Experiential and Cognitive Predictors of Sight-Singing Performance in Music Higher Education

Justine Pomerleau-Turcotte[1] (iD),
Maria Teresa Moreno Sala[1], Francis Dubé[1],
and François Vachon[2]

Abstract

Sight-singing is prevalent in aural skill classes, where learners differ in experience and cognitive abilities. In this research, we investigated whether musical experience, level of study, and working memory capacity (WMC) can predict sight-singing performance and if there is a correlation between WMC and performance among some subgroups of participants. We hypothesized that more experienced students and those with a higher WMC might sight-sing better than those with less experience and lesser WMC. We also hypothesized that the relationship between WMC and sight-singing performance would be more salient for less experienced and less proficient sight-singers. We surveyed 56 subjects about their experience with music, assessed their WMC, and evaluated their performance on a short sight-singing task. The results showed that the age when students began learning music could predict sight-singing performance independently from the number of years of experience and the educational level, suggesting a possible developmental component to sight-singing skill. We also found a negative relationship between WMC and pitch score in the low-performing group and between rhythm and pitch score, suggesting that pitch and rhythm are processed differently. Teachers should be aware of how students' backgrounds might be related to performance and encourage them to develop strong automated skills, such as reading music or singing basic tonal patterns.

[1]Faculté de musique, Université Laval, Québec, QC, Canada
[2]École de psychologie, Université Laval, Québec, QC, Canada

Corresponding Author:
Justine Pomerleau-Turcotte, Faculté de musique, Université Laval, Pavillon Louis-Jacques-Casault, 1055, Avenue du Séminaire, Université Laval, Québec (QC) G1V 0A6, Canada.
Email: justine.pomerleau-turcotte.1@ulaval.ca

Sight-singing, also called *vocal sight-reading*, requires generating a mental representation of sounds before and while singing, making this task challenging for some students. First, it requires the multisensory integration of a visual stimulus (the score) and an auditory stimulus (the sounds to produce; Drai-Zerbib & Baccino, 2018). Furthermore, sight-singers need to understand written notation, which can be difficult for many students entering college (Asmus, 2004). They also need to infer the tonality, remember the tonal center, and keep the pulse steady (Karpinski, 2000). Sight-singing also requires audiation, which is the ability to "think" musically, and this ability usually requires extensive experience with music acquired from a young age (Gordon, 2013). In line with the potential struggles mentioned previously, a survey distributed among music students revealed that aural skills classes were the most susceptible to cause graduation delays (Mennen & van der Klink, 2017). Difficulties faced by students in aural skill classes can also cause anxiety (Ait, 2017). Consequently, aural skills teachers must reflect on ways to improve students' experience within their classes.

Yet students are not the only ones facing challenges with sight-singing: Their teachers do, too. Instructors have to teach aural skills to students with different backgrounds and career paths (Buonviri, 2015a), and they may lack resources to teach to less experienced learners. For example, a content analysis of 10 choral textbooks showed that although most of them suggested reading and singing techniques, very few addressed the challenge of how to teach students to hear internally (Floyd & Haning, 2015). Aural skills instructors need to understand better which factors are related to sight-singing achievement. For example, knowing that early music learning is related to better outcomes could allow teachers to target students who might experience difficulties. If cognitive abilities, such as working memory capacity (WMC), are related to sight-singing performance, teachers could be encouraged to use strategies to alleviate their students' mental load despite their strengths and weaknesses. Consequently, in this study, our aim is to understand how students' musical experience and cognitive abilities are related to sight-singing performance. The next section will address the state of knowledge regarding some of the factors related to musical performance. We chose to focus on two factors that could be related to sight-singing, specifically, musical experience and WMC.

Musical Experience

Many studies suggest there is a relationship between previous experience with music and sight-reading performance. Self-identified music reading experts tend to be better at reading music, partially because they are less affected by adjacent notes' crowding

on a musical staff (Wong & Gauthier, 2012; Wong & Wong, 2016). They also encode more notes and encode them quicker than novices (Wong & Gauthier, 2010a, 2010b). Consequently, reading music is easier for experts than for less experienced music readers and requires less attentional resources. Furthermore, participants with more years of musical experience tend to have better cross-modal integration abilities (i.e., improved audiovisual processing; Drai-Zerbib & Baccino, 2014, 2018; Drai-Zerbib et al., 2012), which could facilitate the execution of sight-singing tasks. Therefore, it is not surprising that, as Wolfs et al. (2020) observed, experience is a significant predictor of sight-reading performance among cellists, and according to Fournier (2020), musical experience is correlated to aural skills performance when combining musical dictation and sight-singing scores. Consequently, it seems plausible that students who begin their postsecondary music education with more musical experience and a more extensive background in music reading should also be better at sight-singing.

Besides, musical experience can also be related to other aural skills, like pitch identification. According to Deutsch (2013), absolute pitch (AP) is the ability to "name musical notes as effortlessly and rapidly as most people name colors, . . . without specific training" (p. 141). Although it is unnecessary to possess AP to be an accomplished musician or perform well in aural skills classes, AP possessors have a significant advantage in sight-singing tasks because they can automatically mentally hear the pitches they read. Many authors suggest there could be a sensitive period for AP acquisition (e.g., Deutsch et al., 2004, 2009; Miyazaki et al., 2012). Even if adults can acquire AP to some extent (e.g., Van Hedger et al., 2019; Wong et al., 2020), it is still plausible that musicians who began their training sooner might develop better perceptual skills, including but not limited to AP.

Although AP is not required to sight-sing, relative pitch (RP), is a necessary ability. RP is the ability to "make pitch judgments about the relation between notes, such as within a musical interval" (Zatorre et al., 1998, p. 3172). This definition can be extended to include the identification of other musical elements such as harmonic progressions and tonalities (Germano et al., 2021) or to detect mistuning in melodies (Schellenberg & Moreno, 2010). Some authors use an even broader definition, stating that anyone without amusia has RP (Leipold et al., 2019). Despite the lack of a unique definition of RP in the literature, one could suggest that most musicians are RP possessors, that RP is required to sight-sing adequately, and that this ability might exist on a continuum because there are individual differences between musicians' abilities. Interestingly, there are some neural similarities between AP and RP possessors. For example, according to a study that used positron emission tomography (PET), assessing if an interval is minor or major elicits a similar response in the left posterior dorsolateral frontal cortex across both AP and RP possessors (Zatorre et al., 1998). This result suggests that similar mechanisms underlie the labeling of these musical attributes. However, according to the same study, only RP possessors show activation in the right inferior frontal region, suggesting they rely on their working memory to perform the task. Therefore, interval identification is not automated for them. Consistently, a more recent study using functional MRI to compare AP and RP possessors showed that blood oxygenation level-dependent signal increased bilaterally in the inferior frontal gyrus during a pitch labeling

task, but only in RP musicians (Leipold et al., 2019). Given that this region has been repeatedly associated with auditory working memory functions (see Schulze et al., 2018), these findings indicated that contrary to RP musicians, AP possessors do not rely on working memory during pitch identification. If beginning music earlier in life is associated with a higher prevalence of AP among musicians, reflecting more automatic processing of pitches, one can wonder whether RP possessors who began music early are also more prone to develop automated musical skills, which can, in turn, help them sight-sing better.

WMC

As mentioned above, reading music is easier for experienced musicians because they probably need less cognitive resources to resolve this task. Some music educators also argue that aural skills, including sight-singing, rely a lot on WMC (e.g., Chenette, 2018; Karpinski, 2000). Working memory is an executive function that allows for attention control and retrieval of information stored in long-term memory (Engle et al., 1999). People use this memory system to store information until they do not need it anymore or until they store it in long-term memory. Working memory also provides a "mental workspace" to manipulate information (Baddeley, 2007; Baddeley & Hitch, 1974; Wickens & Hollands, 1999). However, this "workspace" has limited capacity (e.g., Cowan, 2001). These boundaries are hard to define because the amount of music one can process varies according to experience and musical complexity. For example, beginners might identify patterns, like scales in a simple melody, but struggle with more complex material. A strategy for increasing WMC storage and processing capacity is called chunking, which, in music, can involve making metric, rhythmic, or pitch groupings (Karpinski, 2000). Efficient chunking can improve sight-reading success (Gudmundsdottir, 2010; Pike & Carter, 2010), and one could suggest this is because cognitive resources available in working memory are used more efficiently.

Researchers usually measure WMC with tasks combining memorization and manipulation, such as the *n*-back task (Jaeggi et al., 2010; Miller et al., 2009) or complex spans (Foster et al., 2015; Turner & Engle, 1989; Unsworth et al., 2005). An *n*-back task requires remembering the *n* last items of a list and comparing it with the most recently presented item. A widespread example of a complex span task is the operation span (or OSpan), in which participants have to recall letters in serial order while making arithmetical judgments (e.g., Unsworth et al., 2005). For many complex tasks, a higher WMC is associated with better performance: for instance, reading complicated texts online (Schurer et al., 2020), recalling visual material in the presence of irrelevant sound (Hughes et al., 2013), resuming interrupted dynamic tasks (Labonté & Vachon, 2021), executing complex attacks in volleyball (Bisagno & Morra, 2018), or piloting planes (Cak et al., 2020). However, high-WMC individuals do not outperform their low-WMC counterparts in every context. For example, when participants need to recall information they already know well or when a task is automated, WMC is not related to performance (Unsworth & Engle, 2007). Moreover, when pianists are memorizing music silently, their performance is linked to aural skills scores and

cognitive styles but not to WMC, suggesting that memorization strategies or other acquired abilities could have a greater impact than WMC (Loimusalo & Huovinen, 2018). Consequently, when studying the relationship between cognitive resources and performance, we must remember that musical experience and task particularities might mediate the impact of WMC.

Nevertheless, research suggests that working memory is critical to the accurate execution of musical tasks. For example, increasing working memory load impedes cellists' motor control and can be detrimental to their performance (Maes et al., 2015). Furthermore, WMC contributes to 7.4% of the variance in piano sight-reading achievement (Meinz & Hambrick, 2010). Although the amount of deliberate practice is the most important predictor of sight-reading performance, it is not enough to explain individual differences in scores (Hambrick et al., 2014). These results suggest that WMC is linked to piano sight-reading performance independently from deliberate practice. One might expect a similar relationship for sight-singing tasks because these two tasks are very similar. Indeed, both require reading and performing unfamiliar material, although sight-singing is a task that relies more heavily on knowing in advance which sound will be heard. Pitch identification could also be related to WMC. For example, college students—either nonmusicians or amateur musicians—with superior pitch identification ability tend to score higher on executive functions tests, including WMC tests (Hou et al., 2014). Van Hedger and Nusbaum (2018) provided another yet more nuanced example of such possible relationships. They conducted a study among musicians with absolute pitch to investigate the factors related to achievement in a tricky pitch identification task, including unfamiliar timbres and frequencies. They found no relationship between WMC, assessed with a visual n-back task, and performance to the pitch identification task. Furthermore, participants who did not speak a tonal language (like Mandarin, in which pitch variations impact words' meanings) performed better. However, there was a relationship between WMC and performance on the pitch identification test among tonal language speakers. Even if this relationship only existed for a subgroup of participants—tonal language speakers—this suggests that cognitive abilities might be critical for musical listening capacities. Moreover, more complex musical material also puts a strain on working memory: For example, Lewandowska and Schmuckler (2020) found that pianists make more errors when playing polyphonic textures than homophonic textures. Indeed, polyphonic textures demand more planning and motor control, which require more working memory resources.

Nonetheless, in some contexts, like instrumental sight-reading, the relationship between WMC and performance is not clear, and we need to look for other factors to explain performance. Using regression analysis, Kopiez and Lee (2006) studied 23 variables to understand how each of them could predict piano sight-reading performance for five progressive levels of difficulty. WMC only significantly predicted results for the third level of difficulty but not for the easiest and the hardest melodies. Consequently, the importance of cognitive abilities might depend on how challenging the task is. However, they also found that the experience accumulated before the age of 15 was a strong predictor of performance, suggesting the existence of a critical

period for sight-reading ability development. More generally, variables based on expertise (e.g., piano lessons and sight-reading experience) contributed to the variance of sight-reading performance, whereas cognitive factors related to intelligence, like WMC, did not (Kopiez & Lee, 2008). A study conducted by Cornelius and Brown (2020) suggested that first-year college students might experience difficulties while taking musical dictations precisely because they do not have the expertise to generate schemas, overloading their WMC. Schemas are organized pieces of information from long-term memory (Sweller et al., 2011) that can alleviate working memory load (Sepp et al., 2019). More schemas mean fewer individual score elements to process and consequently that tasks such as musical dictation or music reading are more manageable for those who have sufficient knowledge to use them. A study conducted by Herff and Czernochowski (2019) also suggested that expertise can interact with cognitive resources. In their study, they asked professional musicians to compare melodies while engaging in a number monitoring task aimed at increasing their memory load. Increases in memory load equally impacted musical performances of professionals, amateurs, and nonmusicians. However, professional musicians performed better in the number monitoring task, suggesting their expertise alleviated detrimental effects of a higher working memory load. In light of these results, it seems that although musical experience and WMC both contribute to performance to some extent, the relationships between both variables deserve a more in-depth investigation.

The Current Study

Aural skills, which include sight-singing, are taught worldwide in music higher education programs, and yet, factors explaining individual differences in achievement are not clear. As mentioned previously, music students begin their postsecondary studies with various backgrounds. For example, they do not all have access to private lessons, and therefore their level of preparation might differ (Anderman, 2011; Buonviri, 2015b). Consequently, instructors need to figure out how to explored reach as many learners as possible. Therefore, it appears relevant to gain knowledge on how musical background can predict sight-singing performance. Besides, students differ in their cognitive abilities, such as WMC. Considering that sight-singing is a task requiring significant mental resources, WMC could be related to performance. However, we do not know whether it varies across levels of experience and achievement. In this study, we investigate these two aspects in depth in the context of sight-singing, for which research is scarce.

We wanted to explore the relationships between students' previous music experience, WMC, and sight-singing performance. Therefore, we tested two hypotheses. First, we hypothesized that variables describing musical experience, such as age when participants began learning music, and the number of years of experience, would predict sight-singing performance. We also believed that WMC would be a predictor of sight-singing performance. Second, we expected that the strength of the relationship between WMC and sight-singing performance would differ according to performance level (high- vs. low-performing students) and experience because some students

probably have less musical knowledge and, therefore, less automated schemas to rely on. To test our hypotheses, we conducted a correlational study where participants had to (a) complete questionnaires regarding their musical experiences, (b) complete a WMC test, and (c) sight-sing a short, medium-difficulty melody.

Method

Participants

After approval by the our university's ethical committee, we recruited 56 postsecondary-level music students from institutions in the researchers' urban area that offered music concentrations. Participants all had normal or corrected vision. As compensation, they were offered aural skills tutoring by the experimenter, either immediately after the procedure or at another time convenient for them.

Participants were music students from two education levels: 37 were in cegep (i.e., a postsecondary education, preuniversity college exclusive to the province of Quebec), and 17 were university undergraduates. In cegep, there are four compulsory aural skills courses. Lessons include prepared solfège (singing melodies rehearsed between classes), sight-singing, and musical dictation. cegep usually lasts 2 or 3 years. Undergraduates in the university where the study took place also must take four aural skills courses, the content of which is similar to cegep, but with a stronger focus on harmony and reliance on scale degrees, with more complex singing exercises, dictations, and improvisation and composition. Participants were either following the first or the third aural skills class at their level. We excluded one participant from cegep, who began music very late in comparison to others. We also excluded one participant because of a technical problem during the OSpan task and consequently conducted our analyses with 54 participants. Age of participants ranged from 17 to 67 ($M = 22.3$, $Mdn = 19$, $SD = 9.8$). The age distribution was skewed, and nine participants' ages were outside 1.5 times the interquartile range (over 30 years old). Two participants were over 60 years old. Participants began learning music between 4 and 16 years old ($M = 8.8$, $Mdn = 9$, $SD = 2.9$) and accumulated between 3 and 26 years of experience with music ($M = 10.5$, $Mdn = 10$, $SD = 5.1$). Only three participants reported being AP possessors, and we decided to include them in our study because our performance task focused on rhythm in addition to pitch. We recruited these participants in the context of a larger study about factors predicting sight-singing performance. For additional details on other parts of the study, see Pomerleau-Turcotte et al. (2021, in review).

Material

Questionnaire about musical experience. Participants had to complete information about their musical experience: the age at which they began learning music, their number of years of musical experience (including details about periods when they did not play music), and their current level of education (cegep or university). We also gathered

other information to draw a more precise portrait of our sample (e.g., instrument, major, possession of AP, and learning difficulties). The questionnaire also included questions about sociodemographic characteristics (age and gender).

Complex span task. To assess WMC, we used a shortened version of three shortened span tasks (Foster et al., 2015), which included one block of each of the following tests: OSpan, symmetry span, and rotation span. We chose this version of the task for theoretical reasons—to have a reliable, multiple-indicator-based assessment of WMC (see Conway et al., 2005)—and practical reasons—limiting the experimentation time and facilitating recruitment. Although there are domain-specific WMC assessments, we decided to use a measure that did not rely on music processing because according to Engle et al. (1999), WMC should be constant across domains. It is not uncommon in music research to use a domain-general WMC test (e.g., Colley et al., 2018; Hambrick et al., 2014). Also, because we suspected musical background would vary across our sample, we wanted to avoid experience interfering with WMC test results. In a study about how musical experience mediated the relationship between WMC and musical preferences, Vuvan et al. (2020) found that although this mediation was significant with auditory working memory measures (tone span), it was also significant with nonmusical measures (OSpan and symmetry span). Consequently, we believed that using a combination of three span tasks would accurately assess WMC in our sample.

The French version of the test was automated and administered with E-Prime 3.0 (Psychology Software Tools, Inc., 2016). The Attention & Working Memory Lab from Georgia Tech University provided the task file, and it was translated into French by the PACE Laboratory in Université Laval. For each task, participants had to remember sequences of items while also performing a distractor task. In the first task, the OSpan task, students had to remember sequences of three to seven letters while deciding if mathematical statements were accurate, for example $(2 \times 2) - 1 = 3$. In the second task, the symmetry span task, they had to remember the location of two to five red squares presented successively in a 4×4 grid while assessing if patterns formed of black squares displayed in an 8×8 grid were symmetrical. Finally, in the third task, the rotation span task, they had to remember the size and orientation of two to five arrows presented successively while assessing if rotated letters were accurate or mirrored versions of the letters. Participants had to ensure their accuracy for the distractor task did not go below 85% for each span task.

Sight-singing task. Participants had to sing an eight-measure melody (Figure 1), transposed and slightly modified from a preexisting sight-singing exercise found in a manual from École préparatoire de musique de l'Université Laval (1999). The score was displayed on a computer screen. We chose a medium-difficulty task so participants would be able to finish it despite potential difficulties and avoid a ceiling effect among more proficient sight-singers. This task was used in a pilot study to confirm our perception of its difficulty. Moreover, it includes similar difficulties to Level 6 melody from Cooper's (1965) sight-singing achievement test for college students, which includes 10 melodies of progressive difficulties.

Figure 1. Sight-singing task.

Procedure

The first author of this article met each participant individually and explained the procedure and the compensation: optional aural skills tutoring. After giving consent to participate in the study, the experimenter went out of the room to ensure participants' privacy. Then they completed a questionnaire presented on a computer as a Google Form for about 15 minutes. The experimenter came back into the room to launch the complex span tasks with E-Prime. This part of the procedure lasted about 30 minutes. Each span task included a preparation phase during which participants could familiarize themselves with the task without consequence on the final score. The experimenter went back to the room to stop E-Prime, launch EyeWorks Records (EyeTracking Inc., 2019) for the sight-singing task, and guide the participant through the eye-tracker calibration.[1] Participants were alone in the room to avoid the potential stress caused by the experimenter. They could only play the starting pitch on an electronic piano placed between them and the computer monitor. They could prepare mentally for as long as they wanted. The task began as they started singing. The sight-singing task, which lasted between 5 and 10 minutes, was recorded with EyeWorks Records.

Scoring

WMC. We calculated complex span scores by summing the number of items in every perfectly recalled list. Therefore, the score could range from 0 to 25 in the OSpan task and from 0 to 14 in rotation and symmetry span tasks. A composite score, reflecting the average performance on the three complex span tasks, was computed by converting each span score into a percentage (i.e., dividing the obtained score by the maximum score and then multiplying by 100) and then by averaging the three obtained percentages. This method allowed each span score to have the same weight in the composite score.

Sight-singing task. We used two objective measures—pitch score and rhythm score—and combined them to create a composite sight-singing performance score. We chose these measures because sight-singing tests in higher education focus on these two features. This method is also similar to the scoring system used by Cornelius and

Brown (2020) for musical dictation and in various studies about sight-singing (e.g., Demorest & May, 1995).

The melody comprised 24 notes. Each note counted for 2 points: 1 for the note duration (rhythm) and 1 for the pitch (melody). We evaluated pitches individually, so proper intervals on the wrong notes were considered inaccurate. Raters considered rhythms as correct if they could predict reasonably when the next sound came, even if the pulse fluctuated. We used three different measures in our analyses: rhythm score, pitch score, and a combined score with rhythm and pitch put together. The experimenter rated all performances, and an experienced aural skills instructor assessed 10 performances chosen randomly. Both scorings correlated strongly, $r(8) = .989$, $p < .01$. Therefore, the evaluation conducted by the experimenter was considered reliable.

Analyses

We conducted our analyses in RStudio (R Core Team, 2019), using the packages *lsr* (Navarro, 2015) and *olsrr* (Hebbali, 2020). To determine the extent to which each variable could predict sight-singing performance and test our first hypothesis, we used stepwise linear multiple regressions with a forward selection. To check our second hypothesis, namely, that the relationship between WMC and sight-singing performance could vary across levels of proficiency and experience, we created two subgroups based on sight-singing performance (lower performing group vs. higher performing group) and two subgroups for each variable describing experience (number of years of experience, age when participants began learning music, and level). We then ran Pearson's correlations between WMC and sight-singing performance inside these groups to look for relationships.

Results

To test our first hypothesis, we looked for variables that could predict three dimensions of sight-singing performance. Rhythm scores ranged from 6 to 24 ($M = 18.94$, $Mdn = 19.50$, $SD = 4.47$), pitch scores were between 0 and 24 ($M = 14.74$, $Mdn = 15.00$, $SD = 7.04$), and combined scores ranged from 18 to 48 ($M = 33.69$, $Mdn = 32.00$, $SD = 9.75$). We first compared sight-singing results between students from cegep and university. After that, we investigated possible relationships between musical experience (the age when participants began learning music, number of years of musical experience), WMC (complex span task results), and sight-singing performance (rhythm score, pitch score, and combined score). Descriptive statistics and Pearson correlations appear in Table 1.

After checking for homogeneity of variances, we conducted *t* tests to determine if university students performed differently than cegep students. We found that although rhythm scores did not differ significantly between groups (cegep: $M = 18.43$, $SD = 4.12$; university: $M = 20.06$, $SD = 5.10$), $t(52) = -1.25$, $p = .22$, Cohen's $d = 0.37$, pitch scores did differ significantly (cegep: $M = 13.08$, $SD = 6.74$; university: $M =$

Table 1. Descriptive Statistics and Pearson's Correlations.

Variable	n	M	SD	1	2	3	4	5	6
1. Age beginning	54	8.83	2.91	—					
2. Experience	54	10.46	5.06	−.41**	—				
3. Working memory capacity	54	74.25	14.01	.02	−.11	—			
4. Rhythm score	54	18.94	4.47	−.33*	−.00	.17	—		
5. Pitch score	54	14.74	7.04	−.31*	.21	−.11	.40**	—	
6. Combined score	54	33.69	9.75	−.38**	.15	−.00	.75***	.91***	—

$*p < .05. **p < .01. ***p < .001.$

18.35, $SD = 6.48$), $t(52) = -2.70$, $p = .01$, Cohen's $d = 0.79$, as did combined scores (cegep: $M = 31.51$, $SD = 9.02$; university: $M = 38.41$, $SD = 9.86$), $t(52) = -2.54$, $p = .01$, Cohen's $d = 0.74$. In short, university students outperformed their peers from cegep for melodies and combined score but not for rhythm. Consequently, we needed to include another variable, level, in the regressions analyses.

Before that, we also looked for possible differences between levels for the age when participants began learning music, number of years of experience, and WMC. Cegep students did not begin learning music significantly younger than university students (cegep: $M = 8.51$, $SD = 2.66$; university: $M = 9.52$, $SD = 3.17$), $t(52) = -1.20$, $p = .24$. However, university students accumulated more years of experience (cegep: $M = 9.38$, $SD = 4.17$; university: $M = 12.82$, $SD = 6.09$), $t(52) = -2.43$, $p = .02$. The groups did not differ regarding WMC (cegep: $M = 73.99$, $SD = 12.67$; university: $M = 74.84$, $SD = 16.98$), $t(52) = -0.21$, $p = .84$.

We then looked at which variables could better predict sight-singing performance, using stepwise linear multiple regressions with a forward selection. Variables could be included in our models if they met the variable inclusion criteria proposed by Tabachnick and Fidell (2013), so we set the p value required to enter an independent variable at .15. We used four independent variables: the age at which participants began learning music, educational level (cegep or university), number of years of musical experience, and WMC. An examination of diagnostic plots confirmed that our data met the required assumptions of normality, linearity, and homoscedasticity of residuals.

Table 2 shows how each variable can predict rhythm score, pitch score, and combined score, respectively. We found that the age at which participants began, educational level, and number of years of musical experience explained 19% of the rhythm score variance, $F(3, 50) = 5.13$, $p = .0036$. Level and age when participants began music predicted 24% of pitch score variance, $F(2, 51) = 9.15$, $p = .0004$. Age at which participants began learning music, level, and number of years of musical experience explained 30% of the combined score variance, $F(3, 50) = 8.58$, $p = .0001$; however, in this model, musical experience did not contribute significantly. Furthermore, WMC did not predict sight-singing performance in either of these models.

Table 2. Predictors of Sight-Singing Performance.

	Model 1			Model 2			Model 3		
	B	SE B	β	B	SE B	β	B	SE B	β
Rhythm score									
Age beginning	−0.50	0.20	−0.33*	−0.56	0.20	0.37**	−0.81	0.22	−0.53**
Level				2.20	1.24	0.23	3.47	1.32	0.36*
Experience							−0.30	0.13	−0.34*
R^2		.11			.16			.24	
Adjusted R^2		.09			.13			.19	
F		6.25*			4.82*			5.13**	
Pitch score									
Level	5.27	1.95	0.35**	6.21	1.83	0.41**			
Age beginning				−0.92	0.30	−0.38**			
R^2		.12			.26				
Adjusted R^2		.11			.24				
F		7.30**			9.15***				
Combined score									
Age beginning	−1.26	0.43	−0.38**	−1.48	0.40	−0.44***	−1.89	0.45	−0.56***
Level				8.41	2.47	0.40**	10.40	2.68	0.50***
Experience							−0.47	0.27	−0.24
R^2		.14			.30			.34	
Adjusted R^2		.13			.27			.30	
F		8.57**			10.95***			8.58***	

*$p < .05$. **$p < .01$. ***$p < .001$.

To test our second hypothesis, namely, that there could be a relationship between sight-singing performance and WMC among participants in the low-performing group and participants with less musical experience, we created subgroups of participants based on their performance and musical experience. We used the median as a cutoff point, except for educational level (cegep and university). We first conducted analyses with participants who began learning music earlier (≤8 years old) and with participants who began learning music later (>8). We did not find any significant relationship between sight-singing performance and WMC for either early learners or late learners. We then conducted analyses among less experienced participants (<10 years of musical experience) and more experienced participants (≥10 years of musical experience). We also failed to find any significant relationship between sight-singing performance and WMC for either the group with less experience or the group with more experience.

Next, we investigated whether there was a relationship between WMC and sight-singing performance among participants in the lower performance group (combined sight-singing score of ≤32 of 48) and participants in the higher performance group (combined sight-singing score of ≥33 of 48). Among students from the lower performing group, there was a trend of a relationship between rhythm score and WMC; however, it was nonsignificant, $r(26) = .34$, $p = .08$. Furthermore, we found a

significant, negative correlation between pitch score and WMC, $r(26) = -.43$, $p = .02$, but the relationship between combined score and WMC was not significant, $r(26) = -.15$, $p = .43$. It should also be noted that in that subgroup, rhythm and combined scores did not correlate significantly, $r(26) = .36$, $p = .06$, and rhythm and pitch scores correlated negatively, $r(26) = -.49$, $p = .0086$. On the other hand, pitch and combined score correlated, $r(26) = .63$, $p = .0003$. Finally, in the higher performing group, we found no significant correlations between sight-singing performance and WMC.

Discussion

In this study, we aimed to investigate the relationship between sight-singing performance and experiential and cognitive factors. More precisely, we wanted to find predictors of sight-singing success and study the relationship between sight-singing performance and WMC for different subgroups.

Our first hypothesis, namely, that experiential and cognitive factors could predict sight-singing performance, was partially confirmed. Although we found that factors related to experience (the age when participants began learning music, number of years of experience, and higher education experience) could predict sight-singing performance, we found that WMC could not. Interestingly, we found that the age at which participants first engaged in music learning contributed to sight-singing performance variance independently from the number of years of musical experience even though these two variables are interrelated. Although the number of years of musical experience significantly predicted rhythm score, it did not predict pitch score. It also did not contribute significantly to the combined score variance. This outcome contradicts results obtained by Demorest and May (1995) and Kopiez and Lee (2008) and suggests a plausible developmental component to sight-singing ability. Some authors suggest there could be a critical period for AP acquisition (e.g., Deutsch et al., 2004, 2009; Miyazaki et al., 2012), but such a critical period could also exist for RP, which is the "ability to perceive pitch relations" (Miyazaki et al., 2018, p. 135). Musicians with stronger RP would presumably be able to hear mentally and sing written notation more easily. There could also be a critical period for developing strong tonal automated schemas leading to better sight-singing performance, as suggested by Nikolić and Kodela (2020). Indeed, early learners may master tonal vocabulary (like chords and common patterns) better than late learners. Once students have internalized that vocabulary, sight-singing can include more pattern recognition and less decoding of individual notes. This conclusion is consistent with a study by Kopiez and Lee (2006) about sight-reading, who found that the experience accumulated before 15 years old predicts performance. It could also mean that some patterns are deeply internalized for musicians with more early experience and can trigger automated skills that assist performance.

We also found that the educational level (CÉGEP or university) could predict two measures of sight-singing performance: pitch and combined score. This result suggests that although musical experience before postsecondary education matters, higher

education experience probably helps musicians improve their sight-singing ability to a larger extent. It could mean that in places like Quebec, Canada, where music higher education typically includes 4 years of aural skills instruction students might have the opportunity to become significantly more proficient with that discipline. It would be relevant to measure whether other, more extensive experience with aural skills, such as advanced placement music theory courses or specialized music programs in K–12 settings, could also contribute to sight-singing performance among postsecondary-level students. However, in our study, university students did not outperform students from CÉGEP on rhythm scores. One possible pedagogical explanation is that because singing the right pitches is often seen as the main challenge among students, CÉGEP instructors might allocate more time in their lessons to strengthen this ability, leading to a significant improvement when students enter university. It could also be because the sight-singing task in this study was not rhythmically difficult enough to discriminate different levels of proficiency between participants, leading to a ceiling effect for the rhythm score.

Contrary to our expectation, WMC did not predict sight-singing performance. Even though WMC has been found be related to other musical performance tasks, like piano sight-reading (Hambrick et al., 2014; Meinz & Hambrick, 2010) and pitch identification (Hou et al., 2014), it has not always been shown to contribute significantly to sight-reading performance (e.g., Kopiez & Lee, 2008). Therefore, our results are not in complete contradiction with previous research. There are many possible explanations for our findings. Some sight-singing tasks require students to use more automated skills, and some students rely more on automated skills than their peers, alleviating the possible relationship between WMC and performance (Unsworth & Engle, 2007). Consequently, even if WMC was critical for sight-singing success, some participants with a lower WMC could compensate for it with their experience and the automated schemas they built across time. The reverse could also be true, where some high-WMC participants could compensate for lack of experience and automated skills. This explanation aligns with the conclusions of a study by Cornelius and Brown (2020), who investigated another common aural skills task, musical dictation. Indeed, those authors suggested that some students could be better at creating schemas, which means that taking musical dictation impacts their working memory load less than for some of their peers.

We used only one sight-singing task, which might also partially explain why WMC could not predict sight-singing performance. Indeed, Kopiez and Lee (2006) found that the importance of WMC could vary according to task difficulty. More precisely, in their study, WMC did not predict performance in the easiest and hardest sight-reading tasks, but it did for a moderately difficult task. Therefore, in our study, WMC could have helped predict sight-singing results if we also had various difficulty levels. It is possible that succeeding in more demanding sight-singing tasks might be impacted more by experience. On the contrary, sight-singers can rely mostly on automated skills for more manageable tasks, which explains why WMC would not be a predictive factor in that case.

Although WMC is not domain specific (Engle et al., 1999), some authors suggest that adding a domain-specific test could give a more precise portrait of a situation. For example, in a study comparing jazz and classical musicians' WMC, Nichols et al. (2018) found no difference for verbal working memory tasks but found significant WMC differences in favor of jazz musicians in a test requiring them to remember and play pitches on a piano. Using such a domain-specific test allowed researchers to draw conclusions about how the specificity of jazz musicians' experience could align with cognitive abilities. Although using only nonmusical span tasks was justified in our study, notably because we did not want the variability of musical backgrounds to interfere with our results, it could certainly be appropriate in future studies to add a musical measure to help understand the relationship between performance and WMC.

Our second hypothesis was invalidated. Indeed, we did not find relationships between sight-singing performance and WMC in the subgroups we built according to experience (early learners vs. late learners, less experienced vs. more experienced, and CÉGEP vs. university). However, in the low-performing group, there was a nonsignificant trend, suggesting a possible positive relationship between rhythm score and WMC. This relationship should be investigated in future studies. On the contrary, there was a negative, significant correlation between pitch score and WMC, which is somewhat counterintuitive. One possible explanation is that rhythm and pitch processing might rely on different resources. Jerde et al. (2011) used PET with nonmusicians. They observed different activation patterns depending on whether participants had to execute tasks relying on melodic or rhythmic working memory. Consequently, we can speculate that melody and rhythm are processed separately and rely on different working memory systems. More precisely, we could speculate that participants who obtained better pitch scores in the low-performing group relied more on automated schemas. Therefore, the sight-singing task led to a smaller working memory load, meaning that a lower WMC was less detrimental to their performance. It is also possible that individuals with a lower WMC had to focus more on the melody than rhythm to get to the last note of the sight-singing task and obtained higher pitch scores but lower rhythm scores. In fact, in that subgroup, rhythm and pitch scores were negatively correlated. Some participants probably focused on pitches while ignoring rhythmic difficulties, precisely to be able to finish the exercise. This explanation would be consistent with the notion of dimensional salience, which suggests that while processing music, individuals prioritize pitch over rhythm (Prince & Pfordresher, 2012). On the contrary, it is possible that because we instructed subjects not to stop while singing, they might have lost their tonal center—altering the subsequent pitches—while keeping up with the pulse. Further studies should investigate how musicians with various levels of expertise process rhythmic and melodic material while sight-singing. It could provide valuable insights into what makes this task challenging for them.

Our results have other practical implications for music learning. First, they suggest that learning music early in life could be beneficial to musicians and extend their tonal vocabulary. We could also link this idea to the concept of audiation (thinking in sounds), which, according to Gordon (2013), is preceded by three stages that should occur in early childhood: acculturation, imitation, and assimilation. Learning music at

a young age might simply facilitate this process. Therefore, having access to quality music learning opportunities as a child (through Early Years music lessons, in studios, or K–12 settings) could not only help them discover their musical selves (Creech et al., 2020) and benefit their amateur or professional lifelong musical practices but also help those who would choose to pursue music in higher education succeed.

From a pedagogical perspective, our results also explain some of the differences teachers can expect across learners. Instructors need to be aware that musical background shapes music learning in higher education, maybe more than cognitive abilities. This finding is encouraging because although teachers have little control over their students' cognitive abilities, they can create opportunities to develop stronger automated skills. Therefore, they should provide a wide variety of tools that learners could choose from. For example, some students might need step-by-step instructions to prepare sight-singing efficiently while also alleviating their working memory load. Some others might benefit from tonal exercises to foster automaticity and create schemas, which could help them use their working memory more efficiently. Nevertheless, despite individual differences, these strategies could potentially help all learners.

There are some limitations to this exploratory study. Our only way to assess expertise was to ask when participants began learning music and how long they played or sang music. However, this does not give a precise portrait of their experience. How intensive was their training? How much deliberate practice did it include? Although our approach was appropriate for an exploratory study, further studies should include a more comprehensive measure of musical experience, like, for example, the Goldsmiths Musical Sophistication Index (Müllensiefen et al., 2013). Furthermore, we used an open-ended question to know our participants' level of study (CÉGEP or university), and most of them did not include information about their year of study. We should have asked which aural skill course they were enrolled in, which could have informed us more on the relationship between the postsecondary education experience and sight-singing performance. Also, as stated previously, our sight-singing task could have included melodies of various levels of difficulties. It would have helped us understand how our independent variables could predict performance. The participants of our study could also have benefited from more time to feel acclimated to the task. From a statistical point of view, our small sample size made us select only four variables to enter into our regression analyses. Therefore, the conclusions we can draw from our results are limited. They do not account for other variables that could explain performance, like, for instance, the types of musical experience our participants had, their knowledge of harmony and theory, or the strategies they used.

Conclusion

We conducted this research to gain insights into the relationship between musical background, WMC, and sight-singing performance. Our results suggest that early music learners could have an advantage while pursuing music learning in higher education. Indeed, the age when participants began learning music predicted sight-singing performance independently of their educational level or their number of years of

experience. In contrast, WMC could not predict results for any of the sight-singing performance dimensions we studied (rhythm, pitch, and combined score). Our results also show that rhythm and melody processing could rely on different resources. We conclude that sight-singing performance is related to students' characteristics and background and that instructors should be aware of these differences to offer optimal pedagogical guidance.

Declaration of Conflicting Interest

Funding

ORCID iD

Justine Pomerleau-Turcotte https://orcid.org/0000-0002-5999-5327

Note

1. This article describes a doctoral study embedded in a larger exploratory research project about factors explaining sight-singing results among postsecondary students. Eye tracking was not relevant to the purpose of the present study. Recorded eye-tracking data will be described in another study that is currently in preparation. Because the eye tracker was integrated into the computer monitor and required no chin rest, participants were free to move their head. Hence, its use should have had minimal to no particular impact on the present results.

References

Ait, E. D. (2017). *The effects of performance anxiety on sight-singing achievement* (Publication No. 10283939) [Doctoral dissertation, George Mason University]. ProQuest Dissertations Publishing.

Anderman, M. A. (2011). *Musicianship instruction in California community colleges* (Publication No. 3483464) [Doctoral dissertation, Boston University]. ProQuest Dissertations Publishing.

Asmus, E. P. (2004). Music teaching and music literacy. *Journal of Music Teacher Education*, *13*(2), 6–8. https://doi.org/10.1177/10570837040130020102

Baddeley, A. D. (2007). *Working memory, thought, and action*. Oxford University Press.

Baddeley, A. D., & Hitch, G. (1974). Working memory. In G. H. Bower (Ed.), *Psychology of learning and motivation* (Vol. 8, pp. 47–89). Academic Press. https://doi.org/10.1016/S0079-7421(08)60452-1

Bisagno, E., & Morra, S. (2018). How do we learn to "kill" in volleyball?: The role of working memory capacity and expertise in volleyball motor learning. *Journal of Experimental Child Psychology*, *167*, 128–145. https://doi.org/10.1016/j.jecp.2017.10.008

Buonviri, N. O. (2015a). Effects of a preparatory singing pattern on melodic dictation success. *Journal of Research in Music Education*, *63*(1), 102–113. https://doi.org/10.1177/0022429415570754

Buonviri, N. O. (2015b). Three music education majors' journeys through Aural Skills 101. *Journal of Music Teacher Education*, *25*(1), 95–106. https://doi.org/10.1177/1057083714552328

Cak, S., Say, B., & Misirlisoy, M. (2020). Effects of working memory, attention, and expertise on pilots' situation awareness. *Cognition, Technology & Work*, *22*(1), 85–94. https://doi.org/10.1007/s10111-019-00551-w

Chenette, T. K. (2018). Reframing aural skills instruction based on research in working memory. *Journal of Music Theory Pedagogy*, *32*, 3–20. https://jmtp.appstate.edu/reframing-aural-skills-instruction-based-research-working-memory

Colley, I. D., Keller, P. E., & Halpern, A. R. (2018). Working memory and auditory imagery predict sensorimotor synchronisation with expressively timed music. *Quarterly Journal of Experimental Psychology*, *71*(8), 1781–1796. https://doi.org/10.1080/17470218.2017.1366531

Conway, A. R. A., Kane, M. J., Bunting, M. F., Hambrick, D. Z., Wilhelm, O., & Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review*, *12*(5), 769–786. https://doi.org/10.3758/BF03196772

Cooper, J. J. (1965). *The development of a sight-singing achievement test for use with college students* (Publication No. 6602770) [Doctoral dissertation, University of Colorado]. ProQuest Dissertation Publishing.

Cornelius, N., & Brown, J. L. (2020). The interaction of repetition and difficulty for working memory in melodic dictation tasks. *Research Studies in Music Education*, *42*(3), 368–382. https://doi.org/10.1177/1321103X18821194

Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and Brain Sciences*, *24*(1), 87–114. https://doi.org/10.1017/S0140525X01003922

Creech, A., Varvarigou, M., & Hallam, S. (2020). *Contexts for music learning and participation: Developing and sustaining musical possible selves*. Springer Nature.

Demorest, S. M., & May, W. V. (1995). Sight-singing instruction in the choral ensemble: Factors related to individual performance. *Journal of Research in Music Education*, *43*(2), 156–167. https://doi.org/10.2307/3345676

Deutsch, D. (2013). Absolute pitch. In D. Deutsch (Ed.), *The psychology of music* (3rd ed.). Academic Press.

Deutsch, D., Dooley, K., Henthorn, T., & Head, B. (2009). Absolute pitch among students in an American music conservatory: Association with tone language fluency. *The Journal of the Acoustical Society of America*, *125*(4), 2398–2403. https://doi.org/10.1121/1.3081389

Deutsch, D., Henthorn, T., & Dolson, M. (2004). Absolute pitch, speech, and tone language: Some experiments and a proposed framework. *Music Perception: An Interdisciplinary Journal*, *21*(3), 339–356. https://doi.org/10.1525/mp.2004.21.3.339

Drai-Zerbib, V., & Baccino, T. (2014). The effect of expertise in music reading: Cross-modal competence. *Journal of Eye Movement Research*, *6*(5), 1–10.

Drai-Zerbib, V., & Baccino, T. (2018). Cross-modal music integration in expert memory: Evidence from eye movements. *Journal of Eye Movement Research*, *11*(2), Article 10.16910/jemr.11.2.4. https://doi.org/10.16910/jemr.11.2.4

Drai-Zerbib, V., Baccino, T., & Bigand, E. (2012). Sight-reading expertise: Cross-modality integration investigated using eye tracking. *Psychology of Music*, *40*(2), 216–235. https://doi.org/10.1177/0305735610394710

École préparatoire de musique de l'Université Laval. (1999). *Solfèges mélodiques 10e degré* [Melodic Solfege Exercices, Grade 10]. Université Laval.

Engle, R. W., Kane, M. J., & Tuholski, S. W. (1999). Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence, and functions of the prefrontal cortex. In A. Miyake, & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 102–134). Cambridge University Press.

EyeTracking Inc. (2019). *EyeWorks* (3.0) [Computer software]. eyetracking.com

Floyd, E. G., & Haning, M. A. (2015). Sight-singing pedagogy: A content analysis of choral methods textbooks. *Journal of Music Teacher Education*, *25*(1), 11–22. https://doi.org/10.1177/1057083714539767

Foster, J. L., Shipstead, Z., Harrison, T. L., Hicks, K. L., Redick, T. S., & Engle, R. W. (2015). Shortened complex span tasks can reliably measure working memory capacity. *Memory & Cognition*, *43*(2), 226–236. https://doi.org/10.3758/s13421-014-0461-7

Fournier, G. (2020). *L'apport des stratégies dans l'apprentissage du solfège chez les étudiants en musique de niveau collégial* [The contributions of learning strategies to sight-sing at college level] [Doctoral dissertation, Université Laval]. CorpusUL. https://corpus.ulaval.ca/jspui/handle/20.500.11794/39089

Germano, N. D. G., Cogo-Moreira, H., Coutinho-Lourenço, F., & Bortz, G. (2021). A new approach to measuring absolute pitch on a psychometric theory of isolated pitch perception: Is it disentangling specific groups or capturing a continuous ability? *PLOS ONE*, *16*(2), Article e0247473. https://doi.org/10.1371/journal.pone.0247473

Gordon, E. (2013). *Music learning theory for newborn and young children*. GIA Publications.

Gudmundsdottir, H. R. (2010). Advances in music-reading research. *Music Education Research*, *12*(4), 331–338. https://doi.org/10.1080/14613808.2010.504809

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. https://doi.org/10.1016/j.intell.2013.04.001

Hebbali, A. (2020). *olsrr: Tools for building OLS regression models* (0.5.3) [R]. https://CRAN.R-project.org/package=olsrr

Herff, S. A., & Czernochowski, D. (2019). The role of divided attention and expertise in melody recognition. *Musicae Scientiae*, *23*(1), 69–86. https://doi.org/10.1177/1029864917731126

Hou, J., Chen, C., Wang, Y., Liu, Y., He, Q., Li, J., & Dong, Q. (2014). Superior pitch identification ability is associated with better executive functions. *Psychomusicology: Music, Mind, and Brain*, *24*(2), 136–146. https://doi.org/10.1037/a0036963

Hughes, R. W., Hurlstone, M. J., Marsh, J. E., Vachon, F., & Jones, D. M. (2013). Cognitive control of auditory distraction: Impact of task difficulty, foreknowledge, and working memory capacity supports duplex-mechanism account. *Journal of Experimental Psychology: Human Perception and Performance*, *39*(2), 539–553. https://doi.org/10.1037/a0029064

Jaeggi, S. M., Buschkuehl, M., Perrig, W. J., & Meier, B. (2010). The concurrent validity of the N-back task as a working memory measure. *Memory*, *18*, 394–412. https://doi.org/10.1080/09658211003702171

Jerde, T. A., Childs, S. K., Handy, S. T., Nagode, J. C., & Pardo, J. V. (2011). Dissociable systems of working memory for rhythm and melody. *NeuroImage*, *57*(4), 1572–1579. https://doi.org/10.1016/j.neuroimage.2011.05.061

Karpinski, G. S. (2000). *Aural skills acquisition: The development of listening, reading, and performing skills in college-level musicians*. Oxford University Press.

Kopiez, R., & Lee, J. I. (2006). Towards a dynamic model of skills involved in sight reading music. *Music Education Research*, *8*(1), 97–120. https://doi.org/10.1080/14613800600570785

Kopiez, R., & Lee, J. I. (2008). Towards a general model of skills involved in sight reading music. *Music Education Research*, *10*(1), 41–62. https://doi.org/10.1080/14613800701871363

Labonté, K., & Vachon, F. (2021). Resuming a dynamic task following increasingly long interruptions: The role of working memory and reconstruction. *Frontiers in Psychology*, *12*, Article 659451. https://doi.org/10.3389/fpsyg.2021.659451

Leipold, S., Brauchli, C., Greber, M., & Jäncke, L. (2019). Absolute and relative pitch processing in the human brain: Neural and behavioral evidence. *Brain Structure and Function*, *224*(5), 1723–1738. https://doi.org/10.1007/s00429-019-01872-2

Lewandowska, O. P., & Schmuckler, M. A. (2020). Tonal and textural influences on musical sight-reading. *Psychological Research*, *84*, 1920–1945. https://doi.org/10.1007/s00426-019-01187-1

Loimusalo, N. J., & Huovinen, E. (2018). Memorizing silently to perform tonal and nontonal notated music: A mixed-methods study with pianists. *Psychomusicology: Music, Mind, and Brain*, *28*(4), 222–239. https://doi.org/10.1037/pmu0000227

Maes, P.-J., Wanderley, M. M., & Palmer, C. (2015). The role of working memory in the temporal control of discrete and continuous movements. *Experimental Brain Research*, *233*(1), 263–273. https://doi.org/10.1007/s00221-014-4108-5

Meinz, E. J., & Hambrick, D. Z. (2010). Deliberate practice is necessary but not sufficient to explain individual differences in piano sight-reading skill: The role of working memory capacity. *Psychological Science*, *21*(7), 914–919. https://doi.org/10.1177/0956797610373933

Mennen, J., & van der Klink, M. (2017). Is the first-year predictive for study success in subsequent years? Findings from an academy of music. *Music Education Research*, *19*(3), 339–351. https://doi.org/10.1080/14613808.2016.1189524

Miller, K. M., Price, C. C., Okun, M. S., Montijo, H., & Bowers, D. (2009). Is the n-back task a valid neuropsychological measure for assessing working memory? *Archives of Clinical Neuropsychology*, *24*, 711–717. https://doi.org/10.1093/arclin/acp063

Miyazaki, K., Makomaska, S., & Rakowski, A. (2012). Prevalence of absolute pitch: A comparison between Japanese and Polish music students. *The Journal of the Acoustical Society of America*, *132*(5), 3484–3493. https://doi.org/10.1121/1.4756956

Miyazaki, K., Rakowski, A., Makomaska, S., Jiang, C., Tsuzaki, M., Oxenham, A. J., Ellis, G., & Lipscomb, S. D. (2018). Absolute pitch and relative pitch in music students in the East and the West: Implications for aural-skills education. *Music Perception: An Interdisciplinary Journal*, *36*(2), 135–155. https://doi.org/10.1525/mp.2018.36.2.135

Müllensiefen, D., Gingras, B., Stewart, L., & Ji, J. (2013). *Goldsmiths Musical Sophistication Index (Gold-MSI) v1.0: Technical report and documentation Revision 0.3*. Goldsmiths University.

Navarro, D. J. (2015). *Learning statistics with R: A tutorial for psychology students and other beginners* (0.5) [Computer software]. University of Adelaide. https://learningstatisticswithr.com/

Nichols, B. E., Wöllner, C., & Halpern, A. R. (2018). Score one for jazz: Working memory in jazz and classical musicians. *Psychomusicology: Music, Mind and Brain*, *28*(2), 101–107. https://doi.org/10.1037/pmu0000211

Nikolić, I., & Kodela, S. (2020). Integral aspects of harmonic hearing in the process of sight-singing. *Facta Universitatis, Series: Visual Arts and Music*, *6*(1), 49–60. https://doi.org/10.22190/10.22190/FUVAM2001049N

Pike, P. D., & Carter, R. (2010). Employing cognitive chunking techniques to enhance sight-reading performance of undergraduate group-piano students. *International Journal of Music Education*, *28*(3), 231–246. https://doi.org/10.1177/0255761410373886

Pomerleau-Turcotte, J., Moreno Sala, M.T., Dubé, F., & Vachon, F. (2021). Building a mental toolbox: Relationships between strategy choice and sight-singing performance in higher education [Manuscript under review].

Prince, J. B., & Pfordresher, P. Q. (2012). The role of pitch and temporal diversity in the perception and production of musical sequences. *Acta Psychologica*, *141*(2), 184–198. https://doi.org/10.1016/j.actpsy.2012.07.013

Psychology Software Tools, Inc. (2016). *E-Prime 3.0*. https://www.pstnet.com

R Core Team. (2019). *R: A language and environment for statistical computing*. https://www.R-project.org/.

Schellenberg, E. G., & Moreno, S. (2010). Music lessons, pitch processing, and g. *Psychology of Music*, *38*(2), 209–221. https://doi.org/10.1177/0305735609339473

Schulze, K., Koelsch, S., & Williamson, V. (2018). Auditory working memory. In R. Bader (Ed.), *Springer handbook of systematic musicology* (pp. 461–472). Springer.

Schurer, T., Opitz, B., & Schubert, T. (2020). Working memory capacity but not prior knowledge impact on readers' attention and text comprehension. *Frontiers in Education*, *5*, Article 26. https://doi.org/10.3389/feduc.2020.00026

Sepp, S., Howard, S. J., Tindall-Ford, S., Agostinho, S., & Paas, F. (2019). Cognitive load theory and human movement: Towards an integrated model of working memory. *Educational Psychology Review*, *31*(2), 293–317. https://doi.org/10.1007/s10648-019-09461-9

Sweller, J., Ayres, P., & Kalyuga, S. (2011). *Cognitive load theory*. Springer.

Tabachnick, B. G., & Fidell, L. S. (2013). *Using multivariate statistics* (6th ed.). Pearson Education.

Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task dependent? *Journal of Memory and Language*, *28*, 127–154. https://doi.org/10.1016/0749-596X(89)90040-5

Unsworth, N., & Engle, R. W. (2007). The nature of individual differences in working memory capacity: Active maintenance in primary memory and controlled search from secondary memory. *Psychological Review*, *114*(1), 104. https://doi.org/10.1037/0033-295X.114.1.104

Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. W. (2005). An automated version of the operation span task. *Behavior Research Methods*, *37*(3), 498–505. https://doi.org/10.3758/BF03192720

Van Hedger, S. C., Heald, S. L. M., & Nusbaum, H. C. (2019). Absolute pitch can be learned by some adults. *PLOS ONE*, *14*(9), Article e0223047. https://doi.org/10.1371/journal.pone.0223047

Van Hedger, S. C., & Nusbaum, H. C. (2018). Individual differences in absolute pitch performance: Contributions of working memory, musical expertise, and tonal language background. *Acta Psychologica*, *191*, 251–260. https://doi.org/10.1016/j.actpsy.2018.10.007

Vuvan, D. T., Simon, E., Baker, D. J., Monzingo, E., & Elliott, E. M. (2020). Musical training mediates the relation between working memory capacity and preference for musical complexity. *Memory & Cognition*, *48*, 972–981. https://doi.org/10.3758/s13421-020-01031-7

Wickens, C. D., & Hollands, J. G. (1999). *Engineering psychology and human performance* (3rd ed.). Prentice-Hall.

Wolfs, Z. G., Boshuizen, H. P. A., (Els), & Strien, J. L. H. van. (2020). The role of positional knowledge and tonal approaches in cellists' sight-reading. *Musicae Scientiae*, *24*(1), 3-20. https://doi.org/10.1177/1029864918762269

Wong, Y. K., & Gauthier, I. (2010a). Holistic processing of musical notation: Dissociating failures of selective attention in experts and novices. *Cognitive, Affective, & Behavioral Neuroscience*, *10*(4), 541–551. https://doi.org/10.3758/CABN.10.4.541

Wong, Y. K., & Gauthier, I. (2010b). A multimodal neural network recruited by expertise with musical notation. *Journal of Cognitive Neuroscience*, *22*(4), 695–713. https://doi.org/10.1162/jocn.2009.21229

Wong, Y. K., & Gauthier, I. (2012). Music-reading expertise alters visual spatial resolution for musical notation. *Psychonomic Bulletin & Review*, *19*(4), 594–600. https://doi.org/10.3758/s13423-012-0242-x

Wong, Y. K., Lui, K. F. H., Yip, K. H. M., & Wong, A. C.-N. (2020). Is it impossible to acquire absolute pitch in adulthood? *Attention, Perception, & Psychophysics*, *82*(3), 1407–1430. https://doi.org/10.3758/s13414-019-01869-3

Wong, Y. K., & Wong, A. C.-N. (2016). Music-reading training alleviates crowding with musical notation. *Journal of Vision*, *16*(8), Article 15. https://doi.org/10.1167/16.8.15

Zatorre, R. J., Perry, D. W., Beckett, C. A., Westbury, C. F., & Evans, A. C. (1998). Functional anatomy of musical processing in listeners with absolute pitch and relative pitch. *Proceedings of the National Academy of Sciences*, *95*(6), 3172–3177. https://doi.org/10.1073/pnas.95.6.3172

Author Biographies

Justine Pomerleau-Turcotte is PhD candidate at Université Laval. Her main research interests include aural skills pedagogy and cognition.

Maria Teresa Moreno Sala is professor at the Faculty of Music of Université Laval. Her main research interests include aural skills perception, cognition, pedagogy, and music psychology.

Francis Dubé is professor at the Faculty of Music of Université Laval. His research interests include music game-based learning, music creativity, and well-being.

François Vachon is professor at the School of Psychology of Université Laval. His main research interests include the basic and applied cognitive psychology of attention, memory, and performance.