Psychological Science OnlineFirst, published on July 30, 2014 as doi:10.1177/0956797614541990

Research Article

aps ASSOCIATION FOR PSYCHOLOGICAL SCIENCE

Psychological Science
1–9
© The Author(s) 2014
Reprints and permissions:
sagepub.com/journalsPermissions.nav
DOI: 10.1177/0956797614541990
pss.sagepub.com
SAGE

Practice Does Not Make Perfect: No Causal Effect of Music Practice on Music Ability

Miriam A. Mosing[1], Guy Madison[2], Nancy L. Pedersen[3], Ralf Kuja-Halkola[3], and Fredrik Ullén[1]

[1]Department of Neuroscience, Karolinska Institutet; [2]Department of Psychology, Umeå University; and [3]Department of Medical Epidemiology and Biostatistics, Karolinska Institutet

Abstract

The relative importance of nature and nurture for various forms of expertise has been intensely debated. Music proficiency is viewed as a general model for expertise, and associations between deliberate practice and music proficiency have been interpreted as supporting the prevailing idea that long-term deliberate practice inevitably results in increased music ability. Here, we examined the associations (*r*s = .18–.36) between music practice and music ability (rhythm, melody, and pitch discrimination) in 10,500 Swedish twins. We found that music practice was substantially heritable (40%–70%). Associations between music practice and music ability were predominantly genetic, and, contrary to the causal hypothesis, nonshared environmental influences did not contribute. There was no difference in ability within monozygotic twin pairs differing in their amount of practice, so that when genetic predisposition was controlled for, more practice was no longer associated with better music skills. These findings suggest that music practice may not causally influence music ability and that genetic variation among individuals affects both ability and inclination to practice.

Keywords

training, expertise, music ability, practice, heritability, twin, causality

Received 2/18/14; Revision accepted 6/5/14

One of the most intensely debated questions in differential psychology concerns the relative importance of practice and innate talent for achieving *expertise*, that is, high levels of performance within a specific domain (Detterman & Ruthsatz, 1999; Ericsson, Nandagopal, & Roring, 2005; Howe, Davidson, & Sloboda, 1998; Ruthsatz, Detterman, Griscom, & Cirullo, 2008). There is general agreement that long-term deliberate practice is necessary for high levels of expert performance—here defined as "consistently superior performance on a specified set of representative tasks for a domain" (Ericsson & Lehmann, 1996, p. 277; Hambrick et al., 2014). A frequently quoted rule of thumb is that more than 10,000 hr of deliberate practice are required for expert performance (Gladwell, 2008). Naturally, this number is arbitrary: Young adults may reach high levels of expertise with considerably less practice—an average of 5,000 hr has been reported for samples of expert violinists aged 20 (Ericsson, Krampe, & Tesch-Römer, 1993)—whereas older experts may greatly exceed 10,000 practice hours (Ericsson, 2013).

More controversially, several researchers in the field suggest that deliberate practice is not only necessary for expertise, but also sufficient to explain differences in performance ability between experts and novices. Accordingly, the amount of deliberate practice is the primary constraint on a person's expertise, whereas other factors—such as genetic endowment—are of small or even negligible importance (Coon & Carey, 1989; Ericsson, 2002; Ericsson, Krampe, & Heizmann, 1993; Ericsson et al., 2005; Howe et al., 1998; Krampe & Ericsson, 1996). A central idea in the *expert-performance framework* (Ericsson, 2014; Ericsson, Krampe, & Tesch-Römer, 1993) is that innate talent may be important in accounting for performance differences between individuals who have practiced for only small or moderate

Corresponding Author:
Miriam A. Mosing, Department of Neuroscience, Karolinska Institutet, Retzius v 8, SE-171 77 Stockholm, Sweden
E-mail: miriam.mosing@ki.se

Downloaded from pss.sagepub.com at NATIONAL SUN YAT-SEN UNIV on August 17, 2014

amounts of time; long-term deliberate practice, however, is accompanied by the acquisition of new, domain-specific cognitive and sensorimotor skills and strategies that vastly improve performance within the domain and can circumvent any innate differences in general capacity (Ericsson, 2014). This is corroborated by the fact that, to date, there is no scientific support for the idea that elite performance ability derives from innate talent or capacities (except for height and body size, which are highly heritable attributes important in some sports domains; Ericsson, 2014).

This radically environmentalist position has been increasingly criticized in recent years. Most individuals do not become experts despite many hours of practice (Corrigall, Schellenberg, & Misura, 2013; Hambrick et al., 2014; Ruthsatz et al., 2008), and growing empirical evidence has shown that variables other than practice (e.g., intelligence, personality, or physical traits) influence performance (Corrigall et al., 2013; Ruthsatz et al., 2008; Tucker & Collins, 2012). Many expertise-related traits have been shown to be highly genetic (Dubois et al., 2012; Jang, Livesley, & Vernon, 1996; Posthuma, de Geus, & Deary, 2009), and even variation in self-rated expertise in several domains is partly heritable (Vinkhuyzen, van der Sluis, Posthuma, & Boomsma, 2009). However, little is known about genetic influences on objective measures of expertise (Drayna, Manichaikul, de Lange, Snieder, & Spector, 2001; Ullén, Mosing, Holm, Eriksson, & Madison, 2014). In particular, the importance of genetic influences on practice as well as the associations between practice and expert performance have never been systematically investigated.

One of the most widely studied domains of expertise is music. A common operationalization of music ability is sensory discrimination of auditory musical stimuli of various types (Seashore, 1919/1960). We recently showed that, in line with findings by Drayna et al. (2001), such auditory-discrimination skills are partly heritable (Ullén et al., 2014). Performance on discrimination tests shows substantial associations between these skills and music practice, and professional musicians have been shown to systematically outperform nonmusicians on such tasks (Schellenberg & Weiss, 2013). It is commonly assumed that these associations reflect causal effects of music practice on music ability (Charness, Feltovich, Hoffman, & Ericsson, 2006). However, an alternative explanation is that preexisting differences or other underlying factors influence practice behavior as well as music ability, which results in individuals with greater musical talent also being more likely to engage in music practice (Corrigall et al., 2013; Schellenberg & Weiss, 2013). Such influences can even be time lagged, which could account for associations found in prospective studies. Individual genetic variation could be one underlying factor explaining practice-ability correlations, with the same genes that influence music ability also influencing voluntary music practice.

The present study is the first to use a genetically informative sample—a large twin cohort—to explore the relationship between music practice and ability and to address the questions raised above. Our aims were (a) to estimate genetic influences on music practice and its covariation with music ability and (b) to explore the directionality of these relationships. Specifically, we tested two fundamental predictions based on the causal model stating that music practice causes differences in music ability (operationalized as musical auditory discrimination). First, if practice causally influences ability, all significant influences—shared and nonshared environmental as well as genetic—on the predictor variable (music practice) should also significantly influence the outcome variables (music abilities). Further, if—as suggested by Ericsson, Krampe, and Tesch-Römer (1993)—talent, broadly considered as genetic endowment, does not play a role and anyone who invests enough time in deliberate practice will develop expertise, we would expect the relationship between practice and ability to be largely mediated by nonshared environmental influences. This can be tested by exploring the significance of genetic and environmental correlations between practice and music abilities (Fig. 1a). Second, assuming a causal influence of practice on ability, if the members of a monozygotic (MZ) twin pair (who are genetically identical) differ in the amount of music practice, the twin who has practiced more should possess better music ability (Fig. 1b). In this model, we controlled for influences of innate talent on the relationship between practice and ability because both MZ twins have exactly the same genetic predisposition.

Method

Participants

Data were collected as part of a Web survey sent out to a cohort of approximately 32,000 twins born between 1959 and 1985—the Study of Twin Adults: Genes and Environment (STAGE) cohort (Lichtenstein et al., 2006)—who are part of the Swedish Twin Registry (STR), one of the largest registries of its kind (Lichtenstein et al., 2002; Lichtenstein et al., 2006). The final sample consisted of 10,539 individuals, each of whom had a score for at least one of the studied traits; the full sample comprised 2,569 full twin pairs—1,211 MZ and 1,358 dizygotic (DZ) twin pairs—and 5,401 single twins without the cotwin participating. Participants ranged in age between 27 and 54 years (M = 40.7, SD = 7.7). Single twin individuals were retained for analysis as they contribute to the estimation

Downloaded from pss.sagepub.com at NATIONAL SUN YAT-SEN UNIV on August 17, 2014

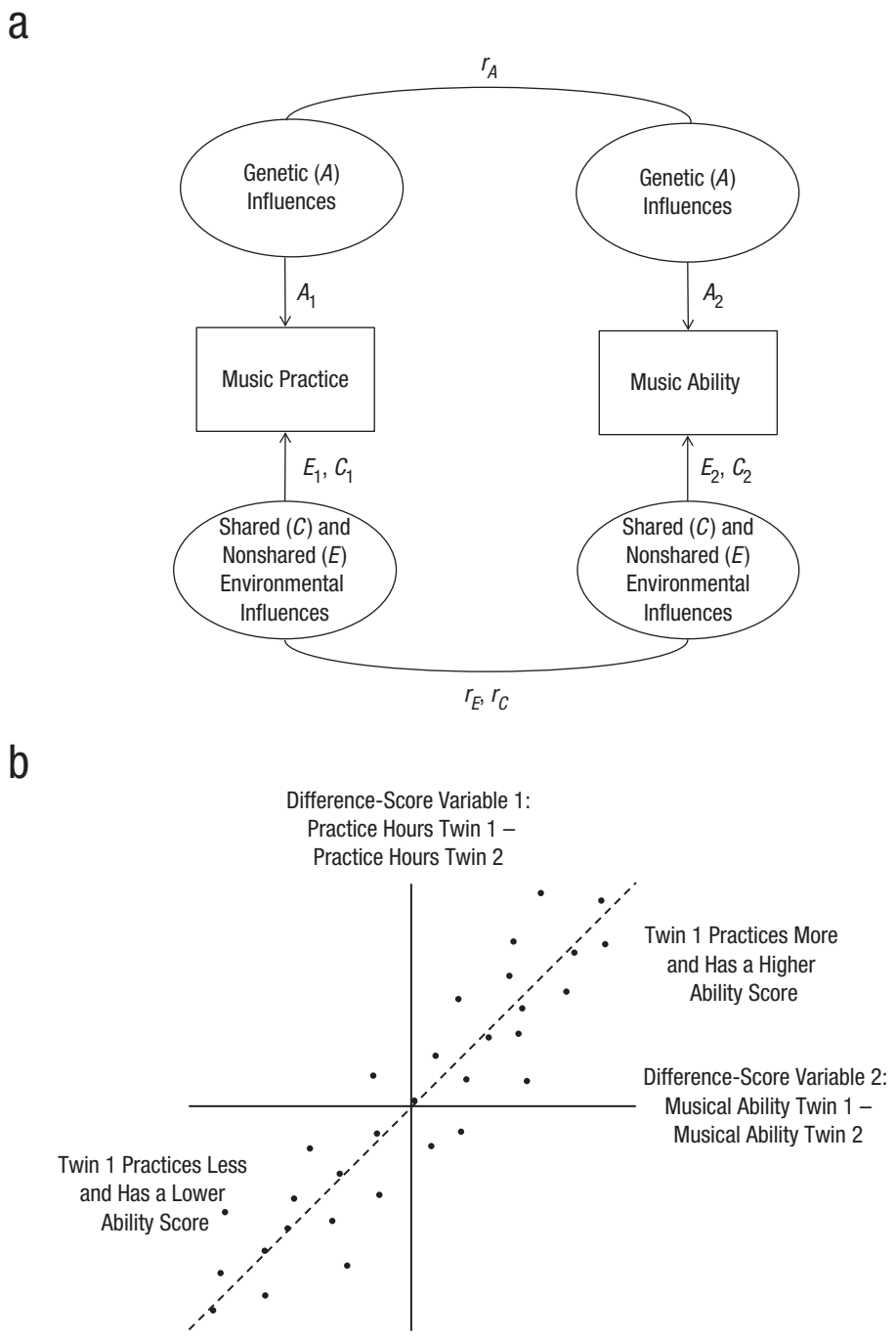


Fig. 1. Graphic representations of the two models used to test the hypothesis that music practice has a causal effect on music ability. The first model (a) suggests that given this causal relationship, the genetic and environmental influences on practice would overlap significantly with the genetic and environmental influences on music abilities. The second model (b) predicts that in identical twins, the twin scoring higher on music practice would also score higher on music ability.

of means, variances, and covariate effects. Zygosity was determined using questions about intrapair similarities and subsequently confirmed in 27% of the twins in the STR using genotyping, which showed that the questionnaire-based zygosity determination was correct for more than 98% of twin pairs. For further details on the STAGE cohort and zygosity determination in the STR, see Lichtenstein et al. (2002, 2006). All participants gave informed consent, and the study was approved by the regional ethics review board in Stockholm (Diary

Downloaded from pss.sagepub.com at NATIONAL SUN YAT-SEN UNIV on August 17, 2014

Table 1. Phenotypic Correlations Between Measures of Music Ability and Hours of Practice

	Music ability			Hours of practice	
Variable	Rhythm	Melody	Pitch	Raw	Log transformed
Rhythm	—	.42 [.39, .45]	.32 [.29, .36]	.25 [.21, .28]	.24 [.23, .28]
Melody	.38 [.35, .40]	—	.41 [.38, .44]	.36 [.32, .39]	.34 [.30, .37]
Pitch	.34 [.31, .36]	.37 [.34, .40]	—	.35 [.34, .38]	.36 [.31, .34]
Raw hours of practice	.18 [.15, .21]	.29 [.26, .31]	.28 [.25, .31]	—	—
Log-transformed hours of practice	.21 [.19, .23]	.30 [.27, .33]	.32 [.29, .34]	—	—

Note: Values for females are presented below the diagonal, and values for males are presented above the diagonal. All variables were corrected for sex and age. Values in brackets are 95% confidence intervals.

Numbers 2011/570-31/5, 2011/1425-31, and 2012/1107/32). The STAGE cohort members were asked to complete assessments on several occasions, and the data for the present study were collected between 2012 and 2013.

Measures

Music practice. Participants were first asked whether they play an instrument (or actively sing). Those who responded positively were questioned about the number of years they practiced during four age intervals (ages 0–5 years, 6–11 years, 12–17 years, and 18 years until the time of measurement) and how many hours a week during each of those intervals they practiced. From these estimates, a sum-score estimate of the total hours played during their lifetime was calculated, with nonplayers receiving a score of zero. As expected, music practice was positively skewed; many individuals had never practiced or had done so infrequently. The data were therefore log-transformed, and univariate analyses were conducted with the transformed and untransformed data. Given that the results were very similar (Tables 1 and 2) and that the sample size was large, untransformed data were used for the final analyses and are reported here. Self-reported practice estimates have been shown to be reasonably reliable, with correlations ranging between .6 and .9 (de Bruin, Smits, Rikers, & Schmidt, 2008; Ericsson, Krampe, & Tesch-Römer, 1993).

Music ability. Music ability was measured using the Swedish Musical Discrimination Test (SMDT; Ullén et al. 2014), which is similar in construction to the Seashore test (Seashore, 1919/1960). The SMDT was designed (a) for online administration, (b) to minimize test time, and (c) to have a suitable difficulty level for modern populations in Western countries. The SMDT consists of three subtests—pitch, melody, and rhythm discrimination—which are briefly outlined here; for a detailed description and psychometric validation, see Ullén et al. (2014). To measure pitch discrimination, we presented 27 trials with two successive tones that had a pitch difference of between 1 and 17 Hz; participants had to indicate whether the second tone was higher or lower than the first. For the melody-discrimination test, which consisted of 18 trials, two sequences with four to nine tones each were presented. One of these tones differed in musical pitch (e.g., an A might be replaced by a C#). The participant had to determine which tone in the second sequence differed from the first. For the rhythm test (18 trials), the participant indicated whether two rhythmical sequences, each of which consisted of five to seven brief tones with the same pitch but different time intervals, were the same or different.

Separate scores for rhythm, melody, and pitch discrimination were calculated by adding up the number of correct trials for each domain. The three music abilities were normally distributed without outliers. Auditory discrimination has repeatedly been shown to be associated with music practice, and professional musicians consistently score higher than nonmusicians on tests of discrimination ability (for a review, see Schellenberg & Weiss, 2013).

Statistical analyses and genetic modeling

All variables were converted to z scores. Utilizing the information of MZ twins (who share 100% of their genes) and DZ twins (who share only 50% of their genes, on average), one can partition the population variance in and between traits into that due to additive genetic (*A*), shared environmental (*C*), and nonshared environmental (*E*) influences. Using maximum-likelihood modeling in the statistical programs Mx (Neale, Boker, Xie, & Maes, 2006; Neale & Maes, 2004) and OpenMX (Boker et al., 2012; Boker et al., 2011) in R, we fitted multiple bivariate *ACE* Cholesky decompositions and estimated *A, C*, and *E* correlations to test whether genetic and environmental influences on music practice and ability, and their covariation, were significant (Hypothesis 1). Univariate general

Downloaded from pss.sagepub.com at NATIONAL SUN YAT-SEN UNIV on August 17, 2014

Table 2. Within-Pair Twin Correlations for Measures of Music Ability and Hours of Practice

	Music ability			Hours of practice	
Zygosity	Rhythm	Melody	Pitch	Raw	Log transformed
MZ	.51 [.48, .56]	.57 [.52, .61]	.48 [.42, .53]	.63 [.60, .66]	.62 [.58, .66]
DZ	.28 [.21, .35]	.32 [.25, .38]	.29 [.21, .35]	.40 [.36, .44]	.38 [.33, .44]
MZ females	.52 [.45, .58]	.59 [.53, .64]	.45 [.43, .52]	.59 [.55, .63]	.60 [.55, .64]
MZ males	.50 [.39, .58]	.53 [.43, .60]	.51 [.41, .59]	.69 [.65, .73]	.66 [.59, .72]
DZ females	.27 [.14, .39]	.25 [.13, .36]	.33 [.20, .44]	.44 [.36, .51]	.48 [.40, .56]
DZ males	.30 [.12, .45]	.45 [.30, .56]	.49 [.36, .60]	.44 [.34, .52]	.42 [.27, .54]
DZ opposite sex	.28 [.17, .38]	.29 [.18, .39]	.17 [.06, .27]	.36 [.29, .42]	.28 [.18, .37]

Note: All variables were corrected for sex and age. Values in brackets are 95% confidence intervals. MZ = monozygotic, DZ = dizygotic.

sex-limitation models were fitted first, which allowed for qualitatively different sources of genetic variance between the sexes (nonscalar sex limitation). However, qualitative sex-specific sources of genetic variance were nonsignificant; therefore, common sex-limitation modeling (univariate and multivariate) was applied subsequently to allow the *ACE* estimates to differ quantitatively between the sexes (i.e., the effect of a factor may be larger on one sex than on the other—scalar sex limitation).

The MZ twin intrapair-differences model was used to further explore causal effects of music practice on ability, specifically, to test whether the twin who trained more also showed higher ability (Hypothesis 2). The within-pair difference between the MZ twins was calculated for the amount of practice and then regressed on the corresponding difference scores of the music-ability variables. Following the causal hypothesis, we would expect that in MZ twins, the within-pair difference in music practice would be positively associated with the within-pair difference in music ability, which would result in significant positive regression coefficients.

Results

Females were more likely than males to be actively involved in music: 80% of women and 62% of men reported that they played an instrument at some stage in their life. Among the participants who had played an instrument, there was a significant sex difference in the amount of time spent playing, $t(7769) = 4.68$, $p < .001$; men played more hours ($M = 3{,}862.42$, $SE = 72.46$) than women ($M = 3{,}270.86$, $SE = 52.86$), although the effect size ($r = .05$) was very small. Further, sex had a small but significant effect on raw pitch scores, $t(6715) = 6.98$, $p < .001$, $r = .09$, with females scoring slightly lower ($M = 17.80$, $SE = 0.07$) than males ($M = 18.65$, $SE = 0.10$). Sex had no effect on the other two musical skills. There was a significant effect of age on hours of music practice, $t(10758) = 13.85$, $p < .001$, $r = .13$; pitch, $t(6715) = -5.06$, $p < .001$, $r = -.06$; and rhythm, $t(6878) = -9.21$, $p < .001$, $r = -.11$, with more hours of practice and lower pitch- and rhythm-discrimination skills in older participants. Therefore, sex and age were included as covariates in all further twin models.

Phenotypic correlations (Table 1) between hours of practice and music ability were all significant and moderate, ranging between .18 and .36, which shows that these variables were associated. Further, a comparison of the confidence intervals for men and women suggested that associations between practice and the three music abilities were stronger for males than for females. MZ and DZ twin correlations suggested that there were potential sex differences in melody, pitch, and music practice: Some of the correlations differed significantly across sexes or DZ groups (with smaller correlations for the opposite-sex than for the same-sex pairs), as indicated by nonoverlapping confidence intervals (Table 2). Generally, DZ twin correlations were more than half the MZ twin correlations, which suggests that an *ACE* model would fit the data best. The overall pattern of cross-twin, cross-trait correlations suggested *A* and *C* influences as well as potential sex differences in the covariation between traits (see Table S1 in the Supplemental Material available online).

ACE estimates derived from univariate genetic modeling are shown in Table 3. Genetic influences on hours of practice were substantial, explaining 69% of the variance in males and 41% in females, with additional shared-environmental influences in females (21%). Music abilities were moderately heritable, ranging between 12% and 61% (for details, see Ullén et al., 2014). Nonshared environmental influences were also significant for all variables. Results of bivariate models testing for the significance of correlations between practice and music abilities are shown separately for males and females in Table 4. In spite of the influences of nonshared environment found in the univariate analyses, none of the nonshared environmental correlations, which ranged

Downloaded from pss.sagepub.com at NATIONAL SUN YAT-SEN UNIV on August 17, 2014

Table 3. Results of Univariate General Sex-Limitation Modeling Showing Genetic (*A*), Shared Environmental (*C*), and Nonshared Environmental (*E*) Influences on Measures of Music Ability and Hours of Practice

Sex and component	Music ability			Hours of practice
	Rhythm	Melody	Pitch	
Females				
A	.52 [.23, .59]	.61 [.50, .66]	.30 [.09, .52]	.41 [.26, .56]
C	.01 [.00, .10]	.01 [.00, .09]	.19 [.00, .38]	.21 [.05, .35]
E	.47 [.41, .54]	.38 [.33, .44]	.52 [.46, .58]	.38 [.37, .42]
Males				
A	.41 [.07, .59]	.31 [.05, .53]	.12 [.00, .35]	.69 [.56, .75]
C	.10 [.00, .40]	.24 [.00, .46]	.38 [.17, .53]	.04 [.00, .15]
E	.49 [.41, .59]	.45 [.38, .54]	.50 [.43, .59]	.28 [.24, .31]

Note: All values were corrected for age. For pitch and hours of practice, male and female estimates could not be equated without significant deterioration of model fit. Heritability estimates for rhythm, melody, and pitch in this sample have been reported previously (Ullén, Mosing, Holm, Eriksson, & Madison, 2014). Values in brackets are 95% confidence intervals.

between .00 and .06, contributed significantly to the associations between the variables. The genetic correlations, however, were significantly different from zero (they ranged between .33 and .57) for all associations except those between practice and pitch in females, which seemed to be mediated by shared environmental influences (r_C = .86). Further, in males, the association between practice and melody as well as between practice and pitch was also partly due to shared environmental influences (r_C = .79–1.00). Regressions of the MZ intrapair-difference score of practice hours on the difference scores of music ability were nonsignificant for melody, $t(698) = -0.79$, $p = .43$, $r = .03$; pitch, $t(687) = 1.18$, $p = .24$, $r = .05$; and rhythm, $t(705) = 0.46$, $p = .64$, $r = .02$.

Discussion

The present study is the first to address causality and genetic influences in the relationship between music practice and music ability. In line with past literature (Schellenberg & Weiss, 2013), the results confirmed that more music practice is significantly associated with better music ability (*r*s = .18–.35). Classical twin modeling showed that the amount of music practice was surprisingly heritable (40%–70%), with estimates similar to those previously reported for music abilities (Ullén et al., 2014). When testing the first hypothesis under the causality assumption (i.e., all influences on music practice also influence music ability), we found that although the amount of music practice was significantly affected by *A*, *C*, and *E* influences, the correlations between practice and our three measures of music ability were mainly due to *A* and (for pitch) some shared *C* influences, with all *E* correlations being small and nonsignificant.

Further, contrary to predictions of the second hypothesis (i.e., in MZ twins, the twin who practices more will have greater ability), results from intrapair-difference modeling showed that once all genetic and shared environmental factors were controlled for, the association between music practice and ability disappeared—in other words, the twin who trained more did not possess better music abilities. This was despite the fact that some intrapair differences between twins were as great as 20,228 hr—a practice amount considerably higher than that reported for many highly skilled experts, including musicians (Ericsson, 2013; Ericsson, Chase, & Faloon, 1980; Ericsson, Krampe, & Tesch-Römer, 1993).

These findings suggest that, contrary to expectations, voluntary music practice in the general population may not causally influence the ability to discriminate musical sounds. Rather, an underlying common factor, consisting mainly of shared genes (genetic pleiotropy) with some additional shared environmental influences, may affect both music practice and the measures of music ability we examined here. Which specific genes underlie voluntary music practicing is unknown, but demographic variables such as socioeconomic status may explain some of the shared environmental influences.

Initially, the present findings may seem at odds with literature on the neuropsychology of skill learning, as well as common day-to-day observations of practice effects. It is clear that practicing a musical instrument results in the acquisition of various skills central to musical performance. Furthermore, several imaging studies—some with longitudinal designs—have suggested that music practice as well as other forms of long-term deliberate practice induce plastic changes in the involved brain regions (e.g., Bengtsson et al., 2005). However, the

Downloaded from pss.sagepub.com at NATIONAL SUN YAT-SEN UNIV on August 17, 2014

Table 4. Bivariate Sex-Limitation Model-Fitting Results for the Association Between Hours of Practice and the Measures of Music Ability

Sex and model	*df*	AIC	−2LL	Δ−2LL	*p*
		Melody			
Females					
Saturated	16,962	12,077.94	46,001.94	—	—
$r_C = 0$	16,963	12,077.50	46,003.50	1.56	.21
$r_E = 0$	16,963	12,075.94	46,001.94	0.00	1.00
$r_A = 0$	16,963	12,091.62	46,017.62	15.68	< .01
Males					
Saturated	16,962	12,077.94	46,001.94	—	—
$r_C = 0$	16,963	12,082.98	46,008.98	7.03	< .01
$r_E = 0$	16,963	12,076.55	46,002.55	0.61	.43
$r_A = 0$	16,963	12,093.15	46,019.15	17.21	< .01
		Pitch			
Females					
Saturated	16,893	12,138.37	45,924.37	—	—
$r_C = 0$	16,894	12,146.06	45,934.06	9.68	< .01
$r_E = 0$	16,894	12,139.56	45,927.56	3.19	.07
$r_A = 0$	16,894	12,136.59	45,924.59	0.22	.64
Males					
Saturated	16,893	12,138.37	45,924.37	—	—
$r_C = 0$	16,894	12,144.65	45,932.65	8.28	< .01
$r_E = 0$	16,894	12,136.54	45,924.54	0.17	.68
$r_A = 0$	16,894	12,143.03	45,931.03	6.66	< .01
		Rhythm			
Females					
Saturated	17,050	12,587.54	46,687.54	—	—
$r_C = 0$	17,051	12,586.14	46,688.14	0.60	.44
$r_E = 0$	17,051	12,585.55	46,687.55	0.01	.95
$r_A = 0$	17,051	12,593.70	46,695.70	8.16	< .01
Males					
Saturated	17,050	12,587.54	46,687.54	—	—
$r_C = 0$	17,051	12,586.92	46,688.92	1.38	.24
$r_E = 0$	17,051	12,586.85	46,688.85	1.31	.25
$r_A = 0$	17,051	12,590.22	46,692.22	4.68	< .05

Note: All values were corrected for age. In the saturated (full) model, the additive genetic (*A*), shared environmental (*C*), and nonshared environmental (*E*) correlations between practice and music ability were allowed to vary. This model was compared with three reduced models, in each of which one of the correlations was set to zero. AIC = Akaike information criterion, −2LL = −2 log likelihood.

music abilities measured here can presumably be regarded as more general sensory capacities used to process musically relevant auditory information. In contrast, the skills that improve from playing an instrument may be more domain specific, involving the acquisition of instrument-specific sequential motor skills, score reading, and memorization. It is likely that the observed effects of music practice on the brain predominantly reflect the development of such specific skills, rather than the improvement of a general ear for music.

Another explanation for the observed associations, in line with the finding of an underlying genetic factor, is that individuals seek out leisure activities they are good at. Success may, in turn, provide further reward, internal or external, and the incentive to continue practicing (de Geus & de Moor, 2008). This explanation suggests an active or reactive gene-environment correlation; however, passive gene-environment correlation may also play a role, with genetic influences accounting for increased abilities also contributing to a more favorable environment for further development (Plomin, DeFries, & Loehlin, 1977).

The present findings challenge several conventional beliefs in the fields of expertise research and differential psychology, as well as in society, about the nature of the relation between music practice and performance. First, the discussion of the relative importance of practice and other variables for skilled performance has often been framed in terms of nurture versus nature. Our findings clearly illustrate that, in the context of practice effects on expertise, this is a false dichotomy. Genes and environment are important for essentially any behavior (Plomin, Shakeshaft, McMillan, & Trzaskowski, 2014), and practice is no exception. This is a strong indication that extreme environmentalist models of expertise (e.g., "practice is everything") are untenable. However, it should be emphasized that a high heritability of music practice does not imply genetic determinism. The present findings are compatible with the possibility that environmental interventions could stimulate deliberate practice in individuals who show little spontaneous motivation for sustained effort (Plomin et al., 2014).

Second, although there is general awareness that correlation does not imply causation, a noncausal relationship between music practice and ability is rather surprising in studies of expert performance. It is tempting to assume that such a relation reflects learning, but the present findings suggest that associations between music practice and musical auditory discrimination can largely be explained by preexisting individual differences. So, contrary to past beliefs, it may be that different individuals choose different leisure activities rather than that music practice makes individuals different. Finally, the present findings show that existing studies on differences between musicians and nonmusicians need to be interpreted with caution. This is obviously true for cross-sectional studies, which constitute the vast majority of the published literature (Schellenberg & Weiss, 2013); however, differences found in longitudinal studies without random assignment (e.g., Hyde et al., 2009) could also reflect genetic differences between individuals who voluntarily engage in long-term music practice and those who do not. Past research may thus have overestimated

Downloaded from pss.sagepub.com at NATIONAL SUN YAT-SEN UNIV on August 17, 2014

the effects of music practice and too quickly concluded that a phenotypic relationship implies practice effects.

We cannot rule out more complex mechanisms underlying the associations explored here, such as reverse or reciprocal causality or combinations of shared genetic factors and causal effects of music practice. These can theoretically be studied using direction-of-causation models (Duffy & Martin, 1994), but one requirement of these models is that the heritability of the predictor and outcome variables must be significantly different, which was not the case here. Past studies providing evidence that variables other than practice may be important for expertise have been subject to criticism, typically on the grounds that the studied population, range of practice, domain, or task fail to meet reasonable criteria, and therefore the findings do not qualify as valid examples of real-life expertise at a high level (Ericsson, 2014). The present sample consisted of a large adult twin cohort that included many individuals with thousands of practice hours and professional engagements as musicians. The ability to discriminate melodies, rhythms, and pitches was measured—abilities obviously central for real-life music performance. Indeed, musicians systematically outperform nonmusicians on such tasks; however, results may have differed if a different measure of music ability had been used (e.g., success in the musical world). In summary, the present findings are highly relevant not only for the neurobiology of learning in general, but also for the understanding of the development of expertise and the nature of relation between practice and expert performance.

Author Contributions

M. A. Mosing developed the study concept, analyzed the data, interpreted the results, and drafted the manuscript. The study was designed and data were collected by G. Madison and F. Ullén. R. Kuja-Halkola and N. L. Pedersen provided statistical advice. All authors provided critical revisions and approved the final version of the manuscript for submission.

Acknowledgments

We would like to thank Robert Plomin for his valuable comments.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

Funding

The present work was supported by the Bank of Sweden Tercentenary Foundation (M11-0451:1), the Swedish Scientific Council (521-2010-3195), and the Sven and Dagmar Salén Foundation.

Supplemental Material

Additional supporting information can be found at http://pss.sagepub.com/content/by/supplemental-data

References

Bengtsson, S. L., Nagy, Z., Forsman, L., Forssberg, H., Skare, S., & Ullén, F. (2005). Extensive piano practicing has regionally specific effects on white matter development. *Nature Neuroscience*, *8*, 1148–1150.

Boker, S. M., Neale, M. C., Maes, H. H., Wilde, M. J., Spiegel, M., Brick, T. R., . . . Brandmaier, A. (2012). *OpenMx user guide: Release 1.2.0-1919*. Retrieved from http://openmx.psyc.virginia.edu/docs/OpenMx/latest/OpenMxUserGuide.pdf

Boker, S. M., Neale, M., Maes, H., Wilde, M., Spiegel, M., Brick, T., . . . Fox, J. (2011). OpenMx: An open source extended structural equation modeling framework. *Psychometrika*, *76*, 306–317.

Charness, N., Feltovich, P. J., Hoffman, R. R., & Ericsson, K. A. (2006). *The Cambridge handbook of expertise and expert performance*. Cambridge, England: Cambridge University Press.

Coon, H., & Carey, G. (1989). Genetic and environmental determinants of musical ability in twins. *Behavior Genetics*, *19*, 183–193.

Corrigall, K. A., Schellenberg, E. G., & Misura, N. M. (2013). Music training, cognition, and personality. *Frontiers in Psychology*, *4*, Article 222. Retrieved from http://journal.frontiersin.org/Journal/10.3389/fpsyg.2013.00222/full

de Bruin, A. B., Smits, N., Rikers, R. M., & 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.

de Geus, E. J. C., & de Moor, M. H. M. (2008). A genetic perspective on the association between exercise and mental health. *Mental Health and Physical Activity*, *1*, 53–61.

Detterman, D. K., & Ruthsatz, J. M. (1999). Toward a more comprehensive theory of exceptional abilities. *Journal for the Education of the Gifted*, *22*, 148–158.

Drayna, D., Manichaikul, A., de Lange, M., Snieder, H., & Spector, T. (2001). Genetic correlates of musical pitch recognition in humans. *Science*, *291*, 1969–1972.

Dubois, L., Ohm Kyvik, K., Girard, M., Tatone-Tokuda, F., Perusse, D., Hjelmborg, J., . . . Martin, M. G. (2012). Genetic and environmental contributions to weight, height, and BMI from birth to 19 years of age: An international study of over 12,000 twin pairs. *PLoS ONE*, *7*(2), Article e30153. Retrieved from http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0030153

Duffy, D. L., & Martin, N. G. (1994). Inferring the direction of causation in cross-sectional twin data: Theoretical and empirical considerations. *Genetic Epidemiology*, *11*, 483–502.

Ericsson, K. A. (2002). Attaining excellence through deliberate practice: Insights from the study of expert performance. In M. Ferrari (Ed.), *The pursuit of excellence through education* (pp. 21–55). Mahwah, NJ: Erlbaum.

Downloaded from pss.sagepub.com at NATIONAL SUN YAT-SEN UNIV on August 17, 2014

Ericsson, K. A. (2013). Training history, deliberate practice and elite sports performance: An analysis in response to Tucker and Collins review—What makes champions? *British Journal of Sports Medicine*, *47*, 533–535. doi:10.1136/bjsports-2012–091767

Ericsson, K. A. (2014). Why expert performance is special and cannot be extrapolated from studies of performance in the general population: A response to criticisms. *Intelligence*, *45*, 81–103.

Ericsson, K. A., Chase, W. G., & Faloon, S. (1980). Acquisition of a memory skill. *Science*, *208*, 1181–1182.

Ericsson, K. A., Krampe, R. T., & Heizmann, S. (1993). Can we create gifted people? [Target article and commentaries]. *Ciba Foundation Symposium*, *178*, 222–249.

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

Ericsson, K. A., & Lehmann, A. C. (1996). Expert and exceptional performance: Evidence of maximal adaptation to task constraints. *Annual Review of Psychology*, *47*, 273–305.

Ericsson, K. A., Nandagopal, K., & Roring, R. W. (2005). Giftedness viewed from the expert performance perspective. *Journal for the Education of the Gifted*, *28*, 287–311.

Gladwell, M. (2008). *Outliers: The story of success*. New York, NY: Little, Brown.

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.

Howe, M. J. A., Davidson, J. W., & Sloboda, J. A. (1998). Innate talents: Reality or myth? *Behavioral & Brain Sciences*, *21*, 399–442.

Hyde, K. L., Lerch, J., Norton, A., Forgeard, M., Winner, E., Evans, A. C., & Schlaug, G. (2009). Musical training shapes structural brain development. *Journal of Neuroscience*, *29*, 3019–3025.

Jang, K. L., Livesley, W. J., & Vernon, P. A. (1996). Heritability of the Big Five personality dimensions and their facets: A twin study. *Journal of Personality*, *64*, 577–591.

Krampe, R. T., & Ericsson, K. A. (1996). Maintaining excellence: Deliberate practice and elite performance in young and older pianists. *Journal of Experimental Psychology: General*, *125*, 331–359.

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., . . . Pedersen, N. L. (2006). The Swedish Twin Registry in the third millennium: An update. *Twin Research and Human Genetics*, *9*, 875–882.

Neale, M. C., Boker, S. M., Xie, G., & Maes, H. H. (2006). *Mx: Statistical modeling* (7th ed.). Richmond: Virginia Commonwealth University, Department of Psychiatry.

Neale, M. C., & Maes, H. H. M. (2004). *Methodology for genetic studies of twins and families*. Dordrecht, The Netherlands: Kluwer Academic.

Plomin, R., DeFries, J. C., & Loehlin, J. C. (1977). Genotype-environment interaction and correlation in the analysis of human behavior. *Psychological Bulletin*, *84*, 309–322.

Plomin, R., Shakeshaft, N. G., McMillan, A., & Trzaskowski, M. (2014). Nature, nurture, and expertise. *Intelligence*, *45*, 46–59.

Posthuma, D., de Geus, E. J. C., & Deary, I. J. (2009). The genetics of intelligence. In T. E. Goldberg & D. R. Weinberger (Eds.), *The genetics of cognitive neuroscience* (pp. 97–122). Cambridge, MA: MIT Press.

Ruthsatz, J., Detterman, D., Griscom, W. S., & Cirullo, B. A. (2008). Becoming an expert in the musical domain: It takes more than just practice. *Intelligence*, *36*, 330–338.

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

Seashore, C. E. (1960). *Manual of instructions and interpretations for Measures of Musical Talent*. New York, NY: Psychological Corp. (Original work published 1919)

Tucker, R., & Collins, M. (2012). What makes champions? A review of the relative contribution of genes and training to sporting success. *British Journal of Sports Medicine*, *46*, 555–561.

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.

Vinkhuyzen, A. A., van der Sluis, S., Posthuma, D., & Boomsma, D. I. (2009). The heritability of aptitude and exceptional talent across different domains in adolescents and young adults. *Behavior Genetics*, *39*, 380–392.

Downloaded from pss.sagepub.com at NATIONAL SUN YAT-SEN UNIV on August 17, 2014