Intelligence 76 (2019) 101383

Contents lists available at ScienceDirect

Intelligence

journal homepage: www.elsevier.com/locate/intell

Predicting piano skill acquisition in beginners: The role of general intelligence, music aptitude, and mindset

Alexander P. Burgoyne*, Lauren Julius Harris, David Z. Hambrick

Department of Psychology, Michigan State University, USA

ARTICLE INFO

Keywords:
Skill acquisition
Music
Intelligence
Cognitive ability
Music aptitude
Mindset

ABSTRACT

This study was designed to investigate sources of individual differences in musical skill acquisition. We had 171 undergraduates with little or no piano-playing experience attempt to learn a piece of piano music with the aid of a video-guide, and then, following practice with the guide, attempt to perform the piece from memory. A panel of musicians evaluated the performances based on their melodic and rhythmic accuracy. Participants also completed tests of working memory capacity, fluid intelligence, crystallized intelligence, processing speed, and two tests of music aptitude (the Swedish Music Discrimination Test and the Advanced Measures of Music Audiation). Measures of general intelligence and music aptitude correlated significantly with skill acquisition, but mindset did not. Structural equation modeling revealed that general intelligence, music aptitude, and mindset together accounted for 22.4% of the variance in skill acquisition. However, only general intelligence contributed significantly to the model ($\beta = 0.44$, $p < .001$). The contributions of music aptitude ($\beta = 0.08$, $p = .39$) and mindset ($\beta = -0.06$, $p = .50$) were non-significant after accounting for general intelligence. We also found that openness to experience did not significantly predict skill acquisition or music aptitude. Overall, the results suggest that after accounting for individual differences in general intelligence, music aptitude and mindset do not predict piano skill acquisition in beginners.

1. Introduction

People differ in the rate at which they acquire complex skills. Music is no exception. As is well known, some people develop musical skill far more rapidly than others, with prodigies at one extreme (Kenneson, 1998; Winner & Martino, 2000), and people with congenital amusia at the other (Ayotte, Peretz, & Hyde, 2002). Among prodigies, Wolfgang Amadeus Mozart is the quintessential example. Although musicologists believe that his father Leopold may have contributed to Mozart's earliest compositions (Sadie, 2006), there is no serious debate about his prodigious skills as a very young child. For instance, at the age of 6, Mozart toured Europe performing for the courts of Paris, London, and Zurich (Sadie, 2006).

What accounts for the striking inter-individual variability in acquiring musical and other complex skills? This question can be framed in terms of a distinction between *ability* and *non-ability* factors. Ability factors refer to stable skills or capacities (Sternberg, 2000) and can be *domain-general* or *domain-specific.* Domain-general abilities (e.g., working memory capacity) can be brought to bear on a wide range of tasks, whereas domain-specific abilities (e.g., music aptitude) are applicable to a relatively narrow range of tasks. Non-ability factors include dispositional attributes such as personality, motivation, attitudes, interests, and beliefs. At least in theory, tests of ability factors capture *maximal performance,* whereas tests of non-ability factors capture *typical performance* (Ackerman, 1994).

1.1. Ability factors

There have been many reports of significant associations between domain-general ability factors and musical skill. For example, in a study of 178 high school band members, Ruthsatz, Detterman, Griscom, and Cirullo (2008) found that scores on a test of fluid intelligence (Raven's Advanced Progressive Matrices) correlated significantly with music achievement ($r = 0.25$, $p = .01$). As another example, Kopiez and In Lee (2008) found that a measure of perceptual speed correlated significantly with sight-reading performance ($r = -0.44$, $p < .001$) in 52 piano major students and graduates. Finally, Meinz and Hambrick (2010) investigated the relation between working memory capacity and sight-reading performance in pianists ranging from novices to experts. They found that working memory capacity was a significant predictor of sight-reading performance ($r = 0.28$, $p < .05$) and that the correlation increased after controlling for amount of music training (partial

* Corresponding author at: Department of Psychology, Michigan State University, East Lansing, MI 48824, USA.
E-mail address: burgoyn4@msu.edu (A.P. Burgoyne).

https://doi.org/10.1016/j.intell.2019.101383
Received 9 May 2019; Received in revised form 6 August 2019; Accepted 13 August 2019
Available online 04 September 2019

$r = 0.37$, $p < .01$).

Domain-specific ability factors also appear to play an important role in the acquisition of musical skill. For instance, Ruthsatz et al. (2008) found that scores on the Advanced Measures of Music Audiation (Gordon, 1989), a measure of auditory discrimination ability, predicted music achievement in high school band members ($r = 0.22$, $p = .01$). As another example, Froseth (1971) found that scores on the Music Aptitude Profile (MAP; Gordon, 1965) positively predicted 5th- and 6th-grade students' performance quality after 1 year of training (see also Gordon, 1968). Similarly, Schleuter (1978) found that MAP scores predicted music performance skills in elementary school students. More recently, in university wind players, Hayward and Eastlund Gromko (2009) found significant correlations between sight-reading ability and scores on the Advanced Measures of Music Audiation ($r = 0.24$, $p < .05$; see also Gromko, 2004). These results are consistent with results of a meta-analysis by Mishra (2014), which revealed an average correlation of 0.40 ($p < .05$) between music aptitude and sight-reading accuracy.

It should also be noted that the relationship between domain-general cognitive ability and music aptitude is well-established. For example, auditory processing is included in the taxonomy of broad cognitive ability factors in the CHC model of intelligence (McGrew, 2009), alongside other ability factors such as fluid reasoning and processing speed. In a study of 84 undergraduates, Swaminathan and Schellenberg (2018) found that cognitive ability correlated positively and significantly with music aptitude ($r = 0.41$, $p < .05$). Mosing, Pedersen, Madison, and Ullén (2014) also found significant relationships between music aptitude and intelligence (rs ranged from 0.23 to 0.29, ps < 0.05). Furthermore, Mosing et al. (2014) used genetic modeling to show that the covariance between music aptitude and general intelligence could be explained by shared genetic influences. However, music aptitude was also predicted by a unique genetic factor, suggesting only partial overlap with general intelligence.

1.2. Non-ability factors

Numerous studies have examined the relation between non-ability factors and skill acquisition in complex tasks (e.g., Ackerman, Kanfer, & Goff, 1995). Recently, however, there has been a great deal of interest in whether skill acquisition can be predicted by people's beliefs, or *mindset*, about their abilities. In a series of studies, Dweck and colleagues reported that people with a *growth mindset*, who believe that their ability in a domain can be changed with effort, showed higher levels of achievement than people with a *fixed mindset,* who believe that their ability is unchangeable (e.g., Dweck & Leggett, 1988; also Stipek & Gralinski, 1996). Nevertheless, a recent meta-analysis by Sisk, Burgoyne, Sun, Butler, and Macnamara (2018) revealed that the average relationship between mindset and academic achievement is relatively weak ($r = 0.10$, $p < .001$).

Although few studies have investigated the effect of mindset on acquiring musical skill, there is reason to think it could play a role. Smith (2005) examined correlations between mindset, goal orientation, and practice in 344 undergraduate instrumentalists. Although mindset correlated significantly with only one practice factor (organization of practice/record keeping), it also correlated significantly with *task motivation*, which reflects a person's drive to master new material. In turn, task motivation correlated significantly with a composite factor representing degree of engagement in a variety of practice activities. This pattern of correlations is consistent with the hypothesis that mindset is related to one's propensity to practice, which in turn enhances skill acquisition.

Another non-ability factor that has been studied in the context of music achievement is openness to experience. Corrigall, Schellenberg, and Misura (2013) found that openness to experience significantly predicted years of playing music regularly ($r = 0.32$, $p < .001$) in a sample of undergraduates, even after accounting for demographics and differences in general intelligence (partial $r = 0.25$, $p = .008$). Openness to experience has also been found to predict music aptitude, and Swaminathan and Schellenberg (2018) found that its relationship to music aptitude remained significant after controlling for music training, general intelligence, and socio-economic status.

1.3. Current study

The goal of this three-session study was to assess the contribution of ability and non-ability factors to skill acquisition in music. We had beginners attempt to learn a piece of music for the piano, and had a panel of musicians evaluate their performances. Participants also completed tests of personality, cognitive ability, and music aptitude. We used structural equation modeling (SEM) to assess the relative contribution of latent factors reflecting general intelligence, music aptitude, and mindset to skill acquisition.

2. Method

2.1. Participants

The participants were 422 undergraduate students (age $M = 20.19$, $SD = 1.47$, range: 18–25; 76.3% were female) recruited from introductory psychology courses at Michigan State University. Participants earned course credit for participating. All reported normal or corrected-to-normal vision and normal hearing. All participants provided informed consent. Prior to the beginning of the study, all potential participants completed a screening survey in which they were asked whether they knew how to play the piano. Only participants who reported not knowing how to play the piano were allowed to participate in the study.

The study consisted of three sessions. Of the 422 participants who completed Session 1 (an online questionnaire), 171 attended Session 2 (an in-laboratory session). Of those 171, 154 attended Session 3 (another in-laboratory session). The decrease in the number of participants from Session 1 to Session 2 is a result of scheduling constraints: We could test only one participant at a time in the in-laboratory sessions and could not offer enough time slots to accommodate all of the participants who completed the online questionnaire.

2.2. Session 1

In Session 1, participants completed an online survey of non-ability factors. The factors of interest are listed below. Participants also completed additional personality scales, which are not considered herein.

2.2.1. Music background

Music background and demographic information were obtained from a questionnaire designed for the study. Participants answered 11 music background questions to assess whether they had any experience playing the piano (see "Data Preparation" below), playing other musical instruments, or participating in a band, choir, or orchestra. Participants reported how many years of experience they had playing musical instruments, how often they listen to music, how often they tap their foot or dance to music, whether any family members play musical instruments, and whether they were familiar with the songs "Happy Birthday" and "The Star Spangled Banner."

2.2.2. Mindset of music ability

Participants completed a questionnaire designed to measure mindset of music ability adapted from Dweck, Chiu, and Hong (1995). An example of a growth mindset item is, "You can always substantially change how much music ability you have." There were 8 items to which participants responded on a 7-point Likert scale. Higher scores correspond to greater growth mindset, reflecting the belief that music ability is malleable.

2.2.3. Openness to experience

Participants responded to 10 items from the Big Five Inventory personality assessment (John, Donahue, & Kentle, 1991; John, Naumann, & Soto, 2008) on a 5-point Likert scale to assess openness to experience.

2.3. Session 2

2.3.1. Music aptitude

Participants completed two batteries of computerized music aptitude tests, the Advanced Measures of Music Audiation (AMMA; Gordon, 1989) and the Swedish Music Discrimination Test (SMDT; Ullén, Mosing, Holm, Eriksson, & Madison, 2014).

The AMMA includes two subscales: *rhythm* and *tonal*. Participants listened to 30 pairs of melodic excerpts; their task was to identify potential rhythmic and melodic deviations in each pair. The SMDT includes three subtests: *pitch*, *rhythm*, and *melody*. In the pitch subtest, participants must decide whether the second of two pitches is higher or lower than the first. In the rhythm subtest, they must decide whether two rhythms are the same or different. In the melody subtest, they must identify the deviant note in pairs of nearly identical melodies.

2.3.2. Skill acquisition task

As a "pre-test" of piano skill, participants were given two opportunities to perform the song Happy Birthday on an electronic piano.[1] Participants were instructed to use their right hand for these and all subsequent performances to match the motor demands of the task across participants and to prevent participants from performing the song with both hands. We expected a majority of participants to be right handed.[2] A green sticker on the keyboard indicated to participants the first note of the song (G4; the G above middle C). After the pre-test performances, participants were given 6 min to practice with an animated video lesson demonstrating how to play the song, which was presented on a computer monitor above the keyboard. In the video, the song was performed in time with a metronome set to 70 beats per minute so that the entire piece, consisting of 25 notes, was completed in 20 s. After the first 6 min of practice, participants were instructed to perform Happy Birthday from memory four times: twice with a metronome and twice without, in that order. These four performances served as a "mid-test" of skill acquisition. Next, participants were given 6 more minutes to practice with the video lesson. Afterward, they performed Happy Birthday from memory four more times: twice with a metronome and twice without. These final four performances served as a "post-test" of skill acquisition.

Each practice session was followed by 1 min of rest directly preceding the first performance. Between each performance was an additional 30 s of rest. Participants were asked to refrain from playing the piano between the practice sessions and performances.

2.3.3. Skill acquisition score

Post-test performances were evaluated by a panel of three judges with extensive formal piano training (all were graduate students pursuing master's or doctoral degrees in piano performance at Michigan State University).[3] The judges evaluated each performance on a 5-point scale (1 = poor, 5 = excellent) according to two criteria: melodic accuracy and rhythmic accuracy.

To compute a skill acquisition score, we averaged the judges' ratings of the four post-test performances. In the descriptive statistics and correlations reported below, scores on these four post-test performances were averaged to create a single skill acquisition score for each participant. The judges' ratings of the post-test performances were highly correlated (Judge 1 with Judge 2: $r = 0.95$, $p < .001$; Judge 1 with Judge 3: $r = 0.92$, $p < .001$; Judge 2 with Judge 3: $r = 0.92$, $p < .001$). Because the judges rated only the post-test piano performances, we computed a secondary measure of skill acquisition for all pre-test, mid-test, and post-test performances: the number of consecutive correct notes played from the beginning of the song (with 25 notes comprising the song, the maximum correct = 25).

2.4. Session 3

In Session 3, participants completed eight domain-general tests of intelligence: two tests of working memory, two of fluid intelligence, two of crystallized intelligence, and two of processing speed. All tests were completed individually in a laboratory room. Except for a paper-and-pencil pattern comparison test, one of the tests of processing speed, all tests were administered via computer.

2.4.1. Reading span

In this test of working memory capacity, participants read sentences, verified their validity, and attempted to remember letters presented after each sentence (Oswald, McAbee, Redick, & Hambrick, 2014). The measure was the number of correctly recalled letters.

2.4.2. Symmetry span

In this test of working memory capacity, participants made judgments about the symmetry of different images, while memorizing the position of colored squares appearing after each symmetry judgment (Oswald et al., 2014). The measure was the number of correctly recalled square positions.

2.4.3. Raven's advanced progressive matrices

In this test of fluid intelligence, participants were presented with a set of patterns with the lower-right portion missing. Participants were to choose a pattern from a set of alternatives that logically completed the series. Participants were given 10 min to complete the 18 odd-numbered items from the test (Raven & Court, 1998). The measure was the number correct.

2.4.4. Letter sets

In this test of fluid intelligence, participants were presented with five sets of four letters (e.g., ABCD) arranged in a row, and were to choose the set that does not follow the same pattern as the other four. Participants were given 5 min to complete 20 items (Ekstrom, French, Harmon, & Dermen, 1976). The measure was the number correct.

2.4.5. Synonyms and antonyms

In these tests of crystallized intelligence, participants were presented with a target word and four words that serve as response options. For synonym items, participants were to choose the response option most similar in meaning to the target word. For antonym items, they were to choose the response option most nearly the opposite in meaning to the target word. Participants were given 5 min for 10 synonym items and 5 min for 10 antonym items (Hambrick, Salthouse, & Meinz, 1999). The measure for each was the number correct.

2.4.6. Pattern comparison

In this test of processing speed, participants judged whether two symbols were the same or different. Participants were given 30 s per set of 30 items (Salthouse & Babcock, 1991). There were two sets of items. The measure was the number correct minus two times the number incorrect.

[1] Prior to the pre-test, participants completed a bimanual motor control test designed for the study. The motor control test did not significantly predict performance in the skill acquisition task.

[2] During Session 1, all participants were given a 22-item handedness questionnaire. Ten participants who completed the skill acquisition task were left-hand dominant. There was no significant difference between left-hand dominant and right-hand dominant participants in the skill acquisition task ($t = -0.17$, $p = .86$).

[3] We wish to thank Elizabeth Clarke, Mary Gossell, and James Schippers for evaluating the piano performances.

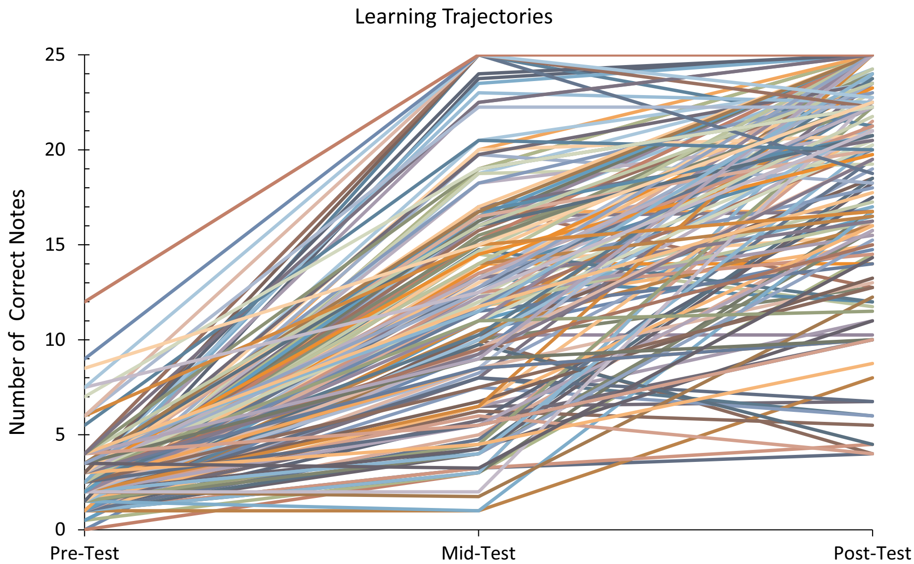

Fig. 1. Change in the number of consecutive correct notes played from the beginning of the song from pre-test to post-test. Each line represents one participant (n = 161). As the figure shows, participants tended to improve from pre-test to post-test, and there were substantial individual differences in skill acquisition trajectories.

2.4.7. Letter/number comparison

In this test of processing speed, participants judged whether two sequences of letters or numbers were the same or different. Participants were given 30 s per set of 72 items (Salthouse & Babcock, 1991). There were two sets of letter items and two sets of number items. The measure was the number correct.

2.5. Data preparation

Of the 171 participants who completed the skill acquisition task during Session 2, seven were excluded prior to data analysis for not following instructions. Three additional participants were excluded because they reported having more than 1 month of piano-playing experience in the music background questionnaire. These exclusions left a useable sample of 161.

2.6. Data analysis

We used structural equation modeling (SEM) to assess the relative contribution of general intelligence, music aptitude, and mindset to skill acquisition in music. Briefly, SEM is a tool for analyzing individual-difference data that combines two statistical techniques. Confirmatory factor analysis is used to create a measurement model that includes latent variables representing hypothetical constructs, and path analysis is used to test models that include relations among the latent variables (Kline, 2011). A major advantage of SEM over other approaches to

Table 1
Descriptive statistics.

Measure	*N*	*M*	*SD*	Min.	Max.	Reliability
Skill acquisition						
Skill acquisition score (Judges' Rating)	158	4.38	0.88	1.13	5	0.97
Pre-test number of correct notes	161	2.16	1.72	0	12	0.54
Mid-test number of correct notes	161	12.39	5.97	1	25	0.82
Post-test number of correct notes	161	18.84	5.80	4	25	0.79
Domain-general intelligence						
Raven's matrices	144	9.99	3.26	2	18	0.76
Letter sets	144	10.21	3.17	3	17	0.72
Reading span	143	57.25	11.20	14	75	0.73
Symmetry span	144	29.85	7.74	7	42	0.77
Pattern comparison	144	36.30	7.17	10	58	0.76
Letter/number comparison	144	51.65	8.88	32	72	0.88
Synonyms	144	3.24	2.06	0	9	0.52
Antonyms	144	3.55	1.96	0	9	0.46
Music aptitude						
Pitch (SMDT)	159	17.86	4.12	9	27	0.87
Rhythm (SMDT)	159	16.04	1.49	11	18	0.82
Melody (SMDT)	159	6.97	2.41	2	14	0.80
Tonal (AMMA)	159	24.88	4.13	16	36	0.80
Rhythm (AMMA)	159	27.09	3.72	13	37	0.80
Non-ability factors						
Mindset	154	5.14	1.01	1.88	7	0.93
Openness to experience	155	3.70	0.50	2.50	5	0.78

Note. "Number of Correct Notes" refers to the number of consecutive correct notes played from the beginning of the song. SMDT = Swedish Musical Discrimination Test; AMMA = Advanced Measures of Music Audiation. The sample sizes differ across measures due to attrition and occasional technical malfunctions. The reliability estimate is Cronbach's alpha unless otherwise noted. We did not have trial-level data for the SMDT and AMMA; thus, alpha values for the SMDT were taken from Ullén et al. (2014); split-half reliabilities for the AMMA were taken from the testing manual (Gordon, 1989). Alpha values for the skill acquisition score are based on the mean of the judges' ratings across the four piano performances.

Table 2
Correlation matrix.

Measure	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Skill acquisition																		
1. Skill acquisition score (Judges' Rating)	–																	
2. Pre-test number of correct notes	**0.22**	–																
3. Mid-test number of correct notes	**0.48**	**0.43**	–															
4. Post-test number of correct notes	**0.82**	**0.22**	**0.51**	–														
Domain-general intelligence																		
5. Raven's matrices	**0.27**	**0.21**	**0.24**	**0.34**	–													
6. Letter sets	**0.17**	0.08	0.11	**0.30**	**0.38**	–												
7. Reading span	**0.20**	**0.21**	**0.20**	**0.23**	**0.30**	**0.24**	–											
8. Symmetry span	**0.30**	−0.10	**0.21**	**0.25**	**0.27**	**0.28**	**0.29**	–										
9. Pattern comparison	**0.20**	0.11	0.12	0.15	**0.29**	**0.17**	0.14	**0.27**	–									
10. Letter/number comparison	0.14	−0.09	0.00	**0.19**	**0.18**	**0.20**	0.09	**0.29**	**0.37**	–								
11. Synonyms	0.09	0.07	0.09	**0.17**	**0.35**	0.16	**0.32**	0.12	0.03	0.03	–							
12. Antonyms	0.09	0.16	0.03	**0.25**	0.15	**0.25**	0.04	−0.05	0.00	−0.02	**0.32**	–						
Music aptitude																		
13. Pitch (SMDT)	**0.21**	**0.20**	**0.27**	**0.22**	0.04	0.08	0.11	0.02	0.12	−0.08	0.05	**0.18**	–					
14. Rhythm (SMDT)	**0.26**	**0.16**	**0.18**	**0.21**	0.14	**0.20**	**0.18**	**0.19**	0.00	0.00	0.07	0.04	0.12	–				
15. Melody (SMDT)	**0.25**	0.05	**0.18**	**0.21**	**0.26**	0.01	0.15	0.10	0.07	−0.07	0.06	0.00	0.15	0.11	–			
16. Tonal (AMMA)	**0.17**	**0.19**	**0.17**	**0.17**	**0.33**	**0.20**	**0.18**	0.12	0.06	−0.09	0.11	0.05	0.06	**0.22**	**0.32**	–		
17. Rhythm (AMMA)	**0.22**	**0.26**	**0.23**	**0.19**	**0.31**	**0.20**	**0.22**	0.13	0.05	−0.04	0.00	0.01	**0.18**	**0.35**	**0.32**	**0.72**	**–**	
Non-ability factors																		
18. Mindset	0.02	0.11	0.04	0.07	−0.09	−0.09	−0.03	**−0.17**	**−0.20**	**−0.24**	−0.03	0.10	0.10	0.04	0.04	0.02	0.08	–
19. Openness to experience	0.14	0.01	0.01	0.16	0.08	0.06	0.01	0.00	0.03	0.02	**0.20**	**0.19**	0.12	0.02	0.15	0.02	0.11	**0.18**

Note. ns range from 139 to 161. Coefficients in bold are statistically significant at $p < .05$. "Number of Correct Notes" refers to the number of consecutive correct notes played from the beginning of the song. SMDT = Swedish Musical Discrimination Test; AMMA = Advanced Measures of Music Audiation.

analyzing individual difference data (e.g., correlations, regression) is that latent variables, which capture variance common to multiple measures of a construct, are free of random measurement error (Kline, 2011). With SEM, we therefore can shift conclusions from the level of observed variables and closer toward the theoretical ability and non-ability constructs of interest.

3. Results

A learning trajectory for each participant, reflecting the number of correct notes played during the pre-test, mid-test, and post-test performances, is depicted in Fig. 1 (see Table 1 for descriptive statistics). As can be seen, there was a large degree of variability, with some participants showing much greater improvement than others (post-test $M = 18.84$, $SD = 5.80$; range = 4–25). A paired-samples t-test revealed that the change in the number of correct notes played from pre-test to post-test was significant ($t = 37.26$, $p < .001$).

Skill acquisition scores did not differ significantly by sex ($M_{\text{men}} = 4.55$, $M_{\text{women}} = 4.32$, $t = 1.36$, $p = .18$) or handedness ($M_{\text{right-handed}} = 4.39$, $M_{\text{left-handed}} = 4.44$, $t = -0.17$, $p = .86$). Examination of the music background variables revealed that participants who had previously played in an ensemble (i.e., band, orchestra, or choir) did not have significantly higher skill acquisition scores than participants who lacked ensemble experience ($M_{\text{ensemble}} = 4.39$, $M_{no\text{-}ensemble} = 4.36$, $t = 0.20$, $p = .84$). Frequency of listening to music was not significantly correlated with skill acquisition scores ($r = 0.06$, $p = .50$), but participants who reported that they often tapped their foot to the beat when listening to music had slightly higher skill acquisition scores ($r = 0.16$, $p = .043$).

Correlations between the major variables are presented in Table 2. In general, the domain-general intelligence measures correlated positively and significantly with judges' ratings of skill acquisition (avg. $r = 0.18$; range = 0.09–0.30). That is, participants with high levels of general intelligence showed greater improvement than participants with lower levels of general intelligence. The same was true for the domain-specific ability measures. Measures of music aptitude correlated positively with skill acquisition (avg. $r = 0.22$; range = 0.17–0.26), indicating that participants with higher levels of music aptitude showed greater improvement than participants with lower ability. By contrast, mindset of music ability correlated near zero with skill acquisition ($r = 0.02$, $p = .84$), and openness to experience did not correlate significantly with skill acquisition ($r = 0.14$, $p = .09$) or music aptitude (avg. $r = 0.08$, all $ps > 0.05$).

3.1. Measurement model

To reiterate, the purpose of this study was to estimate the contribution of ability and non-ability factors to musical skill acquisition (viz., general intelligence, music aptitude, and mindset). We used structural equation modeling (SEM) to address this goal. The first step in the SEM was to specify a measurement model that included ability and non-ability factors and their corresponding indicators. We specified latent variables for the following predictors (indicators listed in parentheses): General Intelligence (Raven's Matrices, Letter Sets, Reading Span, Symmetry Span, Pattern Comparison, Letter/Number Comparison, Synonyms, Antonyms), Music Aptitude (Pitch, Rhythm, and Melody subtests from the SMDT, Tonal and Rhythm subscales from the AMMA), and Mindset (mindset items 1–8). All three latent predictor variables were specified to freely covary with one another.

The measurement model had adequate fit, $\chi^2(186) = 318.27$, $p < .001$, RMSEA = 0.067, CFI = 0.890, NFI = 0.778. The correlation between General Intelligence and Music Aptitude was significant ($r = 0.39$, $p < .001$). General Intelligence accounted for 15.2% of the variance in Music Aptitude, indicating that although there is some overlap between the two constructs, they shared less than half of their reliable variance. The correlation between General Intelligence and Mindset was not significant ($r = 0.18$, $p = .08$); nor was the correlation between Mindset and Music Aptitude ($r = 0.09$, $p = .32$). Although one of the loadings for the Music Aptitude factor (the pitch subtest of the SMDT) was low (0.18), it was still a statistically significant indicator of Music Aptitude ($p = .029$). This low loading may be because the pitch subtest of the SMDT is unlike the other indicators of this factor: whereas the pitch subtest asks participants whether one of two notes is higher or lower than the other, the other subtests had participants compare longer sequences of musical stimuli and therefore may have placed greater burden on working memory capacity.

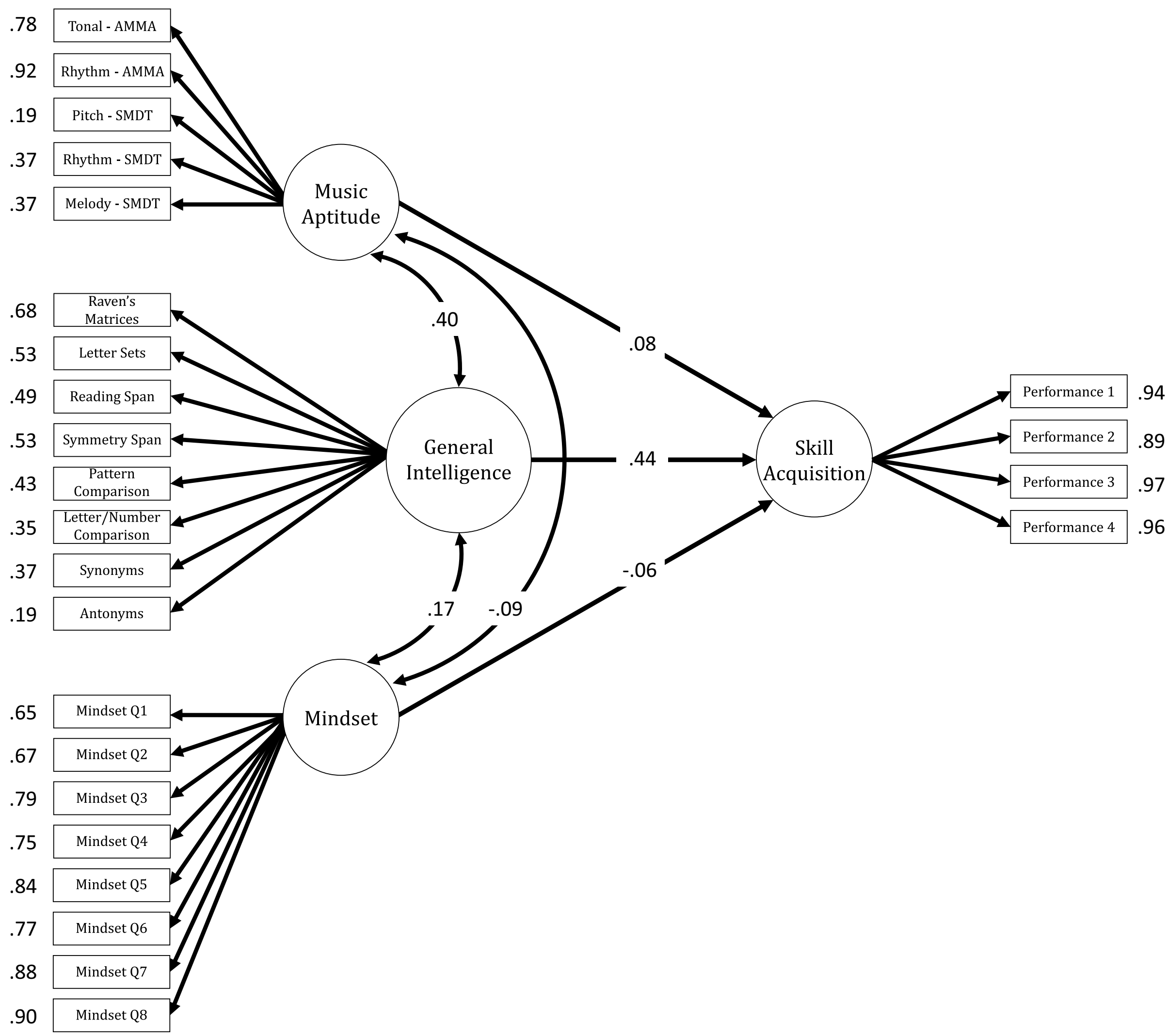

Fig. 2. Structural equation model predicting skill acquisition. Circles represent latent variables; rectangles represent observed variables. Factor loadings are presented to the side of the observed variables. Standardized regression weights are presented along the path from predictor factors to skill acquisition.

3.2. Structural equation model

In the second step of the SEM, we added a latent factor representing skill acquisition to the model. Judges' ratings of the four post-test performances served as indicators of Skill Acquisition. Next, unidirectional paths were added from General Intelligence, the Music Aptitude, and Mindset to Skill Acquisition (Fig. 2).

The full SEM provided an acceptable fit to the data, $\chi^2(269) = 409.48$, $p < .001$, RMSEA = 0.057, CFI = 0.932, NFI = 0.828. Although the predictor constructs together accounted for 22.4% of the variance, only the effect of General Intelligence on Skill Acquisition was statistically significant ($\beta = 0.44$, $p < .001$). Effects of Mindset ($\beta = -0.06$, $p = .50$) and Music Aptitude ($\beta = 0.08$, $p = .39$) on Skill Acquisition were not significant. Moreover, the effect of Mindset on Skill Acquisition was in the unpredicted direction of greater improvement for participants with a fixed mindset than for those with a growth mindset.

Next, to estimate the relative contribution of General Intelligence, Music Aptitude, and Mindset to Skill Acquisition, we sequentially removed predictor factors from the model and examined the change in the proportion of variance accounted for in Skill Acquisition. This is conceptually similar to performing a hierarchical regression analysis in reverse.

Removing Mindset from the full model resulted in good model fit, $\chi^2(116) = 166.32$, $p = .002$, RMSEA = 0.052, CFI = 0.957, NFI = 0.873. The model without Mindset accounted for 22.1% of the variance in Skill Acquisition, indicating that in the full SEM, Mindset accounted for approximately 0.3% of the variance in Skill Acquisition (the contribution of Mindset to Skill Acquisition is estimated by computing $R^2_{\text{Full Model}} - R^2_{\text{Without Mindset}}$).

Removing Music Aptitude from the model without Mindset resulted in good model fit, as well, $\chi^2(53) = 85.59$, $p = .003$, RMSEA = 0.062, CFI = 0.967, NFI = 0.919. This model, which included only General Intelligence as a predictor, accounted for 21.4% of the variance in Skill Acquisition. This indicates that in the full SEM, Music Aptitude accounted for approximately 0.7% of the variance in Skill Acquisition above and beyond General Intelligence. To summarize, General Intelligence accounted for most of the variance in Skill Acquisition (21.4%), distantly followed by Music Aptitude (0.7%) and Mindset (0.3%).

4. Discussion

The purpose of this study was to estimate the relative contributions of ability and non-ability factors to skill acquisition in music. SEM revealed that domain-general intelligence accounted for a substantial portion of the variance in skill acquisition (21.4%), whereas the contributions of music aptitude (0.7%) and mindset (0.3%) were negligible and non-significant. These findings suggest that general intelligence plays an important role during the early stages of learning, which is consistent with previous research (e.g., Klinedinst, 1991; Young, 1971) and predictions made by classical models of skill acquisition (Ackerman, 1988; Fitts & Posner, 1967). Indeed, the results are consistent with claims that complex learning (i.e., training success) is "not much more than *g*" (Ree & Earles, 1991).

Notably, domain-specific music aptitude did not contribute to skill acquisition after accounting for general intelligence. This finding suggests that, although music aptitude has been found to correlate with measures of musical skill (e.g., Froseth, 1971; Gordon, 1968; Schleuter, 1978), this may be simply because music aptitude correlates with general intelligence. As a case in point, in the full SEM, general intelligence accounted for 15.9% of the reliable variance in music aptitude. This is perhaps unsurprising because tests of music aptitude resemble tests of working memory capacity constrained to the auditory domain. For example, to determine whether two rhythms are the same or different (as in the rhythm subtest of the SMDT), one must keep the first rhythm in mind while comparing it with the second. Like tests of fluid intelligence, tests of music aptitude are also novel to the test taker.

That stated, in other types of musical tasks or in persons with greater skill, music aptitude may contribute to skill acquisition above and beyond general intelligence. For example, in our study, participants, lacking music experience, were evaluated for correct notes and for rhythmic accuracy. If, instead, the participants had been musically trained and were auditioning for admission to a music school or academy, higher-order skills such as intonation and musicality would be more important. In that case, the evaluation of their performance might capture variance associated with music aptitude independent of general intelligence. Research is needed to investigate this possibility.

This study also represents one of the first attempts to test Dweck and colleagues' construct of mindset in the domain of musical skill acquisition. Mindset did not correlate significantly with skill acquisition, and its contribution to skill acquisition in the SEM was not significant. In general, mindset did not play an important role in achievement. This finding is consistent with the results of the aforementioned meta-analyses by Sisk et al. (2018), which found a weak ($r = 0.10$) average correlation between growth mindset and academic achievement. Sisk et al. (2018) also found that interventions that encouraged students to adopt a growth mindset had only a small effect on academic achievement ($d = 0.08$, $p = .01$). Moreover, the effect of these mindset interventions did not appear to be driven by changes in mindset because, when mindset did change, academic achievement was not significantly affected.

Finally, we found that openness to experience did not significantly predict skill acquisition ($r = 0.14$, $p = .09$) or music aptitude (avg. $r = 0.08$, all $ps > 0.05$). This finding stands in contrast to recent work by Swaminathan and Schellenberg (2018), who found a significant relationship between openness to experience and measures of auditory discrimination. It is unclear what accounts for this discrepancy. It is possible that our sample was restricted in range on openness, with a mean of 3.7 (out of 5) and a standard deviation of only 0.5. Future research should investigate the robustness of the relationship between music aptitude and openness.

5. Future research

Understanding the interplay between ability and non-ability factors in skill acquisition may lead to improved procedures for training complex skills. For example, if individuals high in domain-general intelligence excel during the initial phase of skill acquisition, they might benefit from accelerated introductory training programs. An important direction for future research will be longitudinal studies of the relative contribution and potential interaction between these factors as a function of task characteristics and level of skill.

Acknowledgments

We wish to thank Deborah Moriarty, Professor of Music and Chair of the Piano Area in the Michigan State University College of Music, for her advice, help planning the study, and for soliciting judges to evaluate the piano performances.

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