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Cognitive Ageing and Experience of Playing a Musical Instrument

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Author Note

Preregistration materials are available at https://osf.io/7ybwd/. The analytic code used to run the main analysis is available at https://osf.io/3dwq6/?view_only=6ce92ff091eb44eca0e45478ece238e1.

Results from the study were presented in 2021 at the Association for Psychological Science Virtual Convention and The Society for Education, Music and Psychology Research Conference: Engaging and Interacting with Education, Music and Psychology Research.

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Abstract

Musical instrument training has been found to be associated with higher cognitive performance in older age. However, it is not clear whether this association reflects a reduced rate of cognitive decline in older age (differential preservation), and/or the persistence of cognitive advantages associated with childhood musical training (preserved differentiation). It is also unclear whether this association is consistent across different cognitive domains. Our sample included 420 participants from the Lothian Birth Cohort 1936. Between ages 70 and 82, participants had completed the same 13 cognitive tests (every three years), measuring the cognitive domains of verbal ability, verbal memory, processing speed and visuospatial ability. At age 82, participants reported their lifetime musical experiences; 40% had played a musical instrument, mostly in childhood and adolescence. In minimally adjusted models, participants with greater experience playing a musical instrument tended to perform better across each cognitive domain at age 70 and this association persisted at subsequent Waves up to age 82. After controlling for additional covariates (childhood cognitive ability, years of education, socio-economic status, and health variables), only associations with processing speed ($\beta = 0.131$, $p = 0.044$) and visuospatial ability ($\beta = 0.154$, $p = 0.008$) remained statistically significant. Participants with varying levels of experience playing a musical instrument showed similar rates of decline across each cognitive domain between ages 70 and 82. These results suggest a preserved differentiation effect: certain cognitive advantages (in processing speed and visuospatial ability) associated with experience playing a musical instrument (mostly earlier in life) are preserved during older age.

Keywords: musical training, visuospatial ability, processing speed, cognitive decline

Public Significance Statement

In this study, older adults who reported greater lifetime experience playing a musical instrument tended to perform at a slightly higher level on tests of processing speed and visuospatial ability. Their test performance declined at a similar rate to older adults who reported less or no experience playing a musical instrument. Overall, these results suggest that certain cognitive advantages associated with musical training are maintained during older age.

Cognitive Ageing and Experience of Playing a Musical Instrument

Many cognitive abilities decline on average with ageing, even in the absence of dementia or other pathology (Boyle et al., 2013; Deary et al., 2009). This ageing process, which can negatively affect wellbeing and independence (Bárrios et al., 2013; Deary et al., 2009; Tucker-Drob, 2011), represents a major economic and social challenge, compounded by an ageing global population (Wimo et al., 2017). Importantly, there is substantial inter-individual variability in cognitive ageing, with some older adults having better cognitive abilities and experiencing less cognitive decline than others (Gow et al., 2011; Salthouse, 2006). Identifying lifestyle behaviours that support such healthy ageing profiles is a research priority. Alongside some other cognitively stimulating experiences from across the lifecourse (including years of education, occupational complexity and playing analog games; Altschul & Deary, 2020; Corley et al., 2018) musical instrument training has been identified as one potentially protective factor for cognitive health in later life (Chan & Alain, 2020; Roman-Caballero et al., 2018; Schneider et al., 2018; Wan & Schlaug, 2010).

Learning to play a musical instrument is a complex, multi-sensory activity that engages many types of cognition, including (but not limited to) attention, memory, motor skills and their coordination with auditory, visual and emotional processing. Initial studies testing for an association between musical activity and cognitive abilities in older age have reported positive results: a scoping review of this literature (Schneider et al., 2018) identified seven observational studies all of which found a small to moderate positive association between musical training and performance on various cognitive tasks, including those involving memory, visuospatial abilities, processing speed, and verbal abilities (Schneider et al., 2018). All the reviewed studies controlled for some potentially confounding variables (variously accounting for socio-economic status, years of education, full-scale IQ, physical activity, general health, disease history, and symptoms of depression). Although evidence from intervention studies of a causal effect of musical training on older-age cognitive function is still limited (Alain et al., 2019; Bugos et al., 2007; Bugos & Kochar, 2017; Degé & Kerkovius, 2018; Guo et al., 2021; Seinfeld et al., 2013), some larger-scale randomised controlled trials are currently underway (Hudak et al., 2019; James et al., 2020).

There are two key ways in which musical instrument training might lead to improved cognitive health in older age. Firstly, musical instrument training might contribute to cognitive development and thus a higher peak level of cognitive ability, which is subsequently preserved in adulthood and older age. Alternatively, or indeed additionally, musical instrument training might play a protective role during older age, delaying the onset or reducing the rate of cognitive decline. These two potential mechanisms describe 'preserved differentiation' and 'differential preservation' effects, respectively (Salthouse, 2006; Salthouse et al., 1990).

In favour of a preserved differentiation effect, there is evidence from some experimental studies (in which children were assigned to a musical intervention) that musical training contributes positively to cognitive development; although, this claim is not without controversy (see Bigand & Tillmann, 2021; Sala & Gobet, 2020). There is also some indication that cognitive or auditory perceptual advantages associated with musical instrument training in childhood are preserved beyond the training period and remain detectable in early adulthood (Schellenberg, 2006,) and even older age (Okely et al., 2022; White-Schwoch et al., 2013).

Turning to differential preservation, authors have proposed various mechanisms that could underlie slower or delayed rates of age-related cognitive decline. The threshold model (Stern, 2002), proposes that individuals with more neural resources or reserve (e.g. larger brain size or synapse count) might take longer to reach a neuropathological threshold, beyond which cognitive decline begins to occur. Analogous to the effect of exercise on physical fitness, others have proposed that continued mental activity, might sustain cognitive health and slow cognitive decline in older age (Hertzog et al., 2008; Salthouse, 2006). It is possible that musical instrument training from across the life course, or during older age, contributes to these protective mechanisms. However, as highlighted in recent reviews of the literature (Chan & Alain, 2020; Hanna-Pladdy & Menken, 2020), due to a lack of longitudinal research with older adults, it is currently not possible to identify whether musical instrument training is associated with reduced rates of age-related cognitive decline.

In a previous observational study (Okely et al., 2022) using Lothian Birth Cohort 1936 (LBC1936) data, we found that participants with greater experience of playing a musical instrument (gained mostly in childhood and adolescence) showed more positive change on a single test of general cognitive ability (the Moray House Test No. 12) between ages 11 and 70. However, using data from only two time points, we could not establish whether this positive association resulted from relatively greater cognitive development in childhood or relatively slower cognitive decline in later life.

A second outstanding question on this topic relates to the specificity of association between musical instrument training and particular domains of cognitive ability. There is good evidence that focused cognitive training and engagement can have positive but narrow effects on cognitive performance, enhancing those skills that are directly or closely related to the training task (Simons et al., 2016). As a multi-modal and complex activity, musical instrument training could thus potentially support a range of perceptual and cognitive skills, and various theories have linked musical training with specific cognitive abilities, rather than general cognitive ability (or IQ). One theory links musical training in childhood with the development of auditory perception and, by extension, some verbal skills including verbal memory and verbal intelligence or ability (Franklin et al., 2008; Kraus & Chandrasekaran, 2010; Moreno, 2009; Moreno et al., 2011). Others highlight visuomotor skills trained during musical performance: rapidly translating musical symbols to fine motor actions. It is suggested that practising these skills might result in non-musical visuospatial and processing speed advantages (e.g. Anaya et al., 2017; Brochard et al., 2004).

Current evidence suggests that recent or past musical instrument training is associated with better performance on a range of cognitive tests in older age including tests of verbal ability and verbal memory as well as visuospatial and processing speed abilities (Fauvel et al., 2014; Gooding et al., 2014; Hanna-Pladdy & Gajewski, 2012; Mansens et al., 2018; Strong & Mast, 2019). However, interpreting this body of literature is difficult as results within individual studies are not consistent; for instance, musical training is found to be associated with certain tests of visuospatial ability but not others (e.g. Hanna-Pladdy & Gajewski, 2012). Secondly, studies use differing and often limited batteries of cognitive tests, often not including tests of several cognitive domains or accounting for general cognitive ability. Here we administer a comprehensive battery of cognitive tests and model each cognitive domain as a latent variable representing shared variance among multiple cognitive tests. This approach captures variance in the theoretical cognitive domain while excluding variance that is specific to any of the individual cognitive ability tests. In subsidiary analysis, we also account for variance associated with general cognitive ability.

A third factor to consider in this area of research, is when the musical instrument training took place. As noted by Chan and Alain (2020), there are at least three broad types of potential exposure level to musical activity: early life musicianship (beginning to play in childhood without continued engagement into adulthood or older age), continued musicianship (beginning to play in childhood and continuing to play throughout adulthood and older age), and later life musicianship (beginning to play in adulthood or older age without any prior engagement). With only a few exceptions (Fancourt et al., 2020; Hanna-

Pladdy & Gajewski, 2012; Hanna-Pladdy & MacKay, 2011; Mansky et al., 2020) most previous observational (and interventional) studies in this field have focused on individuals playing a musical instrument (professionally or as a hobby) in older age at the time of the study, and thus the potential contribution of early life musicianship to older age cognitive ability remains unclear. Consistent with the idea of a "sensitive period" for musical training (Penhune, 2011), it is possible that early life musical training (relative to later life musicianship) is more strongly associated with older-age cognitive function; however, there is currently insufficient research evidence to formulate a precise hypothesis on this point.

In the present study, we used data from the LBC1936 to address the research gaps outlined above (a lack of longitudinal research with older adults, sub-optimal modelling of cognitive domains, and few studies including participants reporting early life musicianship). The participants in this narrow-age longitudinal cohort study, which spans the entire eighth decade of life, are unusually well characterised (Deary et al., 2012; Taylor et al., 2018). The study includes data on lifetime experience playing a musical instrument (indexed by number of musical instruments played, years of formal training, years of regular practice, hours of practice per week, and performance level reached) as well as detailed and repeated assessments of different domains of cognitive ability, conducted every three years between the ages of 70 and 82.

This LBC1936 dataset allows us to test for an association between lifetime experience playing a musical instrument (mostly past experience, typically beginning in childhood) and cognitive performance level at age 70, as well as long-term cognitive decline between ages 70 and 82. We tested for these associations across four domains of cognitive ability (verbal ability, verbal memory, processing speed and visuospatial ability), each modelled as latent variables (using 3 or 4 cognitive tests) , while controlling for a range of potentially mediating or confounding variables (detailed in the Methods section). In subsidiary analysis, we tested whether associations between experience playing a musical instrument and the cognitive outcomes were consistent across participants with early life and continued/older age musicianship or partly driven by an association with older-age general cognitive ability.

Drawing on the prior research findings discussed above, we predicted that greater experience of playing a musical instrument would be a) associated with better performance across all four cognitive domains (verbal ability, verbal memory, processing speed and visuospatial ability) at age 70 and b) less decline in these abilities over time until age 82.

Methods

Transparency and Openness

LBC1936 data cannot be made public as they contain sensitive, identifiable information and consent was given only to provide data access to approved researchers. Researchers can request LBC1936 data by completing a data request form and then via a formal Data Transfer Agreement. For details see https://www.ed.ac.uk/lothian-birth-cohorts/data-access-collaboration. Mplus code for the analysis is available (see Author Note). The cognitive tests are copyright protected and cannot be provided; however the ELMEQ is available (Okely et al., 2021). Unless otherwise stated, the study design, predictions and analysis plan were preregistered on the Open Science Framework before the data were requested (see Author Note).

The measurement models and main analysis were conducted using Mplus version 8.4 (Muthen & Muthen, 2017). Data preparation, management, plotting, and calculation of descriptive statistics were conducted in the R software environment, version 4.0.3 (R Core Team, 2020) with the aid of R packages dplyr (Wickham et al., 2019), ggplot2 (Wickham, 2016), arsenal (Ethan Heinzen et al., 2019), MplusAutomation (Hallquist & Wiley, 2018), tidyverse (Wickham, 2019), expss (Gregory Demin, 2020), and flextable (Gohel, 2020).

The Participants and Measures sections include details about the sample size, any data exclusions, all manipulations, and all measures used in the present study.

Participants

Our sample included 420 participants (of whom 51.4% were women and 100% were White) from the Lothian Birth Cohort 1936 (LBC1936). The LBC1936 is a study of healthy cognitive ageing with longitudinal data from five Waves of assessment currently available. Participants were all born in 1936 and were mostly from the Edinburgh and Lothian areas of Scotland (Deary et al., 2007). We used data collected during Wave 1 (2004-2007, age mean [*M*] = 70); Wave 2 (2007-2010, age M = 73); Wave 3 (2011-2013, age M = 76) Wave 4 (2014-2017, age M = 79); and Wave 5 (2017-2019, age M = 82). At each Wave, participants completed the same battery of cognitive tests as well as various medical, demographic, lifestyle and psychosocial questionnaires. Cognitive testing and medical questionnaires were completed at the Wellcome Trust Clinical Research Facility at the Western General Hospital, Edinburgh; other questionnaires were completed by participants at home before their cognitive testing appointments. Additional information regarding the background, recruitment and testing of LBC1936 participants is provided by Deary et al. (2007, 2012) and Taylor et al. (2018).

Although 1,091 participants attended Wave 1 and 431 participants attended Wave 5 of the LBC1936 study, the present study included only those who responded to the Edinburgh Lifetime Musical Experience Questionnaire (ELMEQ), first administered at Wave 5; 420 responded to the ELMEQ and were thus included in the present study.

Supplementary Tables 1 and 2 show differences between participants included and excluded from the analytical sample on cognitive test scores and the covariate variables at Wave 1 (age 70) (these are described in the Measures section). The excluded group includes participants who did not respond to the ELMEQ at Wave 5 (N=11) and those who had left the larger LBC1936 study before Wave 5 (N=671). On average, participants included in the analytical sample achieved higher scores on all the cognitive tests at age 70 than participants excluded from the sample; effect sizes (Cohen's D) ranged between 0.15 and 0.47 (see Supplementary Table 1). Included participants also had a more affluent childhood environment, a higher childhood cognitive ability, more years of education, a more professional adult occupational class, a lower BMI, and reported more frequent physical activity than excluded participants. Included participants were also less likely to be smokers, or report a history of hypertension, diabetes, CVD, or stroke; effect sizes (Cohen's D or Cramer's V) ranged between 0.06 and 0.30 (see Supplementary Table 2).

Supplementary Tables 3 and 4 show differences between participants who did (N = 420) and did not (N = 11) respond to the ELMEQ at Wave 5. The responding group had a higher childhood cognitive ability, fewer cases of possible dementia and scored higher on 10 out of 13 of the cognitive tests at Wave 5.

Ethical permission was granted by the Multi-Centre Research Ethics Committee for Scotland (Wave 1: MREC/01/0/56), the Lothian Research Ethics Committee (Wave 1: LREC/2003/2/29), and the Scotland A Research Ethics Committee (Waves 2, 3, 4 & 5: 07/MRE00/58). Written consent was obtained from participants at each Wave.

Measures

Cognitive Ability

At each Wave of the LBC1936 study, participants completed the same battery of 13 cognitive ability tests. These tests measure abilities across four cognitive domain categories: verbal ability, verbal memory, visuospatial ability, and processing speed (Ritchie et al., 2016; Tucker-Drob et al., 2014).

Verbal ability (a type of crystallised ability or learned knowledge) was assessed by the National Adult Reading Test (NART; Nelson & Willison, 1991), the Wechsler Test of

Adult Reading (WTAR; Wechsler, 2001), and a test of phonemic verbal fluency (Lezak, 2004). Verbal memory (memory for verbally presented information) was assessed by the Digit Span Backward subtest from the Wechsler Adult Intelligence Scale, 3rd UK Edition (Wechsler, 1998a), and the Verbal Paired Associates and Logical Memory subtests from the Wechsler Memory Scale, 3rd UK Edition (Wechsler, 1998b). Visuospatial ability (the ability to analyse or remember visual and spatial information) was measured using the Spatial Span (Forward and Backward) subtest from the Wechsler Memory Scale, 3rd UK Edition (Wechsler, 1998b), the Matrix Reasoning and Block Design subtests from the Wechsler Adult Intelligence Scale, 3rd UK Edition (Wechsler, 1998a). Finally, processing speed (speed of mental processing) was assessed by the Symbol Search and Digit-Symbol Substitution tests from the Wechsler Adult Intelligence Scale, 3rd UK Edition (Wechsler, 1998a), a computer-based inspection time test (Deary, Simonotto, et al., 2004), and a four-choice reaction time test (Deary et al., 2001).

Musical experience

Participants reported their lifetime experience of playing a musical instrument at Wave 5 of the study (mean age 82) by completing the Edinburgh Lifetime Musical Experience Questionnaire (ELMEQ) (Okely et al., 2021). This 29-item questionnaire consisted of four sections which covered musical instruments, singing, reading music notation, and listening to music (note that after data collection for this study at Wave 5, the final ELMEQ shared in Okely et al., 2021 had 30 items – an additional question was added regarding singing experience). For the current study, we used five ordinal items (with five or six response categories) from the ELMEQ musical instruments section: number of musical instruments played, years of formal training, years of regular practice, hours of practice per week, and performance level reached. Participants reporting no musical instrument experience were instructed to omit further items in the musical instruments section of the

ELMEQ. For the purposes of including these participants in the analysis, we assigned them to a baseline response category for each item (e.g., no hours of practice, no level of music performance). Similarly, participants who reported no formal instrumental training were also assigned to the baseline category for that item. All other omitted responses, from any participants were coded as missing.

Following previous analysis with this dataset (Okely et al., 2021), we combined responses to the five ordinal items using factor analysis to form a continuous variable representing participants' overall *experience playing a musical instrument* (this approach is described more fully in the analysis section). We use the term "experience" rather than "training" here to signify both formal and informal types of musical training, practice, and performance.

Covariates

Based on findings from previous studies (Albert, 2006; Corrigall et al., 2013; Deary, 2014; Lyu & Burr, 2016; Noble et al., 2007; Ritchie & Tucker-Drob, 2018; Theorell et al., 2015) we identified variables associated with musical instrument training and/or older-age cognitive ability that could have a potentially confounding or mediating effect on the results. These were age (in days at time of cognitive testing), sex, childhood environment, years of education, childhood cognitive ability, adult occupational class, health behaviours (smoking status, alcohol consumption, and physical activity), body mass index (BMI), history of chronic disease (high blood pressure, stroke, diabetes, cardiovascular disease), and possible dementia. These variables were assessed at various stages of the LBC1936 study, as described below.

Age 11. Most LBC1936 participants had completed a test of general cognitive ability, the Moray House Test (MHT) No. 12 at age 11 (Deary, Whiteman, et al., 2004; Scottish Council for Research in Education, 1949). MHT scores were corrected for age at time of testing and converted to an IQ-type scale with a mean of 100 and an SD of 15. This variable will be referred to here as childhood cognitive ability.

Wave 1, age 70. Participants retrospectively described their childhood housing conditions in terms of the number of people living in their home, the number of rooms in their home, the number of people sharing toilet facilities, and whether toilet facilities were outdoors. As in previous LBC1936 studies (Johnson et al., 2011), these variables were standardized and then summed to form a composite score representing childhood environment. A higher score on this variable indicates poorer living conditions. At Wave 1, participants also retrospectively reported their age at leaving school, any further and higher education, and details of their highest academic qualification. This information was used to calculate years of full-time education. In addition, participants reported their main occupation before retirement. Occupations were grouped into 6 occupational social class categories ranging from professional (coded as 1) to unskilled (coded as 5) following the Classifications of Occupations system 1980 (Office of Population Censuses and Surveys, 1980).

It is possible that individuals participating in musical activities are more likely to engage in other behaviours such as physical activity, also associated with better cognitive function in older age (Hanna-Pladdy & Gajewski, 2012). To test for this potential effect, we included indicators of health and health behaviours associated with older-age cognitive function. These variables (which were all assessed at Wave 1) were smoking status (recorded as "never smoker", "former smoker", or "current smoker"); alcohol consumption (in grams per week); level of physical activity (recorded on a six-point scale ranging from "moving only in connection with necessary (household) chores" to "keep-fit/heavy exercise or competitive sport several times per week" (adapted from Hirvensalo et al., 1998); and BMI, participants' height and weight were recorded by a research nurse and converted to a BMI score: weight (in kg)/height (in m) squared.

Wave 1-5, ages 70, 73, 76, 79, 82. Cardiovascular disease and its risk factors (including hypertension and diabetes) are associated with poorer cognitive function and steeper cognitive decline in older age (Leritz et al., 2011). To test whether *experience playing a musical instrument* was associated with cognitive performance level or change independently of these known risk factors, we controlled for these variables in the analysis. To account for a diagnosis at any point during the study, we used data on disease history and dementia diagnosis collected at each Wave. At each Wave of the study, participants self-reported whether they had ever been diagnosed with high blood pressure, stroke, diabetes, cardiovascular disease, or dementia. They also completed the Mini Mental State Examination (Folstein et al., 1975; MMSE). Participants who scored less than 24 on the MMSE or reported a history of dementia were identified as having possible dementia.

Because there was a low number of possible dementia cases at each wave, (between 0 and 15) we created a single variable indicating whether participants were identified as having possible dementia at any wave of the study (yes or no).

Missing data

Missing data (on any of the variables in the model) were handled using the Full Information Maximum Likelihood (FIML) algorithm, which produces parameter estimates using all available information, including information from individuals with missing data.

Supplementary Tables 1 and 2 show the number of missing cases for each cognitive and covariate variable in the analytical sample. The number of missing cases ranged from 42 for alcohol consumption to 0 for some of the cognitive tests.

Analysis

We used a structural equation modelling framework to test for an association between *experience playing a musical instrument* and level and/or change in the four cognitive ability domains, between ages 70 and 82.

Measurement Models

Experience Playing a Musical Instrument. The latent variable *experience playing a musical instrument* was initially modelled as part of the structural equation models described in the main analysis (see below). However, some fully adjusted models would not converge. Consequently, we employed a multistage approach to simplify the model. In an initial step, we estimated factor scores for *experience playing a musical instrument*. To accomplish this, we modelled *experience playing a musical instrument* as a latent variable using weighted least squares mean and variance adjusted estimation (WLSMV) with responses to the five ELMEQ items (number of musical instruments played, years of formal training, years of regular practice, hours of practice per week, and performance level reached) treated as ordinal indicators. The suitability of this model was established in a previous paper (Okely et al., 2021). Factor scores from this analysis were saved and added to the dataset. *Experience playing a musical instrument* was then treated as a continuous exogenous variable in the main analysis.

Cognitive Ability Level at Age 70 and Change Between Ages 70 and 82. Using an approach established in previous studies with the LBC1936 sample (Ritchie et al., 2016; Tucker-Drob et al., 2014), we used factor-of-curves models (McArdle, 1988) to estimate levels and changes in each of the four cognitive ability domains (verbal ability, verbal memory, processing speed, and visuospatial ability), each measured using three or four individual cognitive tests. For each group of cognitive ability tests, levels (the intercept at age 70) and slopes (representing change across the five measurement Waves, between ages 70 and 82) were estimated using growth curve models (Duncan & Duncan, 2004; McArdle, 1988). The slope factors were calculated using the average time lag between Waves 1-2 (2.98 years), 1-3 (6.75 years), 1-4 (9.82 years), and 1-5 (12.54 years) as path weights; the path from the slope factor to test scores at Wave 1 was set to zero. Resulting factors representing cognitive test levels and slopes were then treated as indicators of higher-order factors representing cognitive ability domain levels and slopes. Latent variables (cognitive domain levels and slopes) were identified using the marker variable method. We specified correlations between the level and slope factors of each cognitive test and cognitive domain. Residual variances of the cognitive tests were free to vary over time.

In each of the models described above (estimating levels and slopes of performance in each cognitive domain), some of the cognitive tests' slopes had residual variances that were close to zero and were estimated as negative in our models. This issue can occur when all the test's slope variance is shared with the higher-order domain's slope variance. To allow the models to converge on within bounds estimates (without negative residual variances) the residual variance of the following cognitive tests' slopes were fixed to zero in their respective factor of curves models: NART, WTAR, Verbal Paired Associates, Logical Memory, Symbol Search, inspection time, Block Design, and Spatial Span.

Main analysis: Experience Playing a Musical Instrument and Cognitive Domain Levels and Slopes

We tested for an association between *experience playing a musical instrument* and level and/or change in performance in the four cognitive domains by running two models for each cognitive ability domain. Model 1 included the factor-of-curves model, estimating the cognitive domain level and slope, the *experience playing a musical instrument* variable, sex, and participants' age in days at time of testing at each Wave. *Experience playing a musical instrument* and sex were treated as predictors of the cognitive ability domain level and slope. Age was specified as a time-varying covariate and treated as a predictor of cognitive test scores at each wave. Model 2 additionally included the following covariates: childhood environment, years of education, childhood cognitive ability, adult occupational class, health behaviours (smoking status, alcohol consumption, and physical activity), BMI, history of chronic disease (high blood pressure, stroke, diabetes, cardiovascular disease), and possible dementia (at any wave of the study). All these covariates except history of chronic disease were specified as time-invariant and treated as predictors of level and slope of performance in each cognitive domain. Reported diagnoses of high blood pressure, stroke, diabetes, or cardiovascular disease (recorded at each wave of the study) were specified as time-varying covariates and treated as predictors of cognitive test scores at each wave. Sex, history of high blood pressure, stroke, diabetes, cardiovascular disease, and possible dementia were binary variables; all other covariate variables were treated as continuous in the analysis. None of the covariate variables were transformed for the analysis apart from the age in days variables which were mean-centred. These models are summarised in Figure 1.

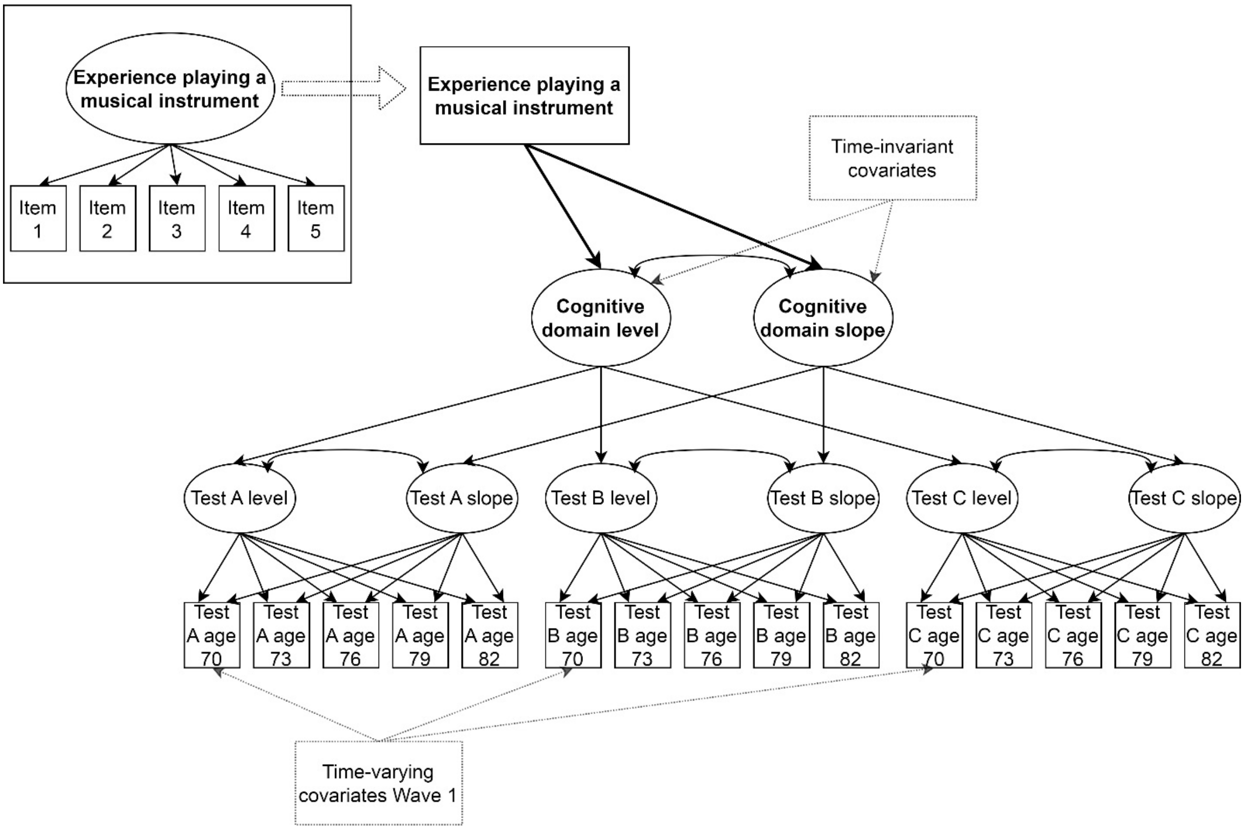
The main analysis was carried out using maximum likelihood estimation with robust standard errors (MLR). Model fit was assessed using the comparative fit index (CFI), Tucker-Lewis index (TLI), and root-mean-square error of approximation (RMSEA). CFI and TLI ≥ 0.90, RMSEA ≤ 0.08 were considered to indicate acceptable fit (Little, 2013).

Inference Criteria

This analysis involved multiple significance tests (2 per domain = 8 in total); *p*-values for the associations between *experience playing a musical instrument* and cognitive ability domains (levels and slopes) were corrected for multiple comparisons using Hochberg's False Discovery Rate (FDR) correction (Benjamini & Hochberg, 1995). An FDR-corrected $p < 0.05$ was considered statistically significant.

Figure 1

Illustration of the factor-of-curves model



Note. Ellipses represent latent variables, rectangles observed variables, double headed arrows correlations, and single headed arrows regression paths or factor loadings. A variable indicating experience playing a musical instrument was estimated in an initial step and then entered as an exogenous variable in the main analysis. The diagram shows how time-invariant and time-varying covariates were included in the model (see dotted lines). For simplicity, we only show time-varying covariates assessed at Wave 1, but the same procedure was applied to covariates assessed at each Wave. A separate model was run for each cognitive ability domain. Level = performance at Wave 1, slope = change in performance between Waves 1 and 5.

Results

Descriptive statistics

Responses to the ELMEQ and Scores on the Covariate Variables

Of the 420 participants included in the analytical sample, 167 (40%) reported some experience of playing a musical instrument. The most typical responses were: playing one musical instrument (N = 115, 69%); playing the piano (N = 112, 67%); formal musical training for 2-5 years (N = 83, 50%); five or fewer years of regular playing (N = 70, 42%); practising between 2-3 hours per week (N = 59, 35%); and achieving an intermediate level of musical performance (N = 76, 46%). For further details (including missing cases for each item) see Supplementary Table 5. Participants started playing a musical instrument at a median age of 10 years (range = 4, 79). Thirty-nine participants reported that they currently played a musical instrument at age 82. The remaining 128 former players stopped playing at a median age of 19 years (range = 7, 81). The distribution of ages participants started and stopped playing a musical instrument is shown in Supplementary Figure 1.

Table 1 shows participants' scores on the covariate variables (assessed at mean age 70, Wave 1) and their correlations with the continuous *experience playing a musical instrument* variable. Consistent with previous reports on this and other participant samples (Albert, 2006; Corrigall et al., 2013; Okely et al., 2021), those with greater *experience playing a musical instrument* tended to report greater socio-economic resources in childhood (reflected by a lower score on the childhood environment variable), have a higher childhood cognitive ability, more years of education, and a more professional adult occupational class (reflected by a lower score on adult occupational class) than participants with less or no experience.

Table 1

Covariate variables at mean age 70 and their correlation with the experience playing a musical instrument variable

Covariate	Scores	Correlation with *experience playing a musical instrument*
Continuous variables		
Childhood environment	-0.23 (2.26)	-0.26**
Age 11 IQ	102.75 (14.67)	0.17**
Years of education	10.91 (1.18)	0.24**
Adult occupational class	2.21 (0.91)	-0.28**
BMI	27.32 (3.95)	-0.04
Smoking status	0.51 (0.57)	0.05
Physical activity	3.14 (1.07)	-0.02
Alcohol consumption	12.58 (15.37)	0.06
Categorical variables		
Sex (female)	216 (51.4%)	0.04
High blood pressure	140 (33.3%)	<0.001
Diabetes	20 (4.8%)	-0.05
CVD	88 (21.0%)	<0.001
Stroke	12 (2.9%)	<0.001
Possible dementia	19 (4.7%)	-0.04

Note. The second column shows means for continuous variables (values in parentheses are standard deviations) and Ns for binary variables (values in parentheses are percentages of the sample (420). Possible dementia represents possible cases of dementia at any age (between 70 and 82). The number of missing responses ranged between 0 (sex and disease history) to 42 (alcohol consumption). The last column shows Spearman rank correlations. A lower score on childhood housing and occupational class indicate better housing conditions and a more professional occupational class, respectively.

*$p<0.05$, **$p<0.01$

Cognitive Ability Levels at Age 70 and Change Between Ages 70 and 82

Supplementary Table 6 shows correlations between the five indicators of *experience playing a musical instrument* and the cognitive test scores at Wave 1 (mean age 70). Correlation coefficients were positive (*r* range = 0.08, 0.24) and mostly statistically significant, indicating that greater musical instrument experience was associated with higher cognitive test scores at age 70. Supplementary Tables 7-10 show these correlations at subsequent Waves (2-5).

We ran initial models (not including any covariate or musical experience variables) for each cognitive domain, to establish model fit and the mean and variance of the cognitive domain levels and slopes. Table 2 shows the mean and variance of the cognitive domain levels and slopes (estimated separately for each cognitive domain). Variance for each cognitive domain level was statistically significant, indicating that participants started the study (at mean age 70) with varying levels of cognitive abilities. Mean slope estimates for verbal memory, processing speed and visuospatial ability were negative and statistically significant, indicating that on average, performance across these cognitive domains had declined over the course of the study. The slope variance for verbal memory, processing speed and visuospatial ability was also statistically significant, indicating that there were significant differences across participants' rate of cognitive decline. For verbal ability, the mean slope estimate, and slope variance were non-significant, indicating little change in this cognitive domain over time and limited variability across participants' rate of change. Model fit was assessed using the comparative fit index (CFI), Tucker-Lewis index (TLI), and root-mean-square error of approximation (RMSEA). CFI and TLI $\geq$ 0.90, RMSEA $\leq$ 0.08 were considered to indicate acceptable fit (Little, 2013). Fit indices for all four cognitive domain models (which did not include any covariate or musical experience variables) were within the acceptable range (CFI = 0.991-0.943; TLI = 0.941-0.990; and RMSEA = 0.041-0.069) see Supplementary Table 11.

In Figure 3, for illustrative purposes only, we show model estimated intercepts and slopes of the cognitive domains (verbal ability, verbal memory, processing speed and visuospatial ability) for participants reporting any experience playing a musical instrument (yes) and participants reporting no experience playing a musical instrument (no). Note that in the main analysis, *experience playing a musical instrument* was treated as a continuous rather than dichotomous variable. Supplementary Figure 2 shows the individual cognitive test scores at each Wave of the study.

Table 2

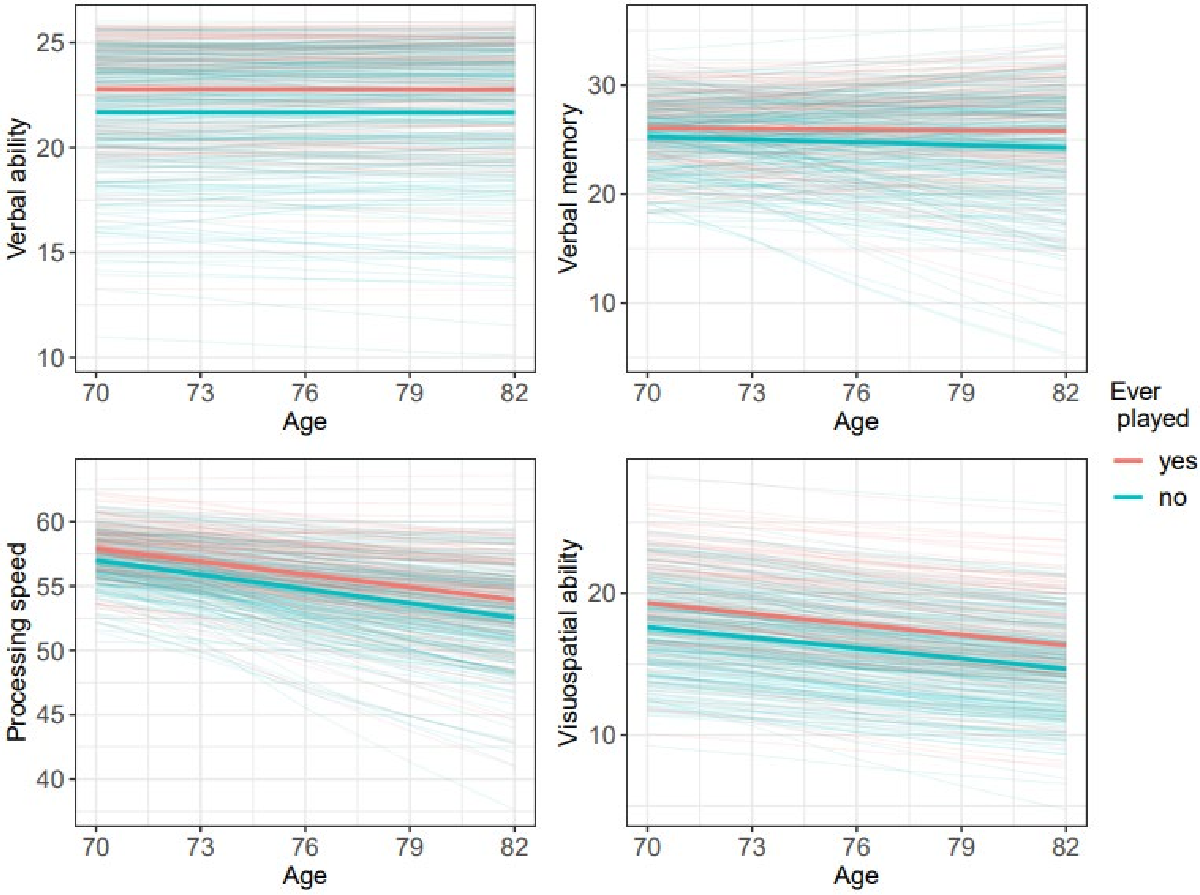
Means and Variances of the cognitive domain levels and slopes

Cognitive domain and parameter	Estimate	95% CI	*p*
Verbal ability			
Level mean	22.086	21.515,22.656	<0.001
Slope mean	-0.001	-0.034,0.031	0.938
Level variance	7.923	5.201,10.645	<0.001
Slope variance	0.006	-0.003,0.016	0.175
Verbal memory			
Level mean	25.603	25.091,26.116	<0.001
Slope mean	-0.058	-0.104,-0.011	0.015
Level variance	15.574	9.551,21.597	<0.001
Slope variance	0.127	0.088,0.166	<0.001
Processing speed			
Level mean	57.343	56.887,57.799	<0.001
Slope mean	-0.334	-0.376,-0.292	<0.001
Level variance	4.643	2.645,6.641	<0.001
Slope variance	0.054	0.026,0.082	<0.001
Visuospatial ability			
Level mean	18.263	17.801,18.725	<0.001
Slope mean	-0.233	-0.259,-0.206	<0.001
Level variance	13.983	10.574,17.392	<0.001
Slope variance	0.020	0.007,0.033	0.003

Note. p-values are uncorrected. Values for each cognitive domain were estimated in separate models. We used the marker variable approach to produce the mean structure for each cognitive domain. The level and slope estimates are scaled according to the cognitive tests used as the marker variables: verbal fluency for verbal ability, Logical Memory for verbal memory, inspection time for processing speed, and Block Design for visuospatial ability. Level = performance at Wave 1, slope = change in performance between Waves 1 and 5.

Figure 3

Model Estimated Levels and Slopes of the Cognitive Domains Grouped According To Whether Participants Reported Any Experience Playing A Musical Instrument



Note. Faint lines show individual participants and bold lines show average trajectories. Lines are grouped and colour coded according to whether participants reported any experience playing a musical instrument (see the labels above).

Main Results

Experience Playing a Musical Instrument and Cognitive Domain Levels and Slopes

Associations between *experience playing a musical instrument* and performance in the four cognitive ability domains (levels and slopes) are reported as standardized regression coefficients, these can be interpreted as change in the outcome, in standard deviation units, for a standard deviation change in the predictor. Standardized coefficients are also indicators of effect size; an effect size of 0.10 represents a small effect, 0.20 a medium effect and 0.30 a large effect (Funder & Ozer, 2019).

We firstly tested for an association between *experience playing a musical instrument* and cognitive domain levels (performance at age 70) and slopes (change in performance between ages 70-82), adjusting only for sex and age at time of testing (Model 1). Estimates from these models (shown in Tables 3-6) therefore represent the total association between *experience playing a musical instrument* and performance on each cognitive variable. We test for the role of potentially mediating or confounding variables in the second iteration of these models (Model 2).

In minimally-adjusted models, *experience playing a musical instrument* was positively associated with level of verbal ability (β = 0.211; 95% CI = 0.119, 0.303; FDR p = 0.003); level of verbal memory (β = 0.148; 95% CI = 0.021, 0.274; FDR p = 0.044); level of processing speed (β = 0.255; 95% CI = 0.151, 0.358; FDR p = 0.003); and level of visuospatial ability (β = 0.267; 95% CI = 0.168, 0.366; FDR p = 0.003). These associations indicate that participants with greater *experience playing a musical instrument* tended to perform better across all four cognitive ability domains at age 70. However, *experience playing a musical instrument* was not statistically significantly associated with the slope of change in any of the cognitive ability domains.

Supplementary Table 12 shows the model-implied associations between *experience playing a musical instrument* and levels of the cognitive ability domains at ages 73, 76, 79, and 82. These estimates were all statistically significant and similar in magnitude to those found at age 70, indicating that greater *experience playing a musical instrument* was positively associated with levels of performance across the cognitive ability domains at all five Waves of the study, between age 70 and 82.

Supplementary Tables 13-16 show residual variance of the cognitive test scores from each cognitive domain model.

Table 3

Associations Between Experience Playing a Musical Instrument and Verbal Ability Level and Slope

Parameter type and parameter	Estimate	95% CI	*p*	FDR *p*
Verbal ability level factor loadings				
VFTOT level	0.511	0.432,0.591	<0.001	
WTAR level	0.981	0.954,1.008	<0.001	
NART level	0.972	0.944,0.999	<0.001	
Verbal ability slope factor loadings				
VFTOT slope	0.442	0.133,0.751	0.005	
WTAR slope[1]	1.000	1.000,1.000		
NART slope[1]	1.000	1.000,1.000		
Regression paths				
Playing instrument → Verbal ability level	0.211	0.119,0.303	<0.001	0.003
Playing instrument → Verbal ability slope	0.015	-0.144,0.174	0.854	0.854
Sex → Verbal ability level	0.003	-0.093,0.099	0.946	
Sex → Verbal ability slope	0.155	-0.003,0.313	0.054	
Age Wave 1 → NART Wave 1	-0.018	-0.066,0.029	0.457	
Age Wave 1 → WTAR Wave 1	-0.048	-0.091,-0.005	0.030	
Age Wave 1 → VFTOT Wave 1	-0.092	-0.166,-0.018	0.015	
Correlations				
VFTOT level ←→ slope	-0.002	-0.268,0.264	0.989	
Verbal ability level←→ slope	0.027	-0.182,0.236	0.798	

Note. All estimates are standardized. VFTOT = verbal fluency, WTAR = Wechsler Test of Adult Reading, NART = National Adult Reading Test, FDR = False Discovery Rate. Age was treated as a time-varying covariate, cognitive tests at each Wave were regressed on age at that Wave. For brevity, only regressions for Wave 1 are shown. Level = performance at Wave 1, slope = change in performance between Waves 1 and 5.

[1]To allow the model to converge on within bounds estimates, residual variances of these slopes were fixed to zero; consequently, the factor loadings are fixed at 1.

Table 4

Associations Between Experience Playing a Musical Instrument and Level and Verbal Memory Level and Slope

Parameter type and parameter	Estimate	95% CI	*p*	FDR *p*
Verbal memory level factor loadings				
Logical memory level	0.772	0.649,0.896	<0.001	
Verbal pairs level	0.714	0.591,0.837	<0.001	
Digit backwards level	0.461	0.35,0.572	<0.001	
Verbal memory slope factor loadings				
Logical memory slope[1]	1.000	1.000,1.000		
Verbal pairs slope[1]	1.000	1.000,1.000		
Digit backwards slope	0.702	0.274,1.131	0.001	
Regression paths				
Playing instrument → Verbal memory level	0.148	0.021,0.274	0.022	0.044
Playing instrument → Verbal memory slope	0.076	-0.024,0.177	0.135	0.216
Sex → Verbal memory level	0.113	-0.028,0.254	0.117	
Sex → Verbal memory slope	0.099	-0.015,0.214	0.088	
Age Wave 1 → Verbal pairs Wave 1	-0.064	-0.141,0.012	0.101	
Age Wave 1 → Logical memory Wave 1	-0.125	-0.211,-0.04	0.004	
Age Wave 1 → Digit backwards Wave 1	-0.096	-0.174,-0.018	0.016	
Correlations				
Digit backwards level ←→ slope	-0.470	-0.833,-0.107	0.011	
Memory level←→ slope	-0.149	-0.309,0.01	0.066	

Note. All estimates are standardized. Age was treated as a time-varying covariate, cognitive tests at each wave were regressed on age at that wave. For brevity, only regressions for Wave 1 are shown. Level = performance at Wave 1, slope = change in performance between Waves 1 and 5, FDR = False Discovery Rate.

[1]To allow the model to converge on within bounds estimates, residual variances of these slopes were fixed to zero; consequently, the factor loadings are fixed at 1.

Table 5

Associations Between Experience Playing a Musical Instrument and Processing Speed Level and Slope

Parameter type and parameter	Estimate	95% CI	*p*	FDR *p*
Processing speed level factor loadings				
Inspection time level	0.532	0.435,0.629	<0.001	
Digit symbol level	0.793	0.714,0.871	<0.001	
Symbol search level	0.860	0.806,0.914	<0.001	
Reaction time level	0.723	0.64,0.807	<0.001	
Processing speed slope factor loadings				
Inspection time slope[1]	1.000	1.000,1.000		
Digit symbol slope	0.941	0.798,1.084	<0.001	
Symbol search slope[1]	1.000	1.000,1.000		
Reaction time slope	0.813	0.673,0.953	<0.001	
Regression paths				
Playing instrument → Pr. speed level	0.255	0.151,0.358	<0.001	0.003
Playing instrument → Pr. speed slope	0.067	-0.06,0.194	0.300	0.400
Sex → Processing speed level	0.031	-0.083,0.144	0.597	
Sex → Processing speed slope	0.049	-0.078,0.177	0.449	
Age Wave 1 → Symbol search Wave 1	-0.200	-0.271,-0.129	0.000	
Age Wave 1 → Digit symbol Wave 1	-0.114	-0.187,-0.041	0.002	
Age Wave 1 → Reaction time Wave 1	-0.101	-0.173,-0.029	0.006	
Age Wave 1 → Inspection time Wave 1	0.001	-0.084,0.086	0.985	
Correlations				
Digit symbol level ←→ slope	-0.632	-1.161,-0.103	0.019	
Reaction time level ←→ slope	0.151	-0.21,0.512	0.413	
Speed level←→ slope	0.178	0.008,0.347	0.040	

Note. All estimates are standardized. Age was treated as a time-varying covariate, cognitive tests at each wave were regressed on age at that wave. For brevity, only regressions for Wave 1 are shown. Level = performance at Wave 1, slope = change in performance between Waves 1 and 5, FDR = False Discovery Rate.

[1]To allow the model to converge on within bounds estimates, residual variance of these slopes were fixed to zero; consequently, the factor loadings are fixed at 1.

Table 6

Associations Between Experience Playing a Musical Instrument and Visuospatial Ability Level and Slope

Parameter type and parameter	Estimate	95% CI	*p*	FDR *p*
Visuospatial ability level factor loadings				
Block design level	0.851	0.792,0.91	<0.001	
Matrix reasoning level	0.896	0.822,0.969	<0.001	
Spatial span level	0.681	0.606,0.755	<0.001	
Visuospatial ability slope factor loadings				
Block design slope[1]	1.000	1,1		
Matrix reasoning slope	0.874	-0.049,1.796	0.063	
Spatial span slope[1]	1.000	1,1		
Regression paths				
Playing instrument → Vs. ability level	0.267	0.168,0.366	<0.001	0.003
Playing instrument → Vs. ability slope	0.032	-0.141,0.205	0.717	0.819
Sex → Visuospatial ability level	-0.265	-0.367,-0.164	<0.001	
Sex → Visuospatial ability slope	0.155	-0.025,0.335	0.090	
Age Wave 1 → Matrix reasoning Wave 1	-0.094	-0.167,-0.022	0.011	
Age Wave 1 → Spatial span Wave 1	-0.116	-0.199,-0.034	0.006	
Age Wave 1 → Block design Wave 1	-0.076	-0.143,-0.009	0.027	
Correlations				
Matrix reasoning level ←→ slope	0.383	-3.125,3.891	0.831	
Visuospatial ability level←→ slope	-0.200	-0.406,0.006	0.057	

Note. All estimates are standardized. Age was treated as a time-varying covariate, cognitive tests at each wave were regressed on age at that wave. For brevity, only regressions for Wave 1 are shown. Level = performance at Wave 1, slope = change in performance between Waves 1 and 5, FDR = False Discovery Rate.

[1]To allow the model to converge on within bounds estimates, residual variance of these slopes were fixed to zero; consequently, the factor loadings are fixed at 1.

Next, we additionally controlled the models for the effects of potentially confounding variables (referred to here as covariates): childhood environment, years of education, childhood cognitive ability, adult occupational class, health behaviours (smoking status, alcohol consumption and level of physical activity) BMI, history of chronic disease, and possible dementia (Model 2). Results from these models are displayed in Supplementary Tables 17-20 (including path estimates for all covariate variables). In these fully adjusted models, the magnitude of associations between *experience playing a musical instrument* and the cognitive variables were reduced but remained statistically significant for processing speed level (β = 0.131; 95% CI = 0.03,0.233; FDR p = 0.044) and visuospatial ability level (β = 0.154; 95% CI = 0.062,0.245; FDR p = 0.008). *Experience playing a musical instrument* was no longer significantly associated with verbal ability level (β = 0.019; 95% CI = -0.044,0.081; FDR p = 0.730); or verbal memory level (β = 0.021; 95% CI = -0.096,0.137; FDR p = 0.730). As in the minimally-adjusted models, *experience playing a musical instrument* was not associated with slopes of any of the cognitive ability domains.

Subsidiary Analysis (Not Pre-Registered)

Here we summarise the subsidiary analysis and results. Full details are provided in the Supplementary File, under the Subsidiary Analysis heading.

Excluding participants with no musical instrument experience

The main analytical sample included participants who had never played a musical instrument. We tested whether the associations found in the main analysis (between *experience playing a musical instrument* and the four cognitive domains) could be replicated in the subsample of participants reporting some musical instrument experience (N = 167). We re-ran the main analysis (described above) including just this subsample. In the age and sex adjusted model, *experience playing a musical instrument* was not associated with any of the cognitive domain levels or changes, even before FDR correction. These results suggest that our main findings could be driven (at least partly) by the contrast between participants with and without any musical instrument experience.

Comparing early life and continued/older age musicianship.

Next, we tested whether the statistically significant results observed in the main analysis (which included participants with no musical instrument experience, henceforth "non-players"), were mostly driven by participants reporting either early life or continued/older age musicianship. This was achieved by re-running the main analysis using two different subsamples. Firstly, to test for the influence of early life musical experience, we included only non-players (N = 294) and participants reporting early life musicianship (defined as playing an instrument only in childhood and/or young adulthood up to age 30; N = 86, total sample N = 380). Secondly, to test for the role of continued or later life musical experience, we included only non-players (N = 294) and participants reporting continued/older age musicianship (defined as playing a musical instrument at age 70 or older; N = 47, total sample N = 341). See the Supplementary File for further details.

In the analysis including only non-players and participants reporting early life musicianship and following adjustment for covariate variables (Model 2), *experience playing a musical instrument* was significantly positively associated with level of processing speed (β =0.163; 95% CI =0.048,0.277; FDR p = 0.048) but was not associated with levels verbal memory, verbal ability or visuospatial ability or change in any of the cognitive ability domains. In the analysis including only non-players and participants reporting continued/older age musicianship and following adjustment for covariate variables (Model 2), e*xperience playing a musical instrument* was not associated with levels or changes in any of the cognitive ability domains. These results could suggest that our main findings mostly reflect an association with early – rather than continued/older age – musicianship; however, it is also likely that the latter analysis was underpowered (with only 47 participants reporting continued/older age musicianship).

Testing for associations with general cognitive ability vs specific cognitive domains

The domain-specific measures of cognitive ability also included some variance associated with general cognitive ability. We ran a bifactor model (described in the Supplementary File and including the full N = 420 participant sample) to test whether the positive association between *experience playing a musical instrument* and the four cognitive domain levels reflected specific associations with these domains, or, whether these results partly reflected an association with general cognitive ability (modelled as the shared variance across all 13 cognitive tests). In this bi-factor model, the magnitude of associations between *experience playing a musical instrument* and the four cognitive domains (which no longer included variance associated with general cognitive ability) were reduced. Reductions in effect size were largest for verbal ability and verbal memory (percentage decrease 70% and 157%, respectively) and smaller for visuospatial ability and processing speed (39% and 22%, respectively). In the fully adjusted bifactor model, *experience playing a musical instrument* was not significantly associated with any of the four cognitive domains or general cognitive ability (see Supplementary Table 21). This suggests that our main results partly reflect an association between *experience playing a musical instrument* and general cognitive ability (as associations with the specific cognitive domains were non-significant once this variable was accounted for).

Discussion

In this observational longitudinal study of healthy older adults with varying levels of musical instrument experience (mostly gained in childhood and adolescence), we found that greater experience of playing a musical instrument was associated, positively, with verbal ability, verbal memory, visuospatial ability, and processing speed at age 70 (and also at age 73, 76, 79 and 82), but not with less decline in these cognitive abilities over the subsequent twelve years. The associations were small to moderate in magnitude, with effect sizes (β) ranging between 0.148 and 0.267. The positive association between experience playing a musical instrument and visuospatial ability and processing speed was reduced but remained statistically significant following further adjustment for potentially confounding variables including childhood environment, years of education, childhood cognitive ability, adult occupational class, health behaviours, BMI, history of chronic diseases, and possible dementia. Results from non-preregistered subsidiary analysis indicated that the above associations might be partly driven by early life musicianship and may reflect an association with general cognitive ability (in older age) as well as domain-specific abilities. These findings extend prior research with the LBC1936 sample (Okely et al., 2022), in which we found a positive association between experience playing a musical instrument and improvement on a single test of general cognitive ability between ages 11 and 70.

The present study is one of the first to test for an association between lifetime experience playing a musical instrument and cognitive change during older age. Our finding that musical instrument experience was positively associated with level but not change in all cognitive ability domains measured suggests a *preserved differentiation* effect; that is, the preservation of cognitive differences originating earlier in life (regardless of whether these were caused by the musical training). A higher cognitive ability at earlier life stages could itself impact musical engagement (Corrigall et al., 2013; Corrigall & Schellenberg, 2015), or at least partly be a consequence of musical training (Bigand & Tillmann, 2021; Swaminathan & Schellenberg, 2021). We controlled the analysis for childhood cognitive ability (MHT score), as well as other covariate variables, and thus could at least partly rule out the former direction of effect (confounding by prior cognitive ability) in favour of the latter (positive effects of musical training on cognitive performance; specifically, in the domains of processing speed and visuospatial abilities). Nevertheless, these positive observational results should be interpreted cautiously as it is possible that other variables not considered here confounded the association between musical instrument experience and performance on visuospatial and processing speed tasks (this issue is discussed in more detail in the limitations section below).

The positive associations found in the fully adjusted model support the idea that specific elements of musical instrument experience (such as reading music notation or extremely fast, fine motor control during musical performance) might enhance specific cognitive abilities such as processing speed and visuospatial abilities. Our results also corroborate findings from previous observational studies with older adults that report a positive association between “musician status” (indexed by past or current musical instrument training experience) and performance on individual tests of processing speed (Mansens et al., 2018) and visuospatial abilities (Hanna-Pladdy & Gajewski, 2012; Strong & Mast, 2019). Other studies have highlighted a potential link between musical training and verbal skills, including verbal memory and vocabulary (verbal ability) (Franklin et al., 2008;

Moreno, 2009; Moreno et al., 2011); however, these association were non-significant in our fully adjusted model. It is possible that effects on verbal skills are not always sustained beyond the musical training period, or that they are effected by more advanced, more extensive, or different kinds of musical training (Overy, 2012)

Domain-specific associations with processing speed and visuospatial abilities would fit with the established finding that cognitive training interventions generally lead to narrow, context-specific rather than general cognitive improvements (Simons et al., 2016). However, in subsidiary analysis which controlled for variance associated with general cognitive ability at age 70 (estimated as the shared variance across all 13 cognitive tests), experience playing a musical instrument was no longer associated with visuospatial or processing speed abilities in the fully adjusted model (including all covariate variables). This result tempers our domain-specific interpretation and suggests that experience playing a musical instrument may be jointly associated with both specific (visuospatial and processing speed) and general cognitive abilities. In a recent review, Stine-Morrow and Manavbasi (2022) outline how specific cognitive improvements resulting from cognitive training or engagement, might lead to greater engagement in other, related cognitive activities and thus growth in a range of related skills over time. This process could potentially also lead to more general cognitive enhancements.

Considering the profile of our musically trained participant sample (most of whom only played a musical instrument in childhood and adolescence), it is plausible that the association between experience playing a musical instrument and performance in rapid processing and visuospatial skills (the cognitive domains) was established in childhood or early adulthood in our sample, and preserved into adulthood and older age. This was partly supported by our subsidiary analysis in which early life musicianship (but not continued/later life musicianship) was positively associated with levels of processing speed (but not visuospatial ability) in the fully-adjusted model.

It is worth noting that longitudinal studies investigating the potentially protective effects of other early life exposures on cognitive ageing, report similar patterns of preserved differentiation, rather than differential preservation (Corley et al., 2022; Ritchie et al., 2016; Tucker-Drob, 2019). For instance, years of formal education which is an established predictor of higher cognitive ability across the lifespan (Opdebeeck et al., 2016; Ritchie & Tucker-Drob, 2018; Strenze, 2007), and lower dementia risk (Sharp & Gatz, 2011), is associated with a higher level but not less decline in cognitive abilities with ageing (Lövdén et al., 2020). This form of cognitive reserve does confer a protective effect against functional impairment: by declining from a higher peak level of cognitive ability, high reserve individuals take longer to reach clinical thresholds for cognitive impairment, despite declining at a similar rate to those with lower reserve.

It is possible that the association between experience playing a musical instrument and cognitive ageing varies depending on the timing of musical training exposure (Chan & Alain, 2020), with continued practice in older age potentially being more strongly associated with slower rates of cognitive decline than early life musicianship. It is likely that our study was under powered to detect such an effect, with only 47 participants reporting musical instrument practice during older age, and only 39 participants continuing to play up to the age of 82. Results from intervention studies indicate that musically naïve older adults who take up musical training can experience some cognitive benefits, at least over the short term (Alain et al., 2019; Bugos et al., 2007; Bugos & Kochar, 2017; Degé & Kerkovius, 2018; Guo et al., 2021; Seinfeld et al., 2013). Further work is needed to test whether the same cognitive benefits are associated with continued musicianship throughout the lifespan.

Ultimately, assuming a causal link is established, musical instrument training could be offered to older adults as an intervention, potentially alongside other activities (e.g., learning a new language; Leanos et al., 2020) to support a broad range of cognitive abilities in later life. We must also emphasise the wider ranging benefits of musical experience for older adults, not least the social and wellbeing benefits of making and enjoying music with others (Creech et al., 2013; Perkins & Williamon, 2014).

Strengths of this study include its longitudinal design, unusually long follow-up period in older age, the comprehensive range of cognitive tests completed by LBC1936 participants, and the information available regarding childhood cognitive ability and education, childhood and adulthood socio-economic circumstances, as well as health behaviours and status in older age. Our approach to modelling cognitive ability domains as latent variables (each indicated by three or four cognitive tests) reduced the influence of measurement error in our analysis and represents a further, important advantage. Finally, by modelling experience playing a musical instrument as a continuous variable, we captured information about individuals with more varying levels of experience. This approach contrasts with most other studies in the field which typically treat musical training as a binary variable, categorising participants as either "musicians" or "non-musicians" based on specific criteria (e.g., at least 10 years of musical training).

Our findings should be interpreted with several limitations in mind. Firstly, the generalisability of our findings must be considered. Our objective was to extend the findings from our participant sample to the wider population of healthy older adults in the UK and other countries with similar musical practices and traditions. However, our Wave 5 sample of 420 participants was characterised by higher levels of healthiness, socio-economic resources, and cognitive ability than found in the larger Wave 1 LBC1936 sample and, by extension, the general population of older adults living in the UK. It is likely that this sample composition resulted in an underestimate of the range of cognitive differences, and potentially, an underestimation of their association with musical instrument experience. Furthermore, our participant sample included only White participants from a specific area of Scotland. The particular musical experiences of these participants (most of whom reported playing the piano and receiving formal musical training) might further limit the generalisability of our results. Further research with a more diverse sample of older adults, including participants from different ethnic groups, cultural and socio-economic backgrounds would expand the generalisability of our findings.

Secondly, due to model complexity, we applied a multistage approach to the analysis: estimating factors scores for *experience playing a musical instrument* and then treating those scores as observed data in the main analysis. Factor scores (which are proxies of the true latent scores) contain more sources of error and introduce the problem of factor indeterminacy (the mathematical problem that factor scores are not uniquely defined) (Grice, 2001). However, factor scores are commonly used, and are recommended as a practical approach that is preferable to summing scores from multiple items (which was the alternative option in our analysis) (McNeish & Wolf, 2020).

Thirdly, musical instrument experience was reported by participants retrospectively, at age 82, and it is possible that participants did not recall their past musical experiences accurately. However, retrospective measures of lifetime activity (e.g., smoking, and physical activity) are commonly used in observational studies and have been generally shown to have good validity (Colby et al., 2011; Vuillemin et al., 2000).

Fourthly, our sample included only six participants who reached a semi-professional or professional level of musical performance. This greatly limited our ability to detect any potential associations with advanced levels of musical training. Results from subsidiary analysis, excluding participants who did not learn to play a musical instrument, indicated that the associations observed in the main analysis (between experience playing a musical instrument and the cognitive domain levels) were potentially driven by the contrast between participants with and without any experience playing a musical instrument (rather than between participants with varying levels of musical training). Nevertheless, it is thus especially noteworthy that we could detect this association in a participant sample with only limited levels of musical expertise. A related limitation is that most participants who had learnt to play a musical instrument received formal instrumental training (86%). This limited our capacity to compare the potential effect of formal relative to other types of musical instrument experience.

Fifthly, although we could control for general cognitive ability at age 11 using the MHT, specific cognitive ability domains (verbal ability, verbal memory, visuospatial ability and processing speed) were not assessed at that age. The content of the MHT test is weighted towards verbal abilities (Deary, Whiteman, et al., 2004) and therefore it is likely that it provided a better "control" for verbal ability than the other domains. As a result, we cannot completely rule out the potential influence of selection effects; that is, the possibility that individuals with higher levels of specifically visuospatial or processing speed abilities in childhood were more likely to engage with musical instrument training.

Finally, it is possible that our findings were driven by more general experiences gained during development: playing a musical instrument could serve as a proxy for greater engagement in a range of cognitively stimulating activities (Orsmond & Miller, 1999), that cumulatively contribute to improved cognitive function (Osler et al., 2013). We could not rule out this potential effect, as data on non-musical leisure activities in childhood was not collected. Other potentially confounding variables not accounted for in our analysis, include genetic factors (Mosing et al., 2016) and parent characteristics (Corrigall & Schellenberg, 2015).

In conclusion, in support of a preserved differentiation effect, we found that experience playing a musical instrument was associated with consistently higher levels of processing speed and visuospatial ability during older age. It is possible that these associations were established at the time of cognitive development, in childhood and adolescence, and preserved in later life. If further work can confirm that this is indeed a causal effect, then lifetime musical instrument training and experience could potentially delay the onset of functional impairment in older age, by raising cognitive ability levels, prior to aging.

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