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BRIEF REPORT

The genetics of music accomplishment: Evidence for gene–environment correlation and interaction

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Abstract Theories of skilled performance that emphasize training history, such as K. Anders Ericsson and colleagues' *deliberate-practice theory*, have received a great deal of recent attention in both the scientific literature and the popular press. Twin studies, however, have demonstrated evidence for moderate-to-strong genetic influences on skilled performance. Focusing on musical accomplishment in a sample of over 800 pairs of twins, we found evidence for gene–environment correlation, in the form of a genetic effect on music practice. However, only about one quarter of the genetic effect on music accomplishment was explained by this genetic effect on music practice, suggesting that genetically influenced factors other than practice contribute to individual differences in music accomplishment. We also found evidence for gene–environment interaction, such that genetic effects on music accomplishment were most pronounced among those engaging in music practice, suggesting that genetic potentials for skilled performance are most fully expressed and fostered by practice.

Keywords Music · Talent · Genetics · Skill · Individual differences

People vary widely in their skill at complex tasks such as playing musical instruments, choosing moves in chess games, and formulating scientific theories. Some people are better—much better—at these tasks than other people. What accounts for this striking variability? As we have recently discussed (Hambrick et al., 2014; Macnamara, Hambrick, & Oswald, 2014), there are two classical views. One view is that experts are "born"—that innate ability puts a limit on the ultimate level of performance that a person can reach through training. Sir Francis Galton (1869) proposed this view on the basis of his finding that eminence in a wide range of fields runs in families. The other view is that experts are "made"—that individual differences in performance can be explained in terms of training history. John Watson (1930) captured this view when he commented that "practicing . . . is probably the most reasonable explanation we have today not only for success in any line, but even for genius" (p. 212).

More recently, K. Anders Ericsson and colleagues proposed that expert performance reflects a long period of *deliberate practice*. In a now famous study, Ericsson, Krampe, and Tesch-Römer (1993) asked elite musicians to estimate the amount of time that they had engaged in deliberate practice. By age 20, elite musicians had accumulated an average of about 10,000 hours, which was thousands of hours more than averages for less-accomplished musicians. Ericsson et al. concluded:

> We agree that expert performance is qualitatively different from normal performance and even that expert performers have characteristics and abilities that are qualitatively different from or at least outside the range of those of normal adults. *However, we deny that these differences are immutable, that is, due to innate talent.* Only a few exceptions, most notably height, are genetically prescribed. (p. 400, emphasis added)

Ericsson and colleagues have consistently interpreted evidence for greater environmental than genetic contributions to individual differences in performance as critical support for their view. As a few examples, Ericsson et al. (1993) noted the finding of larger environmental than genetic effects on music

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performance in a twin study (Coon & Carey, 1989), the finding of no meaningful resemblance in physical ability between Olympians and their parents in another study (de Garay, Levine, & Carter, 1974), and the finding that tennis performance in adolescents was largely determined by parental support in a third study (Schneider, Bös, & Rieder, 1993).

There is no doubt that deliberate practice makes an important contribution to individual differences in performance. Positive correlations between deliberate practice and performance have been observed in many domains (see Ericsson, 2006). However, growing evidence is indicating that the amount of deliberate practice is not sufficient to explain individual differences in performance. Gobet and Campitelli (2007) found a large range of estimated deliberate practice among similarly skilled chess players (e.g., from 832 to 24,284 hours of deliberate practice for chess masters). More recently, in a meta-analysis of 88 studies, Macnamara et al. (2014) found that deliberate practice accounted for well under half of the variance in performance in each of the major domains in which deliberate practice has been studied—music, games, sports, education, and professions (see also Hambrick et al., 2014).

Furthermore, behavioral genetic analyses indicate that nontrivial proportions of individual differences in performance are associated with genetic factors. For example, although Ericsson et al. (1993) emphasized Coon and Carey's (1989) finding of a larger environmental than genetic contribution to music performance, heritability estimates in that study were far from trivial, averaging 30 %. As another example, Vinkhuyzen, van der Sluis, Posthuma, and Boomsma (2009) reported heritability estimates in the range from 50 to 92 % for self-reports of exceptional skill in chess, music, and other domains.

Gene–environment interplay

Researchers employing behavioral genetic methods have paid increasing attention to two forms of gene–environment interplay (Plomin, DeFries, & Loehlin, 1977): *gene–environment correlation* (*r*GE), which occurs when people experience different environments as systematic functions of their genetic differences rather than at random, and *Gene × Environment interaction* (G × E), which occurs when the magnitude of genetic influence on an outcome varies as a function of the type or amount of environmental experience. Gene–environment interplay has been characterized as being key to reconciliation between stark genetic and environmental accounts of behavioral development (Rutter, 2007).

There is strong reason to expect that both *r*GE and G × E operate in acquiring skill. *r*GE would occur if exposure to the experiences relevant to becoming highly skilled in a domain (e.g., deliberate practice) were influenced by genetically influenced traits, such as aptitudes, motivations, and preferences. Galton (1869) alluded to this possibility when he proposed that people differ in their innate capacity for "doing a great deal of very laborious work" (p. 37), as did Ericsson et al. (1993) when they speculated that any genetic effects on performance could be due to genetic effects on factors related to the propensity to engage in deliberate practice.

G × E would occur if the magnitude of the genetic influence on performance was either enhanced or diminished as a function of practice. Ericsson et al. (1993) alluded to this possibility when they claimed that general cognitive ability, which is genetically influenced, is predictive of performance in the initial stages of skill acquisition, but then loses its predictive power (see also Ericsson, 2014). Alternatively, one might expect the opposite: that genetic contributions to individual differences in performance would be magnified by prolonged practice (Bronfenbrenner & Ceci, 1994; Tucker-Drob, Briley & Harden, 2013). For instance, in addition to practice activating otherwise "dormant genes that *all* healthy children's DNA contain" (Ericsson, 2007, p. 4, emphasis added), it may activate otherwise dormant genes, variants of which *differ* across individuals.

Present study

Our analyses addressed three questions using the National Merit Twin Sample. First, what are the sample-average genetic and environmental effects on music practice and music accomplishment? We used the same sample that Coon and Carey (1989) had used, and thus expected to replicate their finding of a genetic effect on music accomplishment. Here, we asked whether we would also find evidence for *r*GE, in the form of a genetic effect on music practice.

Second, to what extent are genetic effects on music accomplishment mediated by music practice? The finding that genetic effects on music accomplishment were completely mediated by music practice would suggest that it is possible to completely account for genetic effects on performance in terms of factors related to the propensity to engage in practice (Ericsson et al., 1993). The finding of genetic effects on music accomplishment, even after controlling for music practice, would suggest that genetically influenced factors impact performance directly (e.g., abilities, aptitudes).

Finally, is there evidence for G × E, such that genetic effects on music accomplishment differ by level of music practice? The finding that genetic effects on music accomplishment are diminished by practice would support the hypothesis that genetic differences only matter for practice-naïve music aptitude, but become overwhelmed by practice (Ericsson et al., 1993). The finding that genetic effects increase as practice increases would instead suggest that genetic potentials for music accomplishment are expressed and fostered by practice.

Method

Sample

Data from the National Merit Twin Study (NMTS) were obtained from the Henry A. Murray Research Archive at Harvard University (www.murray.harvard.edu/). The NMTS sample consisted of 850 same-sex twin pairs who sat for the National Merit Scholarship test in 1962 as high school juniors (i.e., age 17 years, on average), and returned self-report psychosocial surveys and a parent survey in 1963. The sample included 354 male pairs (61.3 % monozygotic) and 496 female twin pairs (59.9 % monozygotic). Further information can be found in Loehlin and Nichols (1976). Since we were performing a secondary data analysis of the NMTS sample, the number of participants was determined by the sample size available in the existing data set. Zygosity was assessed using a physical similarity questionnaire (Nichols & Bilbro, 1966).

Primary measures

For the present project, we made use of variables from the self-report survey that are reflective of music practice and music accomplishment.

Music practice Each twin indicated whether he or she "practiced on a musical instrument" frequently, occasionally, or not at all. Our behavioral genetic decompositions of practice treated it as an ordered trichotomous variable. Of the 1,676 individuals who responded to this question, 357 indicated that they practiced occasionally, and 326 indicated that they practiced frequently. The polychoric correlation for music practice was .81 for the monozygotic twins and .62 for the dizygotic twins.

Music accomplishment Seven items were related to music accomplishment: Items 1–4, "Received a rating of 'Good' or 'Excellent' in a [national, regional, city or county, or school] music contest"; Item 5, "Composed music which has been given at least one public performance"; Item 6, "Performed with a professional orchestra"; and Item 7, "Directed (publicly) a band or orchestra." The numbers of positive endorsements for the seven items were 19, 175, 90, 81, 17, 27, and 35, respectively. Because these accomplishments were very low to moderate in frequency, we chose to model accomplishment as a dichotomous variable for which individuals who endorsed at least one of the seven items positively were considered to have attained a music accomplishment. Of the 1,677 individuals who responded to these items, 269 had attained a music accomplishment, 50 of whom indicated that they practiced on a musical instrument "not at all." The polychoric correlations for music accomplishment were .88 for monozygotic twins and .75 for dizygotic twins.

(We considered whether it would be feasible to model music accomplishment in a more continuous fashion. Because a sum score of total accomplishments would still contain a large number of zeros, it would be inappropriate to apply ordinary linear estimation methods to such a variable. One alternative that we considered was a zero-inflated Poisson approach, which is used to model count data with an excess of zeros. However, such an approach is computationally difficult to estimate as part of a twin model, and is in practice very close to the approach that we adopted, since it estimates two regression equations, one of which models taking on a nonzero value, and the other of which models the nonzero value. Since we were specifically interested in whether a music accomplishment had been attained, as opposed to the number of accomplishments attained beyond zero, our decision to simply model the dichotomous outcome was appropriate.)

The polychoric correlation between practice and accomplishment was .65, which is similar to the correlations between practice and objective measures of skilled performance observed in other studies of music (see Hambrick et al., 2014). Thus, although our measures of practice and accomplishment were from self-report, there was evidence for their validity.

Measure for sensitivity analysis

We sought to test whether our G × E findings would apply specifically to individuals who took private music lessons, but nevertheless differed in their amounts of reported practice. The parent questionnaire included information on whether each twin ever "took private piano, voice or other music lessons. (Do not include music instruction in school)." Concordance on music lessons was 95 % for monozygotic twins and 90 % for dizygotic twins. In total, the parents of 394 pairs reported that both twins took music lessons. Of these, 254 individuals reported that they practiced frequently, 242 individuals reported that they practiced occasionally, and 291 individuals reported that they did not practice at all (there was one missing value).

Analytic approach

Our analytic approach made use of behavioral genetic structural equation models for categorical outcomes in Mplus version 7.1 (Muthén & Muthén, 1998–2012) to partition variation in both music practice and music accomplishment into three variance components: (additive) genetic factors (A) that make more genetically related individuals more similar; shared environmental factors (C) that make children raised in the same family more similar to one another, regardless of genetic relatedness; and nonshared environmental factors (E) that differentiate children raised in the same family (Prescott, 2004). These models make use of information about the resemblance (e.g., intraclass correlation, or in the case of categorical data, polychoric correlation) of twins to one another on a phenotype of interest (e.g., music accomplishment) and of whether this resemblance differs as a function of zygosity.

The extent to which monozygotic twins (who share nearly 100 % of their genes) are more similar in their phenotypes than dizygotic twins (who share approximately 50 % of their genes, on average) is informative about the extent to which the phenotype is heritable. The extent to which twins reared together are more similar to one another in their phenotypes than can be explained by the heritability estimate is informative about the extent to which shared environmental factors influence the phenotype. This basic model could be extended to examine whether the same genetic and environmental factors affect two different phenotypes (e.g., practice and accomplishment) and to examine the extent to which the heritability of a phenotype (e.g., accomplishment) differs as a function of an experiential variable (e.g., practice).

Results

To reiterate, we addressed three questions: First, what are the sample-average genetic and environmental effects on music practice and music accomplishment? Second, to what extent are genetic effects on music accomplishment mediated by music practice? Third, to what extent do genetic effects on music accomplishment differ by level of music practice?

What are the sample-average genetic and environmental effects on music practice and music accomplishment?

The results of our univariate behavioral genetic models indicated that for music accomplishment, genetic variation accounted for 26 %, shared environmental variation accounted for 61 %, and nonshared environmental variation accounted for 12 % of the variation (all *p*s < .001). For practice, these estimates were 38 %, 44 %, and 19 %, respectively (all *p*s < .001).

To what extent are genetic effects on music accomplishment mediated by music practice?

We examined the extent to which music practice mediated the genetic influences on music accomplishment. We began by testing between alternative bivariate models of the practice–accomplishment association. The Cholesky model (top panel of Fig. 1) represents a situation in which the genetic and environmental factors (A_1, C_1, and E_1) associated with music practice also directly affect music accomplishment. The association between music practice and music accomplishment is represented as occurring through “third-variable causation.” The direct-effect model (middle panel of Fig. 1) represents a situation in which music practice itself is directly associated with accomplishment, such that music practice acts as a mediator of some of the genetic and environmental influences on music accomplishment.

The Cholesky model is a more complex model than the direct-effect model, because it requires the estimation of three parameters (a_b, c_b, and e_b) to account for the shared variance between music practice and music accomplishment, whereas the direct-effect model only requires the estimation of one parameter (b) to account for this shared variance. The models are nested within one another, so comparison of their fits can be used to assess whether the Cholesky model is necessary to account for data, or whether the more parsimonious direct-effect model is sufficient. We can also compare intermediate, hybrid, models to the Cholesky and direct-effect models. Such models would allow for a direct effect of music practice on music accomplishment, but also for third-variable causation by either shared environmental or genetic influences.

Parameter estimates and standard errors for the four alternative bivariate models of practice and music accomplishment are reported in the Appendix. The results of our model comparisons are presented in Table 1. The direct-effect + C “third-variable effect” model fit no worse than the Cholesky model, and significantly better than the direct-effect model, and was therefore accepted as the best representation of the data. This model, presented in the bottom panel of Fig. 1, indicates a direct association between practice and music accomplishment, above and beyond family-level environmental effects shared between the two.

We used this final model to calculate the extent to which music practice mediated the genetic and environmental effects on music accomplishment. The top panel of Fig. 2 depicts the regression effects of genes, the shared environment, and the nonshared environment on music accomplishment that are mediated by music practice, confounded with music practice, and unique of music practice, and these indicate a mediated genetic effect of .248 (calculated as $a_1 \times b$—i.e., .613 × .404) in standardized regression units.

Unique genetic influences, independent of practice, are also evident on accomplishment, and are .450 standardized regression units in magnitude. The bottom panel of Fig. 2 expresses the shared and unique effects on practice in terms of proportions of variance (R^2), rather than regression effects. Note that the shared effects include both mediated effects (e.g., $a_1 \times b$) and confounded effects (e.g., a_u; R^2 cannot be cleanly partitioned in mediation models in the way that regression effects can).

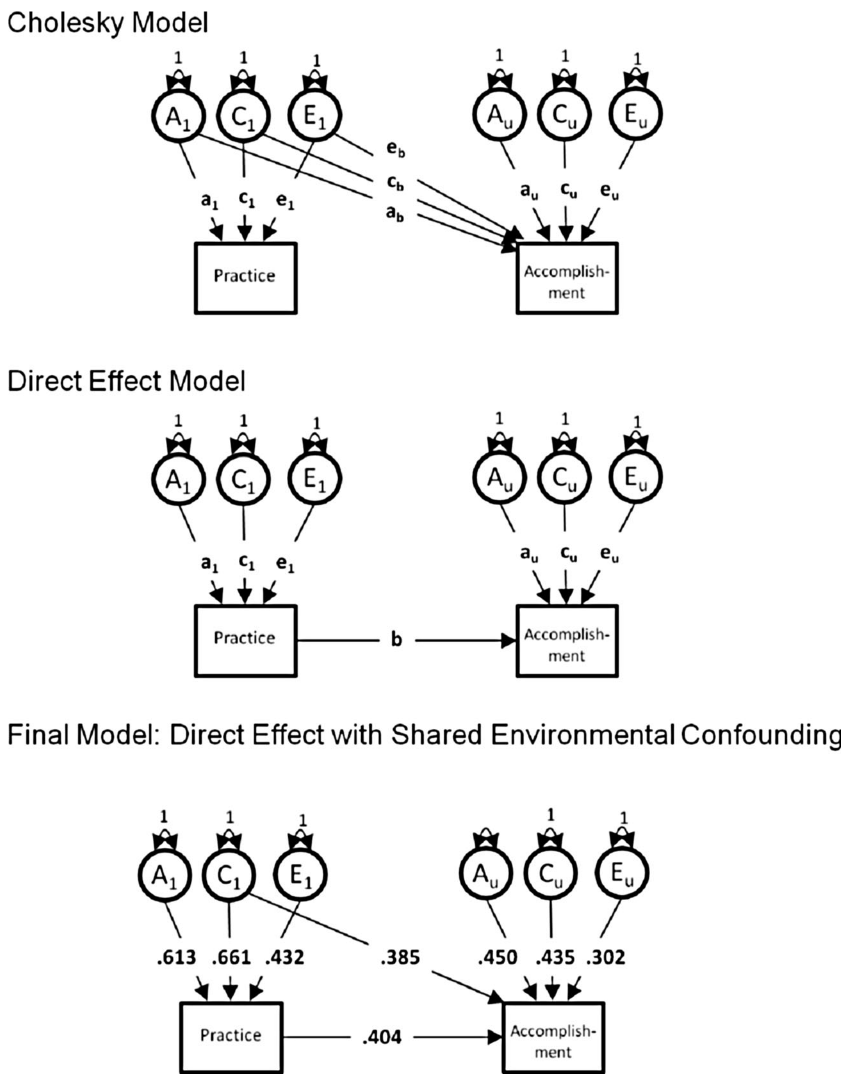

Fig. 1 The Cholesky model (*top panel*) represents a situation in which the genetic and environmental factors (A_1, C_1, and E_1) associated with music practice also directly affect music accomplishment. The direct-effect model (*middle panel*) represents a situation in which music practice itself is directly associated with accomplishment, such that music practice acts as a mediator of some of the genetic and environmental influences on music accomplishment. The model fitting led us to endorse a hybrid model (*bottom panel*) that included a direct association between practice and music accomplishment above and beyond family-level environmental effects shared between the two

Table 1 Comparison of bivariate quantitative genetic models of practice and accomplishment

Model	Vs. Cholesky (Least restrictive model)	Vs. Direct effect (Most restrictive model)
Cholesky	–	$p = .08$
Direct effect	$p = .08$	–
Direct effect + C “Third-variable effect”	$p = .316$	$p = .003$
Direct effect + A “Third-variable effect”	$p = .0047$	$p = .303$

To what extent do genetic effects on music accomplishment differ by levels of music practice?

To test for G × E, we examined whether the magnitudes of genetic and environmental influences differed for individuals who reported no music practice at all to the magnitudes of such influences for individuals who reported occasional or frequent music practice. Statistically significant interactions were detected on the genetic and shared environmental contributions to music accomplishment. Genetic effects on accomplishment were stronger for children who reported practicing (43 %, $p < .01$) than for those who reported not practicing (1 %, $p = .83$), and shared environmental effects were stronger for children who reported not practicing (86 %, $p < .01$) than for

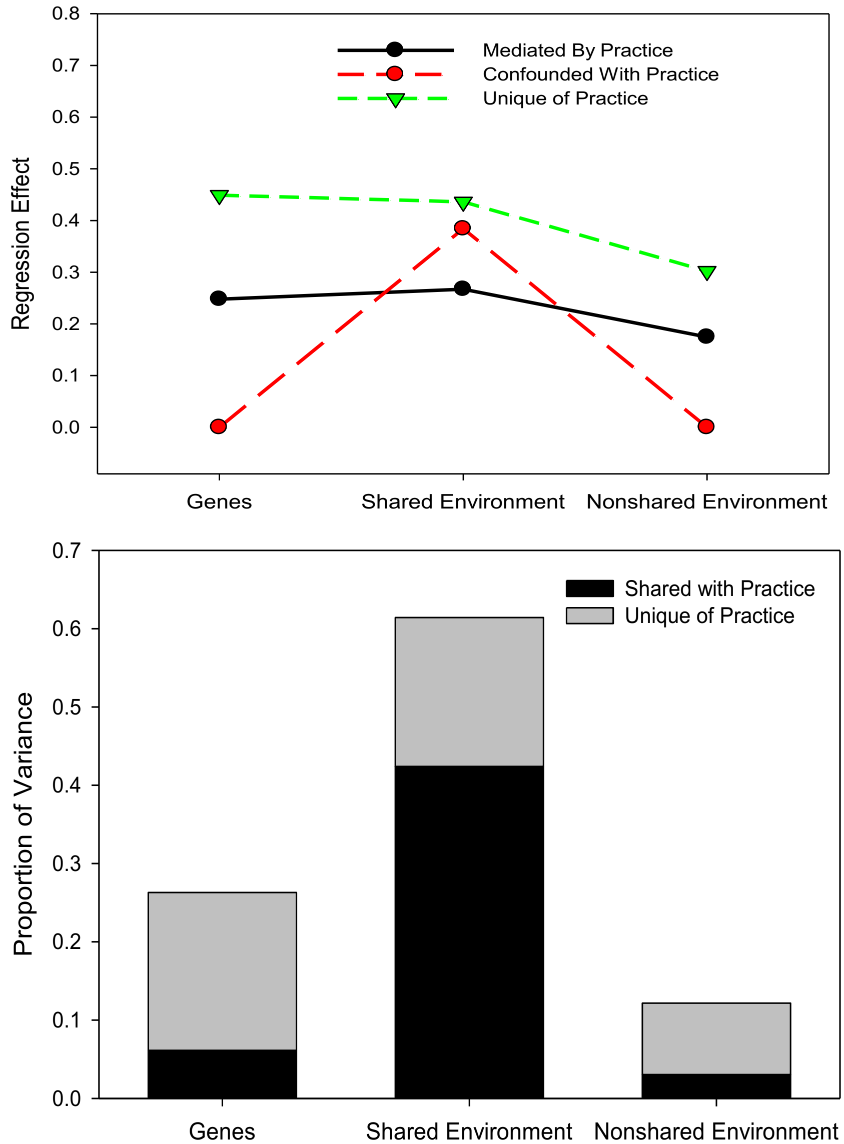

Fig. 2 (*Top*) Standardized regression effects of genes, the shared environment, and the nonshared environment on music accomplishment that are mediated by music practice, confounded with music practice, and unique of music practice. (*Bottom*) Proportions of variance in music accomplishment that is either shared or unique of practice. Note that shared effects include both mediated and confounded effects

children who reported practicing (43 %, $p < .01$). In other words, the difference in the heritability of accomplishment between those who practiced and those who did not was 42 % ($p = .015$), and the difference in the shared environmentality of accomplishment between those who practiced and those who did not was 43 % ($p = .015$). These results, which are presented in Fig. 3, indicate that music practice is associated with the expression of genetic influences on music accomplishment.

Sensitivity analysis

One explanation for the Gene × Practice interactions obtained above is that practice is a proxy for musical lessons. Because practice varied widely even among students who took lessons, we could investigate this possibility by testing for a Gene × Practice interaction in the subsample of students who took lessons. If the Gene × Practice interaction were evident in this subsample of students, this would suggest that it is the act of practice, rather than the experience of taking music lessons, that interacts with genes to affect music accomplishment.

The results revealed that genetic effects on accomplishment were stronger for children who reported practicing (59 %, $p < .01$) than for those who reported not practicing (1 %, $p = .80$). Moreover, the shared environmental effect was stronger for children who reported not practicing (76 %, $p < .01$) than for children who reported practicing (27 %, $p = .015$). In other words, the difference in the heritability of accomplishment

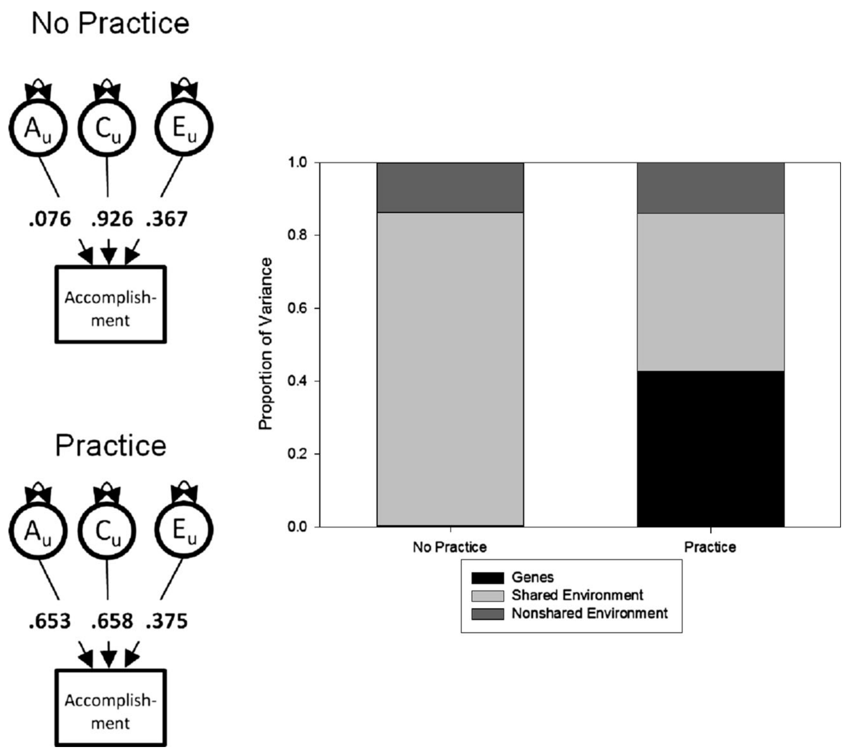

Fig. 3 Results of our G × E analyses. (*Left*) Multiple-group path diagram of the genetic (A), shared environmental (C), and nonshared environmental (E) effects on the music accomplishment of individuals who reported no music practice at all and of individuals who reported occasional or frequent music practice. (*Right*) Proportions of variance in music accomplishment attributable to genetic, shared environmental, and nonshared environmental factors

between those who practiced and those who did not was 58 % ($p < .01$), and the difference in the shared environmentality of accomplishment between those who practiced and those who did not was 49 % (p =.059). Thus, the Gene × Practice interaction not only persisted, but strengthened, when analyses were restricted to participants who took lessons.

Discussion

In the first study of its kind, we investigated gene–environment correlation (*r*GE) and Gene × Environment interaction (G × E) with respect to musical accomplishment. In addition to population-level genetic effects on music accomplishment (h^2 = .26), we found even stronger genetic effects on music practice (h^2 = .38). Genetic effects on music practice are noteworthy, given that practice is conventionally conceptualized as an environmental variable. How might genes get "outside of the skin" to affect music practice? It is likely that genetically influenced penchants and/or aptitudes for music could lead children to dedicate themselves to music practice, whereas children lacking such genetically influenced penchants and aptitudes for music might quit practicing early on, or never even begin. Similarly, children with penchants and aptitudes for music might evoke reinforcement from parents and teachers, leading them to be (even more) motivated to practice. Finally, genetic effects on practice could reflect personality or motivational factors (e.g., general activity level; Ericsson et al., 1993) related to the propensity to engage in sustained practice.

Furthermore, although practice was moderately heritable, genetic influences on practice only mediated a small portion of the genetic effects on music accomplishment. Indeed, after controlling for practice, over three quarters of the genetic variance in music accomplishment remained. Thus, our results indicate that although genetically influenced propensities toward engaging in practice may account for some of the genetic influences on music accomplishment (Ericsson et al., 1993), they are not sufficient to explain all of the genetic influences on accomplishment. These large residual genetic influences on accomplishment may reflect a host of other genetically influenced factors, such as musical aptitude or basic abilities.

Finally, practice magnified the genetic effects on music accomplishment. One might have expected that practice would attenuate genetic effects on music accomplishment, such that genetic differences would only matter for practice-naïve music aptitude and would become overwhelmed by practice (see Ericsson et al., 1993). Instead, our results are most consistent with the hypothesis that genetic potentials for music accomplishment are most fully expressed and fostered by practice, even when analyses were limited to participants who had received music lessons. It is somewhat surprising that, though they were relatively few in number (about 3 % of the total sample), some participants reported no practice, and yet indicated that they had a musical accomplishment. These participants could have acquired a high enough level of skill for a musical accomplishment through music lessons alone, or through playing for enjoyment rather than through practicing. It is also possible that some of these participants had practiced in the past, but had stopped before accumulating enough practice to foster the expression of genes related to music performance.

Whatever the case, including students with no practice in our initial behavioral genetic analysis led to attenuation of the effect of genes on music accomplishment. Many of these students may have had strong aptitudes for music that went unrealized as a result of lack of access or dedication to music training and/or practice. It is possible that among students who continued to practice routinely over early adulthood, genetic influences on music accomplishment would continue to strengthen and magnify, similar to how genetic influences on cognition increase over development (Briley & Tucker-Drob, 2013).

Limitations and future directions

Our measures of both accomplishment and practice were fairly coarse. Future research should measure practice along multiple continuous dimensions to index both frequency and intensity, and should develop and apply quantitative indices of musical accomplishment that index not just whether an accomplishment has been achieved, but also the degree of achievement. We might expect gene–environment correlation to occur for each of these features of practice, such that genes account for variation in intensity of practice, in addition to the frequency or amount of practice. Additionally, although it is interesting and important in its own right, accomplishment is likely to be closely related to, but not equivalent to, skill level, which might be best indexed using standardized measures or objective rating scales. Future research should measure both accomplishment and skill in musicians. In developing more sensitive multidimensional measures, efforts to make use of rating systems and objective tests, rather than simple self-report scales, would be particularly valuable. Importantly, these limitations apply to research on skilled performance generally, and not simply to the present behavioral–genetic investigation.

Another limitation concerns the nature of the sample. Although the participants in the National Merit Twin Study were likely to be a positively selected group of high-achieving students, they were not specifically selected to contain world-class music experts. Thus, the degree to which the present results would generalize to the highest levels of performance is unknown. Future genetically informative research on a special population of professional musicians would be necessary to understand the interplay between genetics, practice, and exceptional music performance.

Conclusions

The present investigation produced evidence for both gene–environment correlation and interaction in the association between music practice and music accomplishment. We found statistically significant, and moderate-in-magnitude, genetic effects on practice that mediated approximately one quarter of the genetic effects on music accomplishment at the population level. Moreover, rather than reducing the effects of genetic variation on individual differences in music accomplishment, practice magnified such effects. These results indicate that children who do not engage in training or practice in music may have hidden talents, or at the very least potentials for talent, that go unrecognized and unrealized.

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Appendix

Table 2 Parameter estimates for alternative bivariate models of practice and music accomplishment

Variable	*b*	*SE*	A	*SE*	C	*SE*	E	*SE*
Cholesky								
Practice			.615	.096	.66	.087	.432	.035
Practice → Music			.235	.238	.661	.177	.181	.088
Music			.456	.150	.421	.247	.299	.069
Direct effect								
Practice			.563	.109	.709	.087	.424	.035
Practice→Music	.679	.049						
Music			.342	.19	.618	.097	.197	.091
Direct effect+C “Third-variable effect”								
Practice			.613	.101	.661	.091	.432	.036
Practice → Music	.404	.096			.385	.137		
Music			.450	.14	.435	.146	.302	.059
Direct effect + A “Third-variable effect”								
Practice			.580	.101	.696	.083	.424	.035
Practice → Music	.765	.218	–.132	.363				
Music			.313	.278	.591	.149	.259	.130

SE Standard error

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