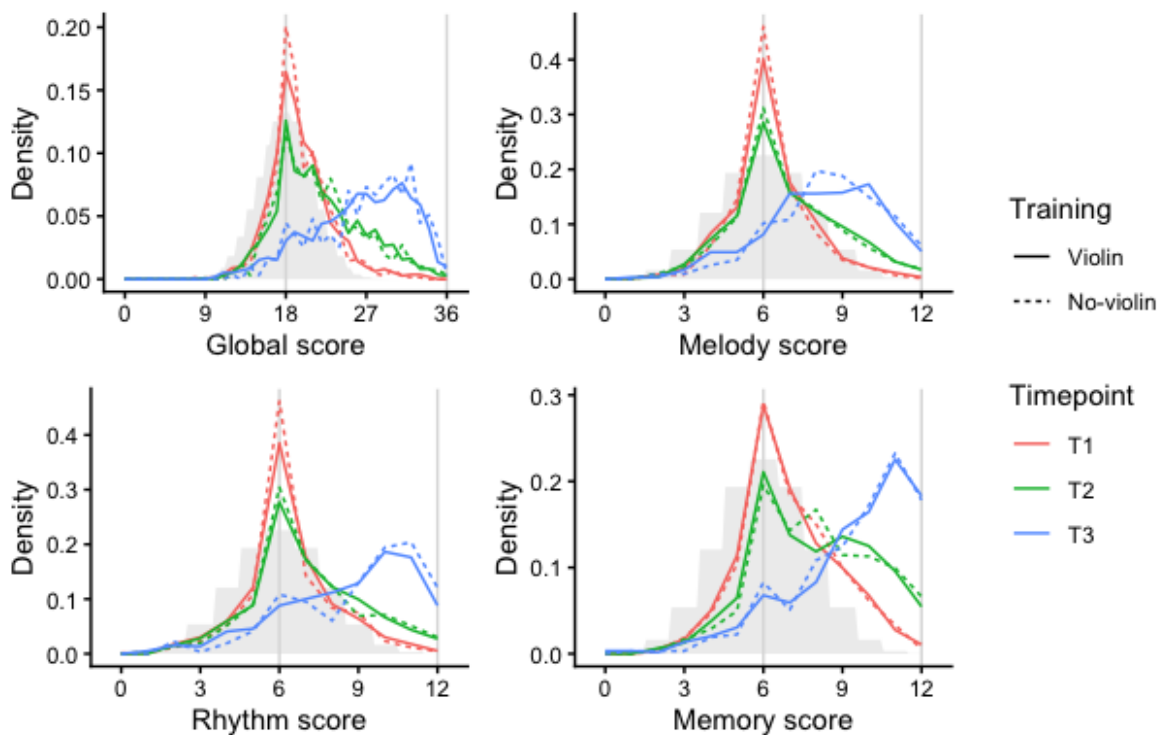


Figure 7. Distribution of scores by timepoint and violin training group in FR. Chance and perfect scores are indicated by gray vertical lines. The expected distribution of scores at chance (random guessing) is represented by the gray filled region.

Reliability and beyond (longitudinal)

Test-retest reliability was evaluated by calculating the Pearson correlation between Global scores obtained at timepoints T1 vs T2 and timepoints T2 vs T3. Reliability was $r(1701) = .39$ ($p < .001$) between T1 and T2 (Figure 7), and $r(651) = .48$ ($p < .001$) between T2 and T3.

As can be seen in Figure 8, improvement was more pronounced between T2-T3, compared to T1-T2. This can be attributed to the introduction of literacy and numeracy in the regular school program but also to a change in test administration from

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individual testing (T1, T2) to class evaluation (T3). Note that the gain is not larger in the violin group.

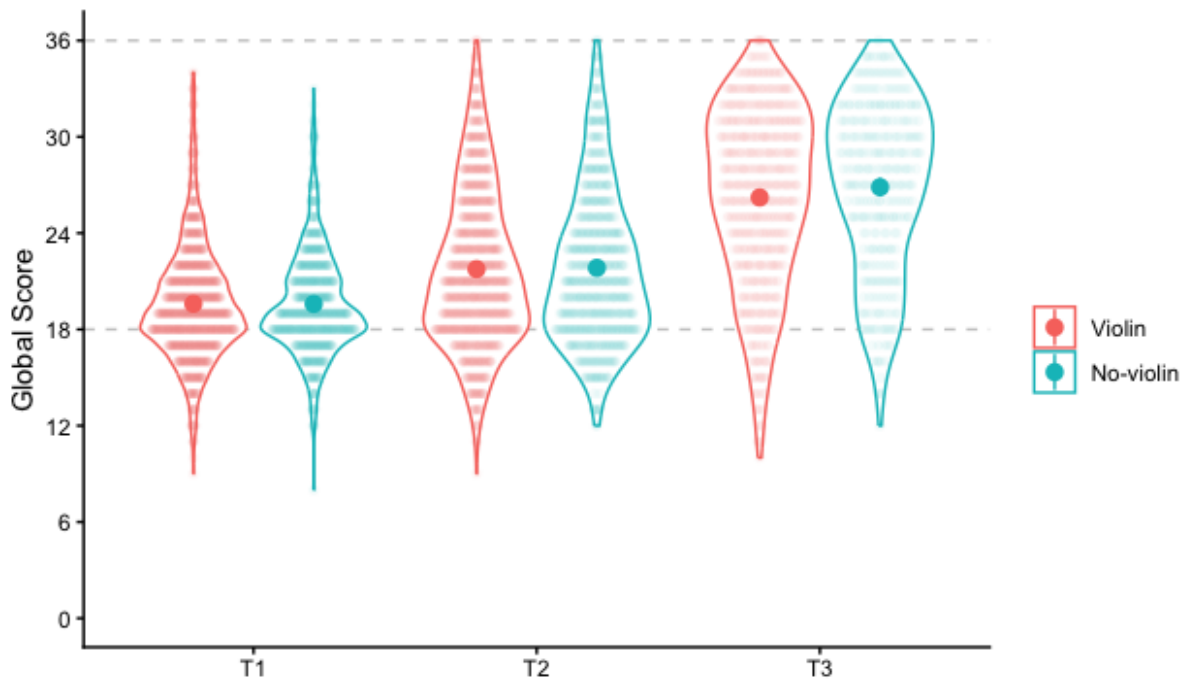


Figure 8. Global scores by violin training group at T1, T2, and T3. Heavy points and vertical lines indicate the mean and its 95% confidence interval. Dashed gray lines indicate chance and perfect performance.

Music training

What is striking in both Table 4 and Figure 7 is that there is little evidence of a superiority of the children who participated to the violin program and those who did not, even at T3 after 3 years of musical lessons (T1: $F(1,1809) \approx 0$, $p \approx 0$, $\epsilon^2_p \approx 0$; T2: $F(1, 1752) = 0.26$, $p = .6$; $\epsilon^2_p < .001$; T3: marginal trend toward no-violin > violin, $F(1, 896) = 3.22$, $p = .10$, $\epsilon^2_p = .002$). To better understand the origin of this lack of difference, we performed several analyses.

First, a power analysis was conducted based on the results in Study 1, in which the musician group superiority was 2.1 *global* points with Cohen's $d = 0.55$. Given this effect size, a sample of 54 participants per group is required to detect such a difference at a power of .8. The sample size in the present analysis is more than 10 times that number. Thus, lack of power to detect a superiority effect of the violin program is not likely.

Second, we considered scores at T2, where the proportion scoring at chance was 29% and the sample size was 1760 participants, offering better conditions for revealing a potential effect of musical training. Here again, a potential effect of the violin program was clearly absent ($F(1, 1752) = 0.26$, $p = .6$; $\epsilon^2_p < .001$). The 95% confidence interval of the difference between the Violin and the No-violin scores is $[-0.58, 0.34]$, where a positive number indicates Violin > No-violin. This musical training effect is close to zero, and far from the 2.1 points observed in Study 1.

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Third, a retrospective power calculation from the present analysis results using the method of Tian and collaborators (2025) finds that this T2 sample is powered at near 1.0 to detect a difference of ≥ 1 point, and at least a power of .8 for differences of ≥ 0.7 points. With those considerations, we conclude that any undetected effect of the violin program in Study 2 must be close to zero.

Fourth, a plot of sample deciles at T2 by group (Figure 9) shows that the distribution of scores is similar in the Violin and the No-violin groups for the full range of scores from chance (18) to perfect score (36).

Finally, impact analyses using entropy balancing found no significant differences in the scores between children who participated in the violin program and those in the comparison group (Pereira, 2025).

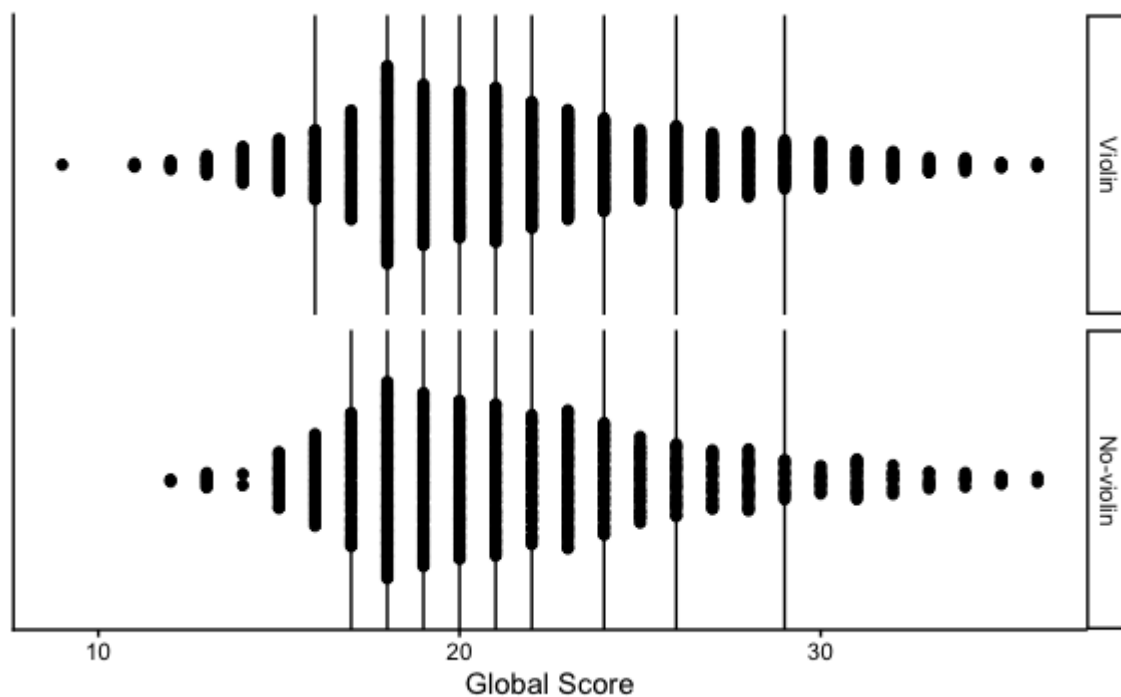


Figure 9. Plot of global score deciles by violin training group. Vertical lines indicate deciles 10% to 90%.

Relation with socio-economic status

Prior to analyzing the effect of socio-economic status, we noted a potential confound between these values and violin lessons. The Violin group had lower SES (SPI) scores than the No-violin group, with SES mean of 86.9 and 96.4, for violin group and no-violin group respectively, $t(1332) = 5.16, p < .001$ as measured at T2 (Table 3). For this reason, we chose to evaluate the effect of SES separately by group.

As can be seen in Figure 10, global scores increased slightly with SES points in both the Violin group (0.03 musical point per SES point, $t(813) = 5.14, p < .001, \epsilon^2 = .03$) and the No-violin group (0.02 musical point per SES point, $t(517) = 3.50, p < .001, \epsilon^2 = .02$). Thus, the socio-economic status has a significant impact on the MBEMA scores but does not seem to be sensitive to the music education program.

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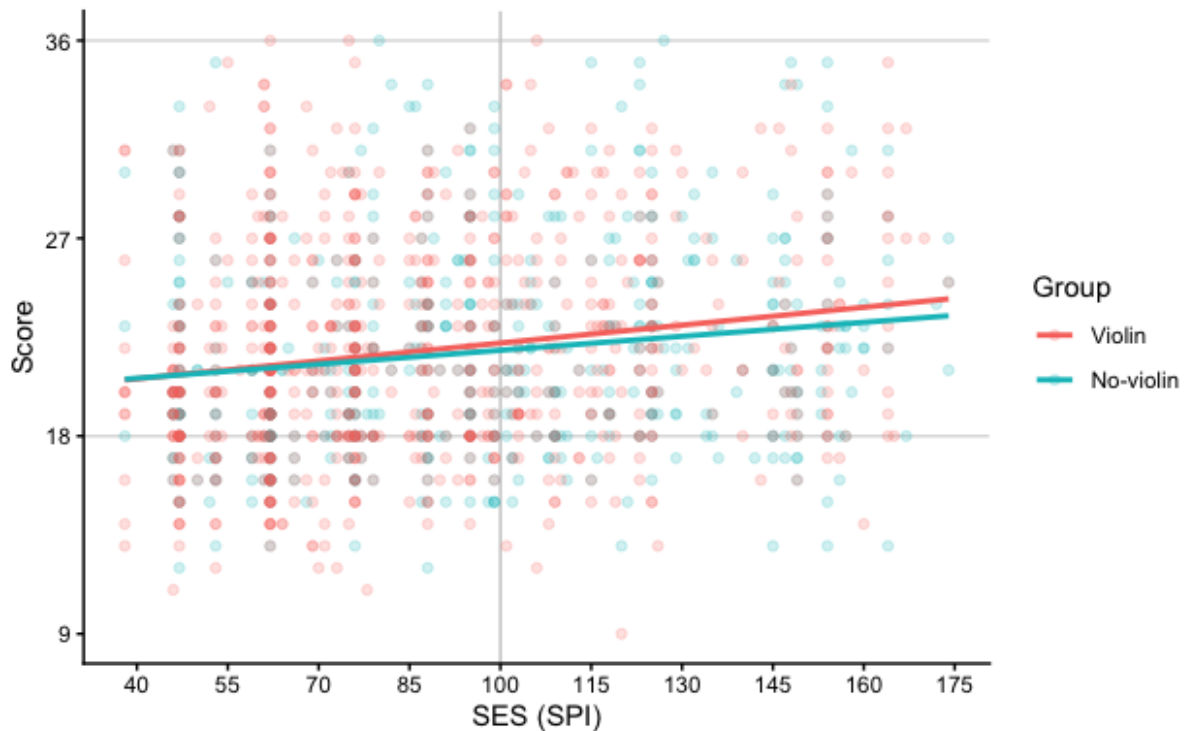


Figure 10. Global musical scores as a function of socio-economic score (SES/SPI) in FR at T2. Horizontal gray lines indicate chance and perfect performance. For reference, the vertical gray line indicates the standardized mean value of 100 for SES (SPI) scores.

Age and sex

The analysis of age and sex was performed on the scores obtained at T2, when the sample size was large and most scores were above chance. As in Study 1, scores increased with age (2.1 points per year, $F(1, 1752) = 27.46$, $p < .001$; $\epsilon^2_p = .01$). In addition, the increase was larger in girls than boys (girls' slope = 3.2 musical points/year, boys' slope = 1.1 points/year, $F(1, 1752) = 6.13$, $p = .01$, $\epsilon^2_p = .003$).

This effect of sex on global scores appeared to be driven by the scores on the *memory* test, in which there was a significant interaction between age and sex, such that girls outscored boys by +0.46 point (out of 12), and additionally had a greater age slope (1.6 pts/year) than boys (0.4 pts/year). In the melody test, there was no effect of sex ($p = .4$), nor interaction between sex and age ($p = .6$).

Overall, the tablet MBEMA proved relatively difficult for many preschool children in Study 2, although performance improved over time, especially at the end of Grade 1. The violin program was not associated with higher scores, even after several years of training, and lower SES does not seem to have contributed to this unexpected lack of musical training effect.

Discussion

The tablet version of the Montreal Battery of Evaluation of Musical Abilities (MBEMA; Peretz et al., 2013) appears to be a sensitive tool for preschool children raised in average- to high-socioeconomic-status backgrounds in both Europe and Canada ($n = 191$; Study 1), with global scores spanning a broad range and fewer than 10% of children performing at chance. Reliability, however, varied across samples. Test-retest reliability was strong in the Canadian sample over a three-month interval, both for

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the global score and across all three MBEMA subtests. In the Belgian sample, longitudinal stability over a nine-month interval was more modest, particularly for Rhythm and Memory. These relatively low correlations warrant some caution, although they should not necessarily be interpreted as evidence that musical ability itself is unstable at this age. Indeed, Couvignou et al. (2024) reported very high longitudinal stability of musical ability across the same transition from kindergarten to first grade. This stability was estimated for a latent music factor combining the three MBEMA subtests. A similar distinction emerged in Kragness et al.'s study (2021), who found substantial stability of an aggregate measure of musical ability over five years, despite considerably lower stability for individual MBEMA tests. Together, these findings suggest that the modest correlations observed for individual subtests in the Belgian sample may partly reflect task-specific variability or measurement error that is attenuated when musical ability is estimated from multiple indicators.

The same version of the MBEMA was surprisingly difficult for a large proportion of children in Study 2, with 40% performing at chance level. Because this study was conducted at an unprecedented scale — nearly 2,000 children tested individually and longitudinally — we focus most of our discussion on its results.

Several contextual factors likely contributed to these low scores. First and foremost, schooling had been disrupted by the COVID-19 pandemic at the time this large cohort of French children was tested. Moreover, these children came from underprivileged schools with a high rate of immigration, a population shown to be particularly vulnerable to the educational consequences of the pandemic, with larger learning losses than their more advantaged peers (Betthäuser et al., 2023). Although the children were tested in September–October 2021, after school had resumed, circumstances remained suboptimal: all adults wore masks and people had not yet been vaccinated. Many children were also from multilingual backgrounds, with French not being spoken at home for 15.5% of them, adding further challenges to the testing context. These circumstances likely contributed to the low scores obtained at that time (T1).

Fortunately, 1,760 of these children (97%) were retested at the end of kindergarten in May–June 2022 (T2), and 51% of the full sample were retested one year later, at the end of Grade 1 (T3). This longitudinal design allows us to address key questions about musical training: namely, the putative benefits of musical enrichment on music perception and memory.

First and foremost, there was no indication that the children who received early and intensive violin lessons performed any better than the children who did not receive this musical program. The schools where the violin program was instantiated happen to have a lower socio-economic status than the control schools. However, the impact of socio-economic status was modest and similar in the two groups of children. Moreover, their musical scores did not differ at baseline (T1) while the musical intervention had not been fully implemented. Furthermore, using entropy balancing to address baseline imbalance and regressions with standard errors clustered at the class level, yielded similar conclusions; attrition was also not differential between the violin and control groups (Pereira, 2025). Therefore, a pre-existing handicap in the group of children who received intensive musical training cannot easily account for the absence of effect of the musical regimen.

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Sex similarly accounted for little variation in MBEMA performance. No sex difference was observed in Study 1, whereas Study 2 revealed a very small sex-by-age interaction, with scores increasing somewhat more steeply with age in girls than in boys. This effect was primarily driven by the memory test. Overall, this pattern is consistent with large-scale evidence showing negligible and inconsistent sex differences across different components of music perception (Bertolo et al., 2023).

The lack of musical training effect came as a surprise, since we had observed a reliable effect of musical training in the Belgian sample in Study 1: the five-year-old children with at least one year of musical training, tested twice on the same tablet version of the MBEMA nine months apart, performed better than those with little or no musical training on both occasions. However, much of the musical enrichment in that study was provided through a school with a special music program, with some children receiving extracurricular instrumental lessons in music schools or through private teachers. We therefore cannot rule out the contribution of parents' musical background and motivation, as well as children's predispositions. To reveal the true effect of musical enrichment, children must be randomly assigned to a musical or non-musical program.

One possibility is that the MBEMA may not capture the musical abilities most directly developed during the early years of violin training. For instance, the musical perception tests do not assess motor and sensorimotor skills, which may constitute an important part of early instrumental learning. Yet, the violin program implemented in Study 2 was not limited to the posture, body movement, and sensorimotor coordination required by the violin but also involved singing and ensemble playing during the first years of instruction (Pereira, 2025). It can still be the case that motor and procedural skills do not develop in parallel with perceptual abilities in music (Kragness et al., 2021).

Nevertheless, one can maintain that progress in fine motor skills acquired through the violin program may impact academic performance. Pereira and Coulangeon (2026) found no support for such a claim. They examined the academic assessments and national standardized test results of the same pool of nearly 2,000 French children, and reported limited gains from musical training. Initial improvements in writing, numeracy, and syllabic skills gradually disappeared over the four-year follow-up, and by the end of the study there was even evidence of negative effects on some language outcomes, particularly reading. Similarly, Morfoisse and collaborators (2026), who studied 528 of the same French children longitudinally, found no significant impact of the violin program on any of the abstraction abilities tested with auditory and visual patterns. Symbolic reasoning nonetheless emerged at the start of formal schooling and deepened as a function of grade, with musically trained and untrained children appearing to rely on similar cognitive strategies.

The present data showed a similar pattern. There was an improvement in MBEMA scores over time, with a more abrupt change between the end of kindergarten and the end of Grade 1 (T2 and T3), a period that coincided with the transition to formal schooling. This larger increase should nevertheless be interpreted cautiously, as T3 differed from the earlier assessments in both testing format and sample composition: testing was conducted collectively using a paper-and-pencil format rather than individually on tablets, and participation at T3 depended on teachers' willingness to take part. The latter may have introduced selection at the classroom level, for example if more engaged teachers were more likely to participate. Critically, these gains were

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identical in the violin and no-violin groups, providing no indication that the improvement was specifically related to musical training. Rather, the overall developmental trend may reflect a combination of age-related cognitive changes, increasing experience with formal classroom settings, and repeated exposure to the task. Increased working memory or attention to detail may, for instance, have enhanced children's ability to detect and remember musical changes independently of prior musical enrichment.

In order to facilitate future research, this tablet version will be added to the two previous versions of the MBEMA, along with normative data, and made freely available on our website: <https://peretzlab.ca/online-test-material/material/mbema-young-children> (as is already the case for the adult version of the MBEA).

To conclude, performance on the tablet version of the MBEMA increased substantially with age and broader developmental and educational experience, whereas SES and sex accounted for comparatively little variation in performance. However, the present findings provide little support for an enrichment effect of the violin program instantiated in France. The absence of measurable gains on the MBEMA does not, of course, exhaust the question of what children may gain from music education. Music-making is a joyful activity that is easily accessible across the lifespan, from very young children to the elderly, and can be practiced alone or in a group. Many facets of music education benefit both the individual and society (Peretz, 2023). In our view, it is more productive to advocate for music's inclusion in school curricula on the basis of its intrinsic value.

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Supplementary Material

Supplemental Table 1. Subtest scores in the FR sample at each timepoint (TP) for the Violin and No-violin group. Subtest scores have a maximum value of 12. %C is percent of participants at chance, and %P is percent attaining a perfect score.

Score	TP	Violin				No-violin			
		Mean	SD	%C	%P	Mean	SD	%C	%P
Melody	T1	6.27	1.56	64.4%	0.4%	6.25	1.38	68.3%	0.1%
Melody	T2	6.86	2.01	50.6%	1.7%	6.83	1.97	52.0%	1.8%
Melody	T3	8.23	2.23	20.3%	5.1%	8.45	2.10	18.2%	6.1%
Rhythm	T1	6.39	1.74	61.5%	0.5%	6.37	1.62	65.9%	0.4%
Rhythm	T2	7.01	2.12	46.9%	2.7%	7.03	2.12	48.2%	3.0%
Rhythm	T3	8.61	2.48	20.8%	8.8%	8.95	2.42	19.4%	12.1%
Memory	T1	6.93	1.85	47.4%	1.1%	6.97	1.81	46.5%	0.6%
Memory	T2	7.89	2.25	33.2%	5.5%	7.98	2.24	29.7%	6.6%
Memory	T3	9.38	2.36	14.1%	18.3%	9.46	2.21	13.4%	17.8%