Twin Research and Human Genetics (2022), **25**, 140–148
doi:10.1017/thg.2022.29

CAMBRIDGE UNIVERSITY PRESS

Article

Investigating the Relationship Between Childhood Music Practice and Pitch-Naming Ability in Professional Musicians and a Population-Based Twin Sample

Jane E. Bairnsfather[1], Fredrik Ullén[2,3], Margaret S. Osborne[1,4], Sarah J. Wilson[1] and Miriam A. Mosing[1,2,5]

[1]Melbourne School of Psychological Sciences, The University of Melbourne, Melbourne, Victoria, Australia, [2]Department of Neuroscience, Karolinska Institutet, Stockholm, Sweden, [3]Department of Cognitive Neuropsychology, Max Planck Institute for Empirical Aesthetics, Frankfurt am Main, Germany, [4]Melbourne Conservatorium of Music, The University of Melbourne, Melbourne, Victoria, Australia and [5]Behaviour Genetics Unit, Max Planck Institute for Empirical Aesthetics, Frankfurt am Main, Germany

Abstract

The relationship between pitch-naming ability and childhood onset of music training is well established and thought to reflect both genetic predisposition and music training during a critical period. However, the importance of the amount of practice during this period has not been investigated. In a population sample of twins ($N = 1447$, 39% male, 367 complete twin pairs) and a sample of 290 professional musicians (51% male), we investigated the role of genes, age of onset of playing music and accumulated childhood practice on pitch-naming ability. A significant correlation between pitch-naming scores for monozygotic ($r = .27$, $p < .001$) but not dizygotic twin pairs ($r = -.04$, $p = .63$) supported the role of genetic factors. In professional musicians, the amount of practice accumulated between ages 6 and 11 predicted pitch-naming accuracy ($p = .025$). In twins, age of onset was no longer a significant predictor once practice was considered. Combined, these findings are in line with the notion that pitch-naming ability is associated with both genetic factors and amount of early practice, rather than just age of onset per se. This may reflect a dose–response relation between practice and pitch-naming ability in genetically predisposed individuals. Alternatively, children who excel at pitch-naming may have an increased tendency to practice.

Keywords: Pitch-naming ability; absolute pitch; practice; music

(Received 18 July 2022; accepted 18 July 2022; First Published online 15 August 2022)

The development of expertise in music is complex and multifactorial, influenced by both genes and the environment (Ullén et al., 2016). The salience of practice in the development of musical expertise is controversial. While the deliberate practice theory claims that the accumulation of hours of practice is the sole determinant of expert performance (Ericsson et al., 1993), others have shown practice alone to be insufficient to explain individual differences in ability (Hambrick et al., 2014; Hambrick et al., 2016; Kragness et al., 2020; Macnamara et al., 2014; Macnamara & Maitra, 2019; Mosing, Madison et al., 2014). Studies highlight the importance of psychological factors such as personality traits (Butkovic et al., 2015; Corrigall et al., 2013; Corrigall & Schellenberg, 2015) and cognitive ability (Corrigall et al., 2013; Lynn et al., 1989; Meinz & Hambrick, 2010; Mosing et al., 2019; Mosing, Pedersen et al., 2014; Schellenberg & Weiss, 2013; Sergeant & Vhatcher, 1974; Swaminathan & Schellenberg, 2018; Swaminathan & Schellenberg, 2020), as well as the role of genetic factors (Hambrick & Tucker-Drob, 2015; Kragness et al., 2020; Mosing, Madison et al., 2014; Ullén et al., 2016; Ullén et al., 2014) in skill acquisition.

One aspect of music ability in which the role of practice is still an open question is pitch naming. Absolute pitch (AP) is the uncommon ability to name isolated musical pitches without the use of a reference tone. AP has largely been regarded separately to other questions around the development of expertise, as it is relatively rare and appears to be less reliant on deliberate practice. AP possessors often report 'discovering' their ability rather than acquiring it through practice (West Marvin et al., 2020), and a heritable component to the skill is likely (see Tan et al., 2014, for a review). While practice-related factors such as pedagogical methods with a focus on pitch naming have been shown to be positively associated with AP, AP itself is not explicitly taught (Gregersen et al., 2001; Miyazaki et al., 2018; Wilson et al., 2012).

Although AP is present in relatively few musicians, the ability to name some pitches is more widespread. A relatively understudied phenomenon, variously known as partial- or quasi-absolute pitch (QAP), refers to those who perform at above chance level in pitch-naming tasks, but below the near-ceiling performance generally accepted as the standard to qualify as possessing genuine AP (Miyazaki, 1988, 1989; Wilson et al., 2012; Wilson et al., 2009). This is in contrast to relative pitch (RP), the ability to use relationships between pitches to label musical tones. RP is the typical form

Author for correspondence: Jane E. Bairnsfather, Email: jbairnsfathe@student.unimelb.edu.au

Cite this article: Bairnsfather JE, Ullén F, Osborne MS, Wilson SJ, and Mosing MA. (2022) Investigating the Relationship Between Childhood Music Practice and Pitch-Naming Ability in Professional Musicians and a Population-Based Twin Sample. *Twin Research and Human Genetics* **25**: 140–148, https://doi.org/10.1017/thg.2022.29

of pitch identification used in music, and people with RP alone perform at chance level in pitch-naming tasks. The prevalence of QAP is not known, and the factors predicting its development remain under investigation. Preliminary studies suggest that QAP is related to AP insofar as the same factors predict its acquisition, although to a lesser extent (Wilson et al., 2012). If AP is the extreme, the existence of QAP suggests that there is a broader continuum of pitch-naming ability; however, more research is needed to determine if there are distinct phenotypes.

One factor that consistently emerges in pitch-naming research is the notion of a critical or sensitive period for acquisition (Baharloo et al., 1998; Deutsch et al., 2009; Levitin & Zatorre, 2003; Vitouch, 2003; Wilson et al., 2012). Analogous to the concept in language development, it refers to a developmental window in which children who may be predisposed to AP should be exposed to musical training to maximize the probability that they will acquire AP. The majority of AP possessors begin musical activities in early childhood, between the ages of 3 and 7, and the proportion of AP possessors who start at an older age decreases steadily, consistent with a gamma distribution (Levitin & Zatorre, 2003). Young age of onset of musical training is also associated with QAP ability (Wilson et al., 2012).

It has also been suggested that current musical practice is important in pitch-naming ability. Some AP musicians can 'shift' their pitch templates through practice on transposing instruments (i.e. instruments for which written notation differs from the produced pitch; West Marvin et al., 2020), and engagement in musical practice has been associated with maintenance of pitch-naming ability (Dohn et al., 2014; Wilson et al., 2012). Reduced engagement in practice can lead to a self-reported decline in pitch-naming ability (West Marvin et al., 2020) and exposure to mistuned stimuli can alter musicians' pitch templates (Hedger et al., 2013; van Hedger et al., 2018). These findings suggest that engagement in music is beneficial for the maintenance and adaptation of pitch-naming skills.

While the role of current practice in maintaining pitch naming is acknowledged, the influence of practice over the course of development has not yet been examined. Practice has largely been considered as present or absent, with little consideration of the role of the amount or intensity of practice. As pitch-naming in adulthood is somewhat malleable when based on practice factors, it stands to reason that practice-related variables during childhood may shape pitch-naming ability as it emerges.

With this in mind, we used data from a large sample of professional musicians to explore whether practice throughout development predicts pitch-naming ability in adulthood, and how this relates to the age of onset of playing. Since previous research has shown that instrument choice also relates to pitch-naming ability (Miyazaki et al., 2018; Wilson et al., 2012), we examined the role of the main instrument that musicians played. To determine whether our findings generalized beyond expert musicians, we replicated these analyses in a large population twin sample who played music during childhood and currently. For a subsample of complete monozygotic (MZ) and dizygotic (DZ) twin pairs, we also investigated the importance of genetic and specific environmental factors on pitch naming ability, including a review of the practice histories of high-performing twin pairs.

Methods

Participants

Participants were drawn from two existing datasets consisting of (1) professional musicians and (2) twins. Data were collected between 2012 and 2014, using matched web-based surveys that collected a range of music-related information.

Musician Sample

Professional musicians were recruited through advertisements in professional music publications, Swedish orchestras and music schools (for details, see Wesseldijk et al., 2021). Sample size was not predetermined, so all participants who responded to the advertisement and fulfilled the following criteria were included. Criteria for inclusion in the present study included participants who (1) currently played music professionally or as tertiary music students, (2) received music lessons during childhood and (3) responded to at least four trials of the pitch-naming task (see task details below). A web-based survey, including music experience-related items (Mosing, Madison et al., 2014), was completed by 582 musicians in 2013–2014, of which 290 ($M_{age} = 48.71$, $SD = 12.06$) met the inclusion criteria.

Twin Sample

Participants were drawn from the Study of Twin Adults: Genes and Environment (STAGE) cohort, which consists of approximately 32,000 twins from the Swedish Twin Registry, born between 1959 and 1985 (Lichtenstein et al., 2002; Lichtenstein et al., 2006). Of this cohort, 11,525 individuals completed the web-based survey in 2012–2013. Sample size was not predetermined as all members of the cohort were invited to participate. Applying the inclusion criteria as detailed for the musicians, this resulted in a sample of 1447 twins ($M_{age} = 40.63$, $SD = 7.99$) including 367 complete twin pairs (734 individuals; 193 MZ pairs, 174 DZ pairs; $M_{age} = 40.27$, $SD = 8.11$).

The musician and twin studies were approved by the Regional Ethics Review Board in Stockholm (Dnr 2011/570-31/5; Dnr 2013/1777-32) and the Office of Research Ethics and Integrity at the University of Melbourne (2021-14,445-14,697-3). All participants provided informed consent.

Measures

The web-based surveys included questions relating to the participants' music experience (for further details, see Mosing, Madison et al., 2014). Relevant items for the current study included: age of onset of musical training, age at which music playing ceased (where appropriate), main instrument and self-reported hours of music practice during different periods of life.

Age of onset of playing. Participants reported the age at which they commenced playing an instrument.

Hours of music practice. Since retrospective self-report has been shown to be a reasonably reliable estimate of practice hours (de Bruin et al., 2008; Ericsson et al., 1993; Howard, 2011), participants were asked to estimate the number of hours they practiced music per week, based on 10 response options, ranging from 0 to >40 h per week, for each of three age intervals: 0–5, 6–11 and 12–17 years. Based on these responses and the number of years within each age bracket, taking account of age of onset, the total amount of practice within each age bracket was calculated for each participant.

Current weekly practice. Participants estimated the amount they currently practiced music per week. Response options were again divided into 10 categories, ranging from 0 to >40 h per week.

Main instrument. Since previous research has shown that both early and current practice on a 'fixed-do' instrument predicts AP (Wilson et al., 2012), participants were asked to name their main instrument (or voice). For analysis, responses were categorized into either fixed- or moveable-do instruments. Fixed-do instruments are those with fixed tunings, such as the piano, compared with instruments with pitch that varies based on the musician's skill (e.g. string and woodwind instruments).

Pitch-naming task. Pitch-naming ability was assessed using a brief online task. Participants were asked to identify the pitch class (chroma) of 24 single-tone auditory stimuli by clicking the note name corresponding to the pitch they heard. Note names were presented on the screen in a circle, with C in the 12 o'clock position. Twelve stimuli were piano tones sampled from a Bösendorfer grand piano in Kontakt software 4 (Native Instruments), and 12 were sine tones generated using Audacity 2.1.2 (Audacity Team, www.audacityteam.org). Stimuli were drawn from the central range (C4-B5), with each chroma presented once as a piano tone and once as a sine tone. Each stimulus was 1 s in duration, and participants were given a maximum of 3 s to respond. A six-trial practice block comprising three piano and three sine tones preceded the task. No feedback was provided throughout the task.

The task was scored and analyzed as the mean absolute deviation (MAD) in cents from the participant's response to the target chroma across all 24 trials. Larger cent values refer to larger errors, with an error of one semitone (e.g. responding G# when the correct answer is G) corresponding to a deviation of 100 cents. We treated pitch naming as a continuum, rather than applying a strict threshold for AP qualification, to gain an understanding of the full spectrum of the trait and its relation to practice variables. The total number of tones correctly identified was also calculated for descriptive purposes.

Statistical Analyses

Statistical analyses were performed using RStudio (Version 1.3.959), including R packages *tidyverse*, version 1.3.0 (Wickham et al., 2019), *psych*, version 2.1.9 (Revelle, 2021), *broom*, version 0.7.9 (Robinson et al., 2021), *sandwich*, version 3.0–1 (Zeileis, 2004; Zeileis et al., 2020), *lmtest*, version 0.9-38 (Zeileis & Hothorn, 2002) and *ggridges*, version 0.5.3 (Wilke, 2021) and IBM SPSS Statistics 26.

Factors predicting pitch-naming ability. We used hierarchical multiple regressions to investigate the factors associated with pitch-naming ability. To correct for skew, a Box-Cox transformation was applied to the MAD variable ($\lambda = 2.30$ for musicians, $\lambda = 18$ for twins). Three regression models were fitted to each dataset, first predicting MAD from age, sex, age of onset of playing and main instrument (base model 1). Second, the three accumulated practice variables (i.e. total hours of childhood practice during 0–5, 6–11 and 12–17 years) were added to the base model (Model 2), followed by current weekly practice (Model 3). To adjust for relatedness in the twin sample, the robust standard error estimator for clustered observations was used.

Additional twin analyses. Twin correlations for MAD scores were computed separately for MZ and DZ twin pairs. As the familial environment is assumed to be shared across both members of a twin pair, trait differences between twins may be attributable to genetic and unique environment influences (for DZ twins) or unique environment alone (for MZ twins). To further explore environmental influences on pitch-naming ability, within-pair differences in the practice histories of twins with at least one co-twin performing with a MAD of <200 cents (one tone) were explored in greater detail.

Results

Pitch-Naming Accuracy

Detailed participant information for both samples is shown in Table 1, with additional music experience and pitch-naming task details in Supplementary Table 1. Figure 1 shows the distribution of MAD for both samples. Although musicians outperformed the general population twin sample as expected, pitch-naming accuracy was generally low in both samples, falling along a continuum from chance level to highly accurate performance. Supplementary Figure 1 shows the distribution of correctly identified tones against a binomial (chance) distribution ($p = 1/12$ [2/24]) for each sample, confirming that most participants (particularly in the population twin sample) performed around the chance level and lacked the ability to reliably name pitches despite being musically active.

Factors Predicting Pitch-Naming Ability in Musicians

Hierarchical multiple regressions showed that the base model predicted the transformed MAD ($F[4, 28] = 3.17$, $p = .014$, adjusted $R^2 = .03$; see coefficients in Table 2). Sex significantly predicted pitch-naming ability, with females showing better performance (lower MAD). Age of onset of playing showed a trend, suggesting that younger age of onset resulted in lower MAD. When adding the three childhood practice variables (Model 2: $F[7, 282] = 2.95$, $p = .005$, adjusted $R^2 = .05$; see coefficients in Table 2), sex showed a trend and age of onset was nonsignificant, while accumulated hours of practice between the ages of 6 and 11 years were associated with lower MAD. In Model 3 ($F[8, 281] = 2.71$, $p = .007$, adjusted $R^2 = .05$), accumulated practice between the ages of 6 and 11 years remained significant ($p = .040$), with no significant contribution of current practice ($p = .309$). Regression coefficients for Model 3 and correlations between predictors are shown in Supplementary Tables 2–4.

Factors Predicting Pitch-Naming Ability in the Population Twin Sample

Regression analyses were replicated in the general population twin sample. Results from Model 1 are shown in Table 3 ($F[-4, 1446] = 6.17$, $p < .001$, adjusted $R^2 = .01$). Both a younger age of onset and playing a fixed-do main instrument predicted better pitch-naming ability (MAD).

Adding the practice variables in Model 2 resulted in age of onset no longer contributing significantly to the model (see Table 3). In this sample, however, accumulated hours of practice between 6 and 11 years did not approach significance, while playing a fixed-do instrument was associated with better pitch-naming ability (MAD). Adding current practice to Model 3 showed that playing a fixed-do main instrument remained significant ($p = .002$), while current practice did not contribute to the model ($p = .422$). Regression coefficients for Model 3 and correlations between predictors are shown in Supplementary Tables 5–7.

Table 1. Demographic and music experience of the participants

Variable	Professional musicians (*N* = 290) Mean (*SD*)	Range	Population twin sample (*N* = 1447) Mean (*SD*)	Range	Complete twin pairs (*N* = 734 individuals) Mean (*SD*)	Range
Age	48.7 (12.1)	22–85	40.6 (8.0)	27–54	40.3 (8.1)	27–54
Sex	148 M (51%)		562 M (39%)		271 M (37%)	
Age of onset of playing	7.4 (2.3)	2–16	8.2 (2.5)	2–29	8.2 (2.5)	2–29
Currently playing (*n*)	290 (100%)		1244 (86%)		537 (73%)	
Accumulated hours of practice during ages:						
0–5 years	59.5 (159.2)	0–1040	41.8 (156.5)	0–1872	39.8 (159.0)	0–1872
6–11 years	976.2 (629.5)	0–2808	826.5 (577.1)	0–3120	821.7 (577.3)	0–3120
12–17 years	2014.4 (542.1)	520–3120	1518.0 (666.1)	0–3120	1454.9 (691.9)	0–3120
Total accumulated hours (0–17 years)	3050.1 (1082.37)	520–6448	2386.3 (1146.0)	0–7332	2316.5 (1185.0)	0–7332
Current practice (hours/week)[a]	15–40	2–66+	3–5	0–66+	3–5	0–66+
Main instrument 'fixed-do'	95 (33%)		294 (20%)		166 (23%)	
Pitch-naming						
Accuracy	3.5 (4.5)	0–24	2.27 (1.9)	0–22	2.37 (2.01)	0–20
MAD[b]	255.7 (85.1)	0–408	292.7 (44.6)	13–438	291.8 (45.6)	14–413

[a]Means reflect spans across categorical response options rather than point estimates.
[b]MAD = mean absolute deviation, measured in cents (1 semitone = 100 cents).

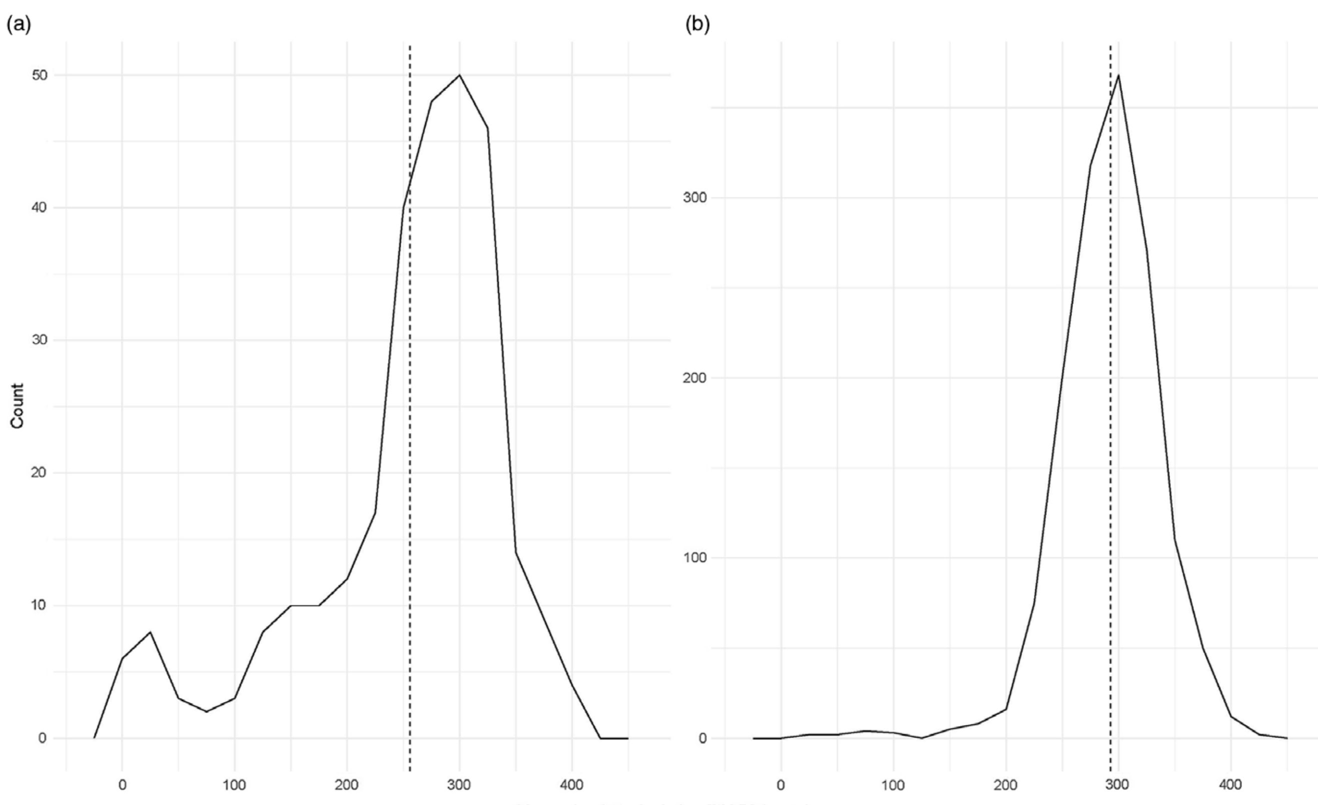

Fig. 1. Mean absolute deviation (MAD; cents) distributions for (a) musicians and (b) the general population twin sample
Note: Dashed lines indicate the mean MAD for each sample.

https://doi.org/10.1017/thg.2022.29 Published online by Cambridge University Press

Table 2. Models predicting pitch-naming ability in musicians

Predictors	B (95% CI)	Standard error	β	Significance
Model 1				
(Intercept)	151932.2 (99210.3, 204654.1)	26785.2	−0.1	<.001***
Sex (M)	22584.5 (328.4, 44840.5)	11307.1	0.2	.047*
Main instrument ('fixed-do')	−15065.8 (−38304.6, 8173.0)	11806.4	−0.2	.203
Age	−370.0 (−1295.7, 555.8)	470.3	−0.1	.432
Age of onset of playing	4657.4 (−106.4, 9421.2)	2420.2	0.1	.055
Model 2				
(Intercept)	231998.6 (147569.3, 316427.8)	42892.1	−0.1	<.001***
Sex (M)	21930.0 (−575.9, 44435.8)	11433.5	0.2	.056
Main instrument ('fixed-do')	−11503.8 (−35000.4, 11992.7)	11936.8	−0.1	.336
Age	−326.9 (−1251.1, 597.3)	469.5	−0.0	.487
Age of onset of playing	−4002.9 (−11774.2, 3768.5)	3948.0	−0.1	.312
Accumulated hours of practice (0–5 years)	−60.2 (−143.1, 22.7)	42.1	−0.1	.154
Accumulated hours of practice (6–11 years)	−33.8 (−63.4, −4.2)	15.1	−0.2	.025*
Accumulated hours of practice (12–17 years)	8.6 (−15.6, 32.8)	12.2	0.1	.485

Note: $*p < .05$, $**p < .01$, $***p < .001$.

Twin Correlations for Pitch-Naming Performance in MZ Versus DZ Twins

Twin correlations for MAD in MZ and DZ pairs are shown in Figure 2. MAD was significantly correlated for MZ twin pairs, $r = .27$, $p < .001$, indicating that twins within MZ pairs were likely to have similar pitch-naming scores. No such correlation was seen in DZ pairs, $r = -.04$, $p = .63$. It should be noted that the MZ correlation was heavily influenced by two high-performing MZ twin pairs, in which both members had very low MADs. There were no similarly outstanding performances by both members of DZ twin pairs. Since it is unlikely that both twins performed so well due to chance and pitch naming is treated as a continuous ability here, we decided to retain these high-performing pairs in the analysis.

Practice Profiles of High-Performing Twins and Their Co-Twins

Practice profiles for twin pairs in which at least one individual had a MAD < 200 cents on the pitch-naming task ($n = 14$ pairs, 28 individuals) are shown in Figure 3.

The majority of MZ and DZ twin pairs played instruments within the same class (both movable-do or both fixed-do) and often within the same instrument family (e.g. both members of Pair 1 play a string instrument and both members of Pair 12 are singers). Where instrument choice differed within a pair, the individual with the higher pitch-naming score was usually the one who played a fixed-do instrument, with the exception of Pair 4. Few participants accumulated any practice hours between the ages of 0 and 5 years, indicating that they did not start playing until after this time. With the exception of one participant (the female member of Pair 8), all twins were musically active between ages 6 and 11. Within MZ pairs, but not DZ pairs, the twin who accumulated more hours of practice in childhood consistently outperformed the twin with fewer hours of practice.

Discussion

In this study, we explored how the age of onset and accumulated music practice throughout childhood relate to pitch-naming ability in adulthood, in both professional musicians and a sample of twins. We found that high pitch-naming accuracy is relatively rare even in a sample with a significant history of music playing. As expected, professional musicians performed somewhat better than amateur musicians from the general population, with pitch-naming accuracy lying along a continuum of ability for both groups. Overall, pitch-naming ability in musicians was significantly predicted by hours of accumulated practice between ages 6 and 11, and an analysis of twin pairs suggested a heritable component to pitch-naming ability.

Factors Predicting Pitch Naming

Age of onset of musical training initially predicted pitch-naming in both samples, although not quite reaching significance in musicians. When accumulated practice during childhood was considered, however, age of onset no longer predicted pitch-naming performance in either group. In musicians, accumulated practice between ages 6 and 11 predicted pitch-naming, whereas the earlier and later practice measures were nonsignificant. Although this finding did not approach significance in the twin sample, the overall direction of results mirrored that of the musicians — an initial contribution of age of onset, disappearing in favor of practice in the 6-to-11 age period. The contribution of practice is consistent with previous findings by Wesseldijk and colleagues (2021), who similarly showed that age of onset associations with musical and sporting achievements was no longer significant after adjusting for lifetime accumulated practice. Overall, the finding of a critical window for accumulated practice is consistent with the notion that an early start is relevant. The age bracket of 6–11 years broadly adheres with models of AP, showing that younger age of onset is associated with greater AP prevalence (Baharloo et al., 1998;

https://doi.org/10.1017/thg.2022.29 Published online by Cambridge University Press

Table 3. Models predicting pitch-naming ability in the twin sample

Predictors	B (95% CI)	Standard error	β	Significance
Model 1				
(Intercept)	15408.3 (14174.7, 16641.9)	628.9	0.0	<.001***
Sex (M)	404.8 (−67.1, 876.7)	240.6	0.1	.093
Main instrument (‘fixed-do’)	−844.1 (−1349.1, −339.1)	257.4	−0.2	.001**
Age	−12.3 (−38.0, 13.4)	13.1	−0.0	.347
Age of onset of playing	91.0 (5.9, 176.0)	257.4	0.2	.036*
Model 2				
(Intercept)	15857.3 (14147.6, 17567.0)	871.6	0.0	<.001***
Sex (M)	372.7 (−106.7, 852.2)	244.4	0.1	.127
Main instrument (‘fixed-do’)	−791.6 (−1300.9, −282.3)	259.6	−0.2	.002**
Age	−11.8 (−37.5, 13.8)	13.1	−0.0	.366
Age of onset of playing	49.1 (−71.0, 169.2)	61.2	0.0	.422
Hours of practice (0–5 years)	0.7 (−0.9, 2.2)	0.8	0.0	0.399
Hours of practice (6–11 years)	−0.4 (−1.1, 0.2)	0.3	−0.1	.182
Hours of practice (12–17 years)	0.1 (−0.2, 0.5)	0.2	0.0	.438

Note: $*p < .05$, $**p < .01$, $***p < .001$.

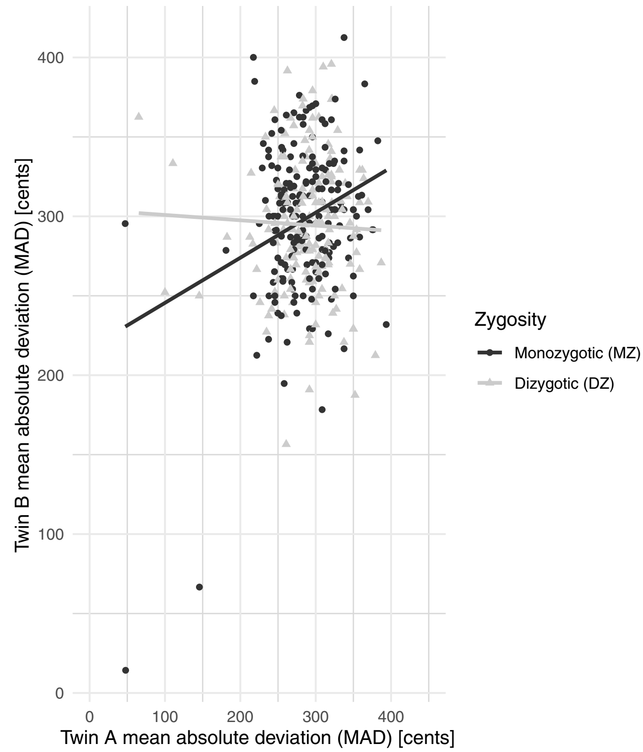

Figure 2. Scatterplot showing pitch-naming performance (MAD) for MZ and DZ twin pairs

Deutsch et al., 2009; Levitin & Zatorre, 2003; Vitouch, 2003; Wilson et al., 2012).

While the association between early accumulated practice and pitch-naming may be causal, equally it could suggest that a predisposition for good pitch-naming may lead to an increased likelihood of intense early practice (i.e. a reverse causality or gene–environment correlation), or that a generalized predisposition to musicality leads to both intense early practice and good pitch naming (aligning with findings suggesting that a tendency towards practice is heritable; Kragness et al., 2020; Mosing, Madison et al., 2014). Further research is required to explore each of these possibilities.

In the twin sample, choice of main instrument was a significant predictor of pitch-naming accuracy, with playing a fixed-do instrument predicting better performance. This aligns with previous AP research showing that pitch-naming is more accurate in musicians who play fixed-do instruments such as piano (Miyazaki et al., 2018; Wilson et al., 2012). In the more expert sample of musicians, however, instrument choice was not a significant predictor, suggesting that the salience of this factor may reduce with greater musical expertise.

Pitch Naming in Twin Pairs

Among twins, there was a significant within-pair correlation in pitch-naming ability for MZ but not DZ pairs, pointing to a role for genetic factors in pitch-naming ability. This is consistent with research suggesting genetic contributions to AP (Baharloo et al., 1998; Baharloo et al., 2000; Gregersen et al., 2001; Gregersen et al., 2013; Profita & Bidder, 1988; Theusch et al., 2009; Theusch & Gitschier, 2011); however, this finding should be interpreted with caution due to the small number of high-performing pairs in the sample. It is noteworthy that the pairs in which both members performed well were MZ, and that no similar patterns of performance were seen among DZ pairs.

Although there was much variation in the practice profiles of high-performing twin pairs and too few pairs to draw any firm conclusions, there were a few notable features. Differences in practice hours appeared to be consistently associated with pitch-naming differences among MZ pairs, but not DZ pairs. Although this is a small sample, it suggests that when genetic contributions are held constant (as in MZ pairs), differences in practice intensity may partly explain pitch-naming differences, while additional elements (e.g. playing a fixed- vs. movable-do instrument) may be at play when genetic factors vary (as in DZ pairs). These findings are consistent with an underlying gene–environment interplay. Aligning with the overall predictive model for the general population sample, the higher-performing individuals were generally those who played fixed-do instruments. As in previous work, these high-performing pairs tended to play instruments from the same class (Mosing & Ullén, 2018), though there were too few pairs to make comparisons between MZ and DZ pairs.

Limitations and Future Directions

A notable feature of both samples is the rarity of good pitch-naming performance. While this is consistent with an estimated AP prevalence of 1/10,000 (Bachem, 1955), it is not reflective of more recent estimates, particularly when taking QAP-level performance into account. AP has been reported in between <1% and up

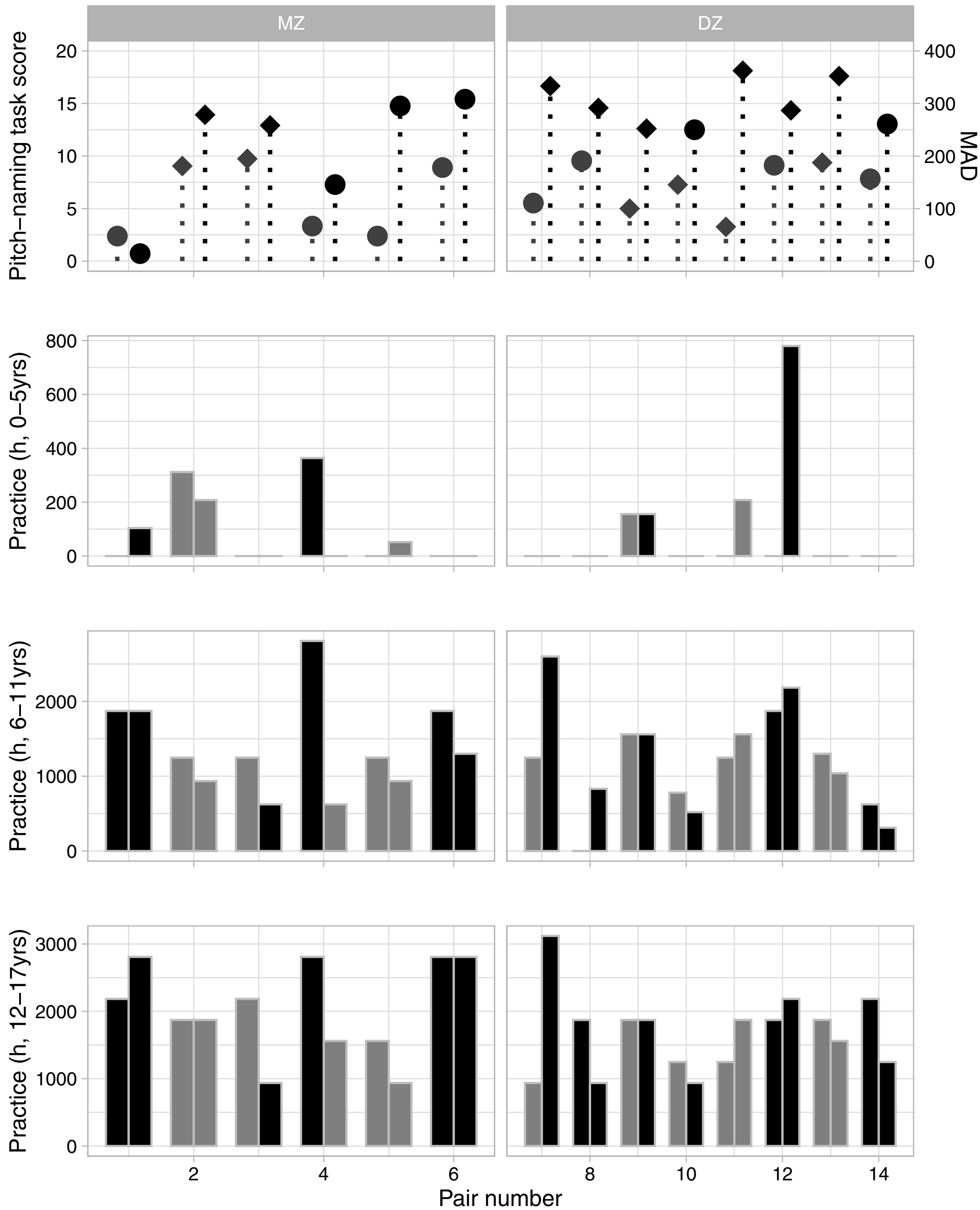

Figure 3. Practice profiles and pitch-naming performance of high-performing twins and their co-twins.
Note: Panels are to be read vertically, such that aligned columns show data for the same participant. Paired columns show data for a single twin pair, with the highest-performing individual on the pitch-naming task always shown on the left. Panels grouped to the left show monozygotic (MZ) twin pairs, and the right panels show dizygotic (DZ) twin pairs. In the top row, the columns refer to the raw scores on the pitch-naming task (higher values = better performance), while the lollipops refer to the mean absolute deviations (MADs; lower values = better performance). Round tops on the lollipops denote female participants, while diamonds denote males. The practice panels show the accumulated hours of practice for each individual across the three age periods of interest. In these panels, column color indicates main instrument choice: black refers to movable-do instruments, and gray refers to fixed-do instruments.

to 65% of tertiary music students (Deutsch et al., 2006; Leite et al., 2016; Miyazaki et al., 2012; Miyazaki et al., 2018), a wide estimate reflective of different ethnicities, populations and accuracy thresholds for AP.

The task used in this study is comparable to other lab-based and web-based pitch-naming studies in terms of stimulus length and response interval (Athos et al., 2007; Bermudez & Zatorre, 2009; Chavarria-Soley, 2016; Deutsch et al., 2006; Miyazaki et al., 2012; Oechslin et al., 2010; Wilson et al., 2009), so increased task difficulty is unlikely to account for the low overall performance. More nuanced profiles of intermediate performance could have been gained with an increased number of trials, as increased accuracy for some notes over others would have been evident, but highly accurate AP can be detected with a small number of trials (e.g. 20 trials, Hutka & Alain, 2015; 24 trials, Aruffo et al., 2014). Generally, larger estimates of AP come from studies conducted in East Asian countries, with lower prevalence in Europe and the United States (Miyazaki et al., 2018). Musicians with East Asian ethnicity or language background are more likely to have AP than those of other ethnicities (Deutsch et al., 2006; Gregersen et al., 2001; Henthorn & Deutsch, 2007; Miyazaki et al., 2018). Since our sample is drawn from Sweden, this may have contributed to the relatively low prevalence of AP. As this study drew from existing datasets and did not recruit for participants with AP, this may have impacted the prevalence of good pitch-naming in this sample. It is notable that we still found consistent practice-related results in such a low-prevalence sample, which might have been expected to weaken our findings.

Although our results show that pitch-naming ability is likely to be influenced by childhood practice, the extent to which this applies to higher-accuracy AP musicians is yet to be determined. Intermediate pitch-naming ability (QAP), which is largely seen in this sample, may be influenced by practice-related factors to a greater extent than AP. For example, QAP musicians often use 'reference notes' to aid their pitch-naming, which tend to be pitches common in their practice experience, such as notes used for tuning (Bachem, 1937; Miyazaki, 1988, 1989, 1990; Wilson et al., 2009). Increased practice-related exposure to these notes leads to their increased recognition in pitch-naming tasks, potentially accounting for the influence of practice in the current sample. Future work with AP musicians should investigate the possibility that different mechanisms may be at play for AP as opposed to QAP musicians.

Conclusion

Our study is the first to show that in expert musicians, the amount of accumulated music practice in early childhood relates to pitch-naming ability in adulthood over and above the age of practice onset. Increased practice during a sensitive period may interact with other predisposing factors to influence pitch-naming aptitude, or a predisposition for pitch-naming ability may encourage additional practice. In a general population sample, playing a fixed-do instrument is associated with improved pitch-naming ability, though this is not evident in expert musicians. The basis of an underlying genetic predisposition to pitch-naming requires additional exploration, though this endeavor is challenged by the rarity of good pitch-naming ability, even in our large genetically informative sample. Our preliminary exploration shows that pitch naming is more similar in MZ than DZ twin pairs, supporting a heritable component to this skill.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/thg.2022.29.

Author Contributions. JB analyzed the data, interpreted the results and drafted the manuscript. FU and MM designed the study and collected the data. MM and SW interpreted the results. All authors provided critical revisions and contributed to the manuscript. JB is responsible for the integrity of the data analyzed.

Financial Support. The present work was supported by the Bank of Sweden Tercentenary Foundation (M11-0451:1), the Sven and Dagmar Salén Foundation and the Marcus and Amalia Wallenberg Foundation (MAW 2018.0017). The Swedish Twin Registry is managed by Karolinska Institutet and receives funding through the Swedish Research Council under the grant no 2017-00641.

Conflict of Interest. None.

References

Aruffo, C., Goldstone, R. L., & Earn, D. J. D. (2014). Absolute judgment of musical interval width. *Music Perception*, *32*, 186–200.

Athos, E. A., Levinson, B., Kistler, A., Zemansky, J., Bostrom, A., Freimer, N., & Gitschier, J. (2007). Dichotomy and perceptual distortions in absolute pitch ability. *Proceedings of the National Academy of Sciences*, *104*, 14795–14800.

Bachem, A. (1937). Various types of absolute pitch. *Journal of the Acoustical Society of America*, *9*, 146–151.

Bachem, A. (1955). Absolute pitch. *Journal of the Acoustical Society of America*, *9*, 146–151.

Baharloo, S., Johnston, P. A., Service, S. K., Gitschier, J., & Freimer, N. B. (1998). Absolute pitch: An approach for identification of genetic and non-genetic components. *American Journal of Human Genetics*, *62*, 224–231.

Baharloo, S., Service, S. K., Risch, N., Gitschier, J., & Freimer, N. B. (2000). Familial aggregation of absolute pitch. *American Journal of Human Genetics*, *67*, 755–758.

Bermudez, P., & Zatorre, R. J. (2009). A distribution of absolute pitch ability as revealed by computerized testing. *Music Perception*, *27*, 89–101.

Butkovic, A., Ullén, F., & Mosing, M. A. (2015). Personality related traits as predictors of music practice: Underlying environmental and genetic influences. *Personality and Individual Differences*, *74*, 133–138.

Chavarria-Soley, G. (2016). Absolute pitch in Costa Rica: Distribution of pitch identification ability and implications for its genetic basis. *Journal of the Acoustical Society of America*, *140*, 891–897.

Corrigall, K., Schellenberg, E. G., & Misura, N. (2013). Music training, cognition, and personality. *Frontiers in Psychology*, *4*, Article 222.

Corrigall, K. A., & Schellenberg, E. G. (2015). Predicting who takes music lessons: Parent and child characteristics. *Frontiers in Psychology*, *6*, Article 282.

de Bruin, A. B. H., Smits, N., Rikers, R. M. J. P., & Schmidt, H. G. (2008). Deliberate practice predicts performance over time in adolescent chess players and drop-outs: A linear mixed models analysis. *British Journal of Psychology*, *99*, 473–497.

Deutsch, D., Dooley, K., Henthorn, T., & Head, B. (2009). Absolute pitch among students in an American music conservatory: association with tone language fluency. *The Journal of the Acoustical Society of America*, *125*, 2398–2403.

Deutsch, D., Henthorn, T., Marvin, E., & Xu, H. (2006). Absolute pitch among American and Chinese conservatory students: Prevalence differences, and evidence for a speech-related critical period. *The Journal of the Acoustical Society of America*, *119*, 719–722.

Dohn, A., Garza-Villarreal, E. A., Ribe, L. R., Wallentin, M., & Vuust, P. (2014). Musical activity tunes up absolute pitch ability. *Music Perception*, *31*, 359–371.

Ericsson, K., Krampe, R., & Tesch-Roemer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review*, *100*, 363–406.

Gregersen, P. K., Kowalsky, E., Kohn, N., & Marvin, E. W. (2001). Early childhood music education and predisposition to absolute pitch: Teasing apart genes and environment. *American Journal of Medical Genetics*, *98*, 280–282.

Gregersen, P. K., Kowalsky, E., Lee, A., Baron-Cohen, S., Fisher, S. E., Asher, J. E., Ballard, D., Freudenberg, J., & Li, W. (2013). Absolute pitch exhibits phenotypic and genetic overlap with synesthesia. *Human Molecular Genetics*, *22*, 2097–2104.

Hambrick, D. Z., Oswald, F. L., Altmann, E. M., Meinz, E. J., Gobet, F., & Campitelli, G. (2014). Deliberate practice: Is that all it takes to become an expert? *Intelligence*, *45*, 34–45.

Hambrick, D. Z., & Tucker-Drob, E. M. (2015). The genetics of music accomplishment: Evidence for gene-environment correlation and interaction. *Psychonomic Bulletin and Review*, *22*, 112–120.

Hambrick, Z., Macnamara, B., Campitelli, G., Ullén, F., & Mosing, M. (2016). Beyond born versus made: A new look at expertise. *Psychology of Learning and Motivation*, *64*, 1–55.

Hedger, S. C., Heald, S. L., & Nusbaum, H. C. (2013). Absolute pitch may not be so absolute. *Psychological Science*, *24*, 1496–1502.

Henthorn, T., & Deutsch, D. (2007). Ethnicity versus early environment: Comment on 'Early childhood music education and predisposition to absolute pitch: Teasing apart genes and environment' by Peter K. Gregersen, Elena Kowalsky, Nina Kohn, and Elizabeth West Marvin [2000]. *American Journal of Medical Genetics Part A*, *143*, 102–103.

Howard, R. W. (2011). Testing the accuracy of the retrospective recall method used in expertise research. *Behavior Research Methods*, *43*, 931–941.

Hutka, S. A., & Alain, C. (2015). The effects of absolute pitch and tone language on pitch processing and encoding in musicians [Article]. *Music Perception*, *32*, 344–354.

Kragness, H. E., Swaminathan, S., Cirelli, L. K., & Schellenberg, E. G. (2020). Individual differences in musical ability are stable over time in childhood. *Developmental Science*, *24*, 313081.

Leite, R. B. C., Mota-Rolim, S. A., & Queiroz, C. M. T. (2016). Music proficiency and quantification of absolute pitch: A large-scale study among Brazilian musicians. *Frontiers in Neuroscience*, *10*, 1–11.

Levitin, D. J., & Zatorre, R. J. (2003). On the nature of early music training and absolute pitch: A reply to Brown, Sachs, Cammuso, and Folstein. *Music Perception*, *21*, 105–110.

Lichtenstein, P., De Faire, U., Floderus, B., Svartengren, M., Svedberg, P., & Pedersen, N. L. (2002). The Swedish Twin Registry: A unique resource for clinical, epidemiological and genetic studies. *Journal of Internal Medicine*, *252*, 184–205.

Lichtenstein, P., Sullivan, P. F., Cnattingius, S., Gatz, M., Johansson, S., Carlström, E., Björk, C., Svartengren, M., Wolk, A., Klareskog, L., de Faire, U., Schalling, M., Palmgren, J., & Pedersen, N. L. (2006). The Swedish Twin Registry in the third millennium: An update. *Twin Research and Human Genetics*, *9*, 875–882.

Lynn, R., Graham Wilson, R., & Gault, A. (1989). Simple musical tests as measures of Spearman's g. *Personality and Individual Differences*, *10*, 25–28.

Macnamara, B. N., Hambrick, D. Z., & Oswald, F. L. (2014). Deliberate practice and performance in music, games, sports, education, and professions: A meta-analysis. *Psychological Science*, *25*, 1608–1618.

Macnamara, B. N., & Maitra, M. (2019). The role of deliberate practice in expert performance: Revisiting Ericsson, Krampe & Tesch-Römer (1993). *Royal Society Open Science*, *6*, 190327–190327.

Meinz, E. J., & Hambrick, D. Z. (2010). Deliberate practice is necessary but not sufficient to explain individual differences in piano sight-reading skill: The role of working memory capacity. *Psychological Science*, *21*, 914–919.

Miyazaki, K. (1988). Musical pitch identification by absolute pitch possessors. *Perception & Psychophysics*, *44*, 504–512.

Miyazaki, K. (1989). Absolute pitch identification: Effects of timbre and pitch region. *Music Perception*, *7*, 1–14.

Miyazaki, K. (1990). The speed of musical pitch identification by absolute-pitch possessors. *Music Perception*, *8*, 177–188.

Miyazaki, K., Makomaska, S., & Rakowski, A. (2012). Prevalence of absolute pitch: A comparison between Japanese and Polish music students. *Journal of the Acoustical Society of America*, *132*, 3484–3493.

Miyazaki, K., Rakowski, A., Makomaska, S., Jiang, C., Tsuzaki, M., Oxenham, A. J., Ellis, G., & Lipscomb, S. D. (2018). Absolute pitch and relative pitch in music students in the east and the west: Implications for aural-skills education. *Music Perception*, *36*, 135–155.

Mosing, M. A., Hambrick, D. Z., & Ullén, F. (2019). Predicting musical aptitude and achievement: Practice, teaching, and intelligence. *Journal of Expertise*, *2*, 184–197.

Mosing, M. A., Madison, G., Pedersen, N. L., Kuja-Halkola, R., & Ullén, F. (2014). Practice does not make perfect: No causal effect of music practice on music ability. *Psychological Science*, *25*, 1795–1803.

Mosing, M. A., Pedersen, N. L., Madison, G., & Ullén, F. (2014). Genetic pleiotropy explains associations between musical auditory discrimination and intelligence. *PLOS ONE*, *9*, Article e113874.

Mosing, M. A., & Ullén, F. (2018). Genetic influences on musical specialization: A twin study on choice of instrument and music genre. *Annals of the New York Academy of Sciences*, *1423*, 427–434.

Oechslin, M. S., Imfeld, A., Loenneker, T., Meyer, M., & Jäncke, L. (2010). The plasticity of the superior longitudinal fasciculus as a function of musical expertise: A diffusion tensor imaging study. *Frontiers in Human Neuroscience*, *3*, Article 76.

Profita, J., & Bidder, T. G. (1988). Perfect pitch. *American Journal of Medical Genetics*, *29*, 763–771.

Revelle, W. (2021). *psych: Procedures for psychological, psychometric, and personality research*. Northwestern University. https://CRAN.R-project.org/package=psych

Robinson, D., Hayes, A., & Couch, S. (2021). *broom: Convert statistical objects into tidy tibbles*. https://CRAN.R-project.org/package=broom

Schellenberg, E. G., & Weiss, M. W. (2013). Music and cognitive abilities. In D. Deutsch (Ed.), *The psychology of music* (3rd ed., pp. 499–550). Academic Press.

Sergeant, D., & Vhatcher, G. (1974). Intelligence, social status and musical abilities. *Psychology of Music*, *2*, 32–57.

Swaminathan, S., & Schellenberg, E. G. (2018). Musical competence is predicted by music training, cognitive abilities, and personality. *Scientific Reports*, *8*, 9223.

Swaminathan, S., & Schellenberg, E. G. (2020). Musical ability, music training, and language ability in childhood. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *46*, 2340–2348.

Tan, Y. T., McPherson, G. E., Peretz, I., Berkovic, S. F., & Wilson, S. J. (2014). The genetic basis of musical ability. *Frontiers in Psychology*, *5*, Article 658.

Theusch, E., Basu, A., & Gitschier, J. (2009). Genome-wide study of families with absolute pitch reveals linkage to 8q24.21 and locus heterogeneity. *American Journal of Human Genetics*, *85*, 112–119.

Theusch, E., & Gitschier, J. (2011). Absolute pitch twin study and segregation analysis. *Twin Research and Human Genetics*, *14*, 173–178.

Ullén, F., Hambrick, D. Z., & Mosing, M. A. (2016). Rethinking expertise: A multifactorial gene-environment interaction model of expert performance. *Psychological Bulletin*, *142*, 427–446.

Ullén, F., Mosing, M. A., Holm, L., Eriksson, H., & Madison, G. (2014). Psychometric properties and heritability of a new online test for musicality, the Swedish Musical Discrimination Test. *Personality and Individual Differences*, *63*, 87–93.

Van Hedger, S. C., Heald, S. L., Uddin, S., & Nusbaum, H. C. (2018). A note by any other name: Intonation context rapidly changes absolute note judgments. *Journal of Experimental Psychology: Human Perception and Performance*, *44*, 1268–1282.

Vitouch, O. (2003). Absolutist models of absolute pitch are absolutely misleading. *Music Perception*, *21*, 111–117.

Wesseldijk, L. W., Mosing, M. A., & Ullén, F. (2021). Why is an early start of training related to musical skills in adulthood? A genetically informative study. *Psychological Science*, *32*, 3–13.

West Marvin, E., VanderStel, J., & Siu, J. C.-S. (2020). In their own words: Analyzing the extents and origins of absolute pitch. *Psychology of Music*, *48*, 808–823.

Wickham, H., Averick, M., Bryan, J., Chang, W., D'Agostino McGowan, L., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Lin Pedersen, T., Miller, E., Milton Bache, S., Müller, K., Ooms, J., Robinson, D., Seidel, D. P., Spinu, V., Takahashi, K., … Yutani, H. (2019). Welcome to the tidyverse. *Journal of Open Source Software*, *4*, Article 1686.

Wilke, C. O. (2021). *ggridges: ridgeline plots in 'ggplot2'*. https://CRAN.R-project.org/package=ggridges

Wilson, S. J., Lusher, D., Martin, C. L., Rayner, G., & McLachlan, N. (2012). Intersecting factors lead to absolute pitch acquisition that is maintained in a 'fixed do' environment. *Music Perception*, *29*, 285–296.

Wilson, S. J., Lusher, D., Wan, C. Y., Dudgeon, P., & Reutens, D. C. (2009). The neurocognitive components of pitch processing: Insights from absolute pitch. *Cerebral Cortex*, *19*, 724–732.

Zeileis, A. (2004). Econometric computing with HC and HAC covariance matrix estimators. *Journal of Statistical Software*, *11*, 1–17.

Zeileis, A., & Hothorn, T. (2002). Diagnostic checking in regression relationships. *R News*, *2*, 7–10.

Zeileis, A., Köll, S., & Graham, N. (2020). Various versatile variances: An object-oriented implementation of clustered covariances in R. *Journal of Statistical Software*, *95*, 1–36.