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Auditory cognitive aging in amateur singers and non-singers

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ABSTRACT

The notion that lifestyle factors, such as music-making activities, can affect cognitive functioning and reduce cognitive decline in aging is often referred to as the *mental exercise hypothesis.* One ubiquitous musical activity is choir singing. Like other musical activities, singing is hypothesized to impact cognitive and especially executive functions. Despite the commonness of choir singing, little is known about the extent to which singing can affect cognition in adulthood. In this cross-sectional group study, we examined the relationship between age and four auditory executive functions to test hypotheses about the relationship between the level of mental activity and cognitive functioning. We also examined pitch discrimination capabilities. A non-probabilistic sample of 147 cognitively healthy adults was recruited, which included 75 non-singers (mean age 52.5 ± 20.3; 20–98 years) and 72 singers (mean age 55.5 ± 19.2; 21–87 years). Tests of selective attention, processing speed, inhibitory control, and working memory were administered to all participants. Our main hypothesis was that executive functions and age would be negatively correlated, and that this relationship would be stronger in non-singers than singers, consistent with the *differential preservation hypothesis*. The alternative hypothesis - *preserved differentiation* – predicts that the difference between singers and non-singers in executive functions is unaffected by age. Our results reveal a detrimental effect of age on processing speed, selective attention, inhibitory control and working memory. The effect of singing was comparatively more limited, being positively associated only with frequency discrimination, processing speed, and, to some extent, inhibitory control. Evidence of *differential preservation* was limited to processing speed. We also found a circumscribed positive impact of age of onset and a negative impact of singing experience on cognitive functioning in singers. Together, these findings were interpreted as reflecting an age-related decline in executive function in cognitively healthy adults, with specific and limited positive impacts of singing, consistent with the *preserved differentiation hypothesis*, but not with the *differential preservation hypothesis.*

1. Introduction

Given the rapid growth in the older adult population, and the large variations in cognitive health and function that exist in this population, there is a need to develop and implement evidence-based health programs to promote successful aging. Successful aging is “*characterized by a level of functioning that allows one to strive to fulfill personal goals and maintain personal standards*” (Freund, 2008, p. 94). The notion that lifestyle factors can affect cognitive functioning and reduce cognitive decline in aging, sometimes referred to as the *mental exercise hypothesis*, is an appealing hypothesis that has spread widely within and beyond the scientific literature, leading to the development of a plethora of “brain-training” programs, many of which lacking scientific support (Simons et al., 2016). Though several studies have shown that cognitive interventions can improve cognitive functioning in older adults (e.g. Lampit et al., 2014; Lampit, Hallock, & Valenzuela, 2014), the evidence supporting the mental exercise hypothesis is not wholly conclusive, and the mechanisms underlying the proposed relationship between mental exercise and cognitive aging remains unclear. Specifically, the degree of transfer from trained to untrained skills is highly variable and generally modest, and there is limited evidence of an impact on daily activities (*A consensus on the brain training industry from the scientific community*, 2022; Gates et al., 2020; Simons et al., 2016). Further, the exact effects of specific activities remain largely unknown, as well as those most likely

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to benefit from them (Schooler, 2007).

One set of concurrent hypotheses, developed by Salthouse, aims at clarifying the mechanisms underlying the relationship between the level of mental activity and cognitive functioning (Salthouse, 2006; Salthouse, Babcock, Skovronek, Mitchell, & Palmon, 1990). The first hypothesis, coined the *differential preservation hypothesis*, proposes that, in younger age, highly active and less cognitively active individuals do not differ. With age, however, only highly active individuals maintain a youth-like performance. This hypothesis requires that an interaction between age and group be found, meaning that group differences should increase with age, with highly active individuals showing maintained or improved performance over time, and less active individuals showing decreased performance over time. The second possibility, coined the *preserved differentiation hypothesis* (Salthouse, 2006; Salthouse et al., 1990), is that the difference in performance is preserved over the lifespan. This hypothesis requires that a main effect of group be found in the absence of a group by age interaction, meaning that highly active individuals maintain a stable advantage over less active individuals throughout their lifespan. For Salthouse, only a pattern of result consistent with the *differential preservation hypothesis* supports the mental exercise hypothesis. This is because, in Salthouse's perspective: "*The primary hypothesis is not that there is a main effect of mental exercise, but instead that there is an interaction of age and activity, such that greater loss (or decline as a function of age) occurs with less use (less mental exercise). Because aging is a dynamic concept that refers to change over time, the primary outcome of an intervention designed to affect aspects of aging should be rate of change over time in the relevant variable.*" (Salthouse, 2007, p. 32). Although this interpretation has been criticized (e.g., Schooler, 2007), it provides a framework within which to design and interpret results that address the question of the mental exercise hypothesis. This framework can be used to study the association between musical activities and cognitive aging (Alain, Zendel, Hutka, & Bidelman, 2014).

One type of activity that has been researched extensively within the broadly defined field of "successful aging" is music making. The appeal of musical activities (including singing and instrument playing) lies in their universality and, perhaps most importantly, unlike most cognitive training programs, in their contribution to psychological well-being in people of all ages (e.g. Coulton, Clift, Skingley, & Rodriguez, 2015; Johnson et al., 2020; Seinfeld, Figueroa, Ortiz-Gil, & Sanchez-Vives, 2013). Moreover, because musical activities do not exercise a single domain, akin perhaps to multicomponent interventions, music-making activities may have, at least in theory, stronger transfer potential than cognitive training programs, though this remains to be established. Because music-making activities indirectly train attention, planning, memory and self-discipline, these activities could have a positive impact on executive functions. Consistent with this notion, there is some empirical evidence showing that the practice of musical activities is associated with various cognitive (e.g. Bidelman & Alain, 2015; Hanna-Pladdy & Gajewski, 2012; Mansens, Deeg, & Comijs, 2018; Zendel & Alain, 2014) and communicative benefits including enhanced speech in noise perception (e.g. Dubinsky, Wood, Nespoli, & Russo, 2019).

One widespread musical activity with strong affective and social components is choir singing. Singing is a complex, multicomponent activity that engages auditory, sensorimotor, linguistic, cognitive, and emotional processes. It is associated with increased well-being, mental health and reduced social isolation (Coulton et al., 2015; Skingley, Martin, & Clift, 2016; Teater & Baldwin, 2014; Williams, Dingle, & Clift, 2018). Evidence suggests positive impacts of singing at all ages. In children, musical abilities, including singing, are associated with the development of cognition and language, phonetic skills and speech imitation (Christiner & Reiterer, 2013, 2018), though others have found no behavioural effect of singing training (Hennessy, Sachs, Ilari, & Habibi, 2019). Singing has also been proposed as a protective factor against dementia through an effect on cognitive reserve (Tan et al., 2018). However, empirical evidence for a cognitive benefit of choral singing in healthy older adults is scarce. In a study of 49 healthy older adults, Fu, Belza, Nguyen, Logsdon, and Demorest (2018) reported improved performance in verbal fluency (phonological and semantic) and immediate word recall after a 12-week group singing program that consisted of 75 min per week of pre-singing exercises (muscle stretching, deep breathing, and vocal exercise), song singing and learning, and post-singing socialization time. There was, however, no effect on the Trail making test. As part of the Community of Voices (COV) multisite randomized trial, Johnson et al. (2020) examined the effect of a choir intervention (90 min choir weekly sessions for 44 weeks, including 3–4 informal public performances) on three executive measures (set shifting, attention and inhibitory control and episodic memory). The choir intervention group ($n = 208$) was compared to a wait-list control group ($n = 182$). After 6 months, no group by time interaction was found on any of the executive measures. More recently, Pentikainen et al. (2021) compared a group of older singers ($N = 39$) to a group of older non-singers ($N = 35$) using an extended cognitive battery that assessed ten domains (general cognition, verbal flexibility, shifting, inhibition, processing speed, working memory, arithmetic, episodic memory: immediate and delayed recall, and verbal skills) and found a difference only in verbal flexibility (subcohort results). Similarly, Dege & Kerkovius (Dege & Kerkovius, 2018) found improvements in visual and verbal memory after 15 weeks of group music making (including singing and drumming) in healthy older adults, but no improvement in working memory. As part of a small-scale randomized trial, Pongan et al. (2017) recruited adults aged $\geq$60 years with probable Alzheimer's disease with mild or major neurocognitive disorder. Participants received either a singing ($N = 33$) or a painting ($N = 32$) intervention over a 12 weekly two-hour session over a three-month period. A cognitive battery was administered, which included measures of verbal episodic memory, information-processing speed and mental flexibility, working memory, inhibition, verbal fluency and cognitive dysexecutive syndrome (measured using the *Frontal Assessment Battery*). The results showed that singing and painting had a positive impact on working memory and inhibition with no group difference. A recent longitudinal training study (Alain et al., 2019) examining the impact or group music making (including singing) found no impact of the intervention on auditory executive function. Interestingly, however, a change in brain activity indexing auditory and executive functions was found, suggesting that short-term music practice may be associated with rapid neuroplasticity, which could lead to behavioural differences if music practice occurred over a longer period. These results highlight the need to study the impact of training duration and musicians' musical experience (e.g., the number of years of practice) on cognitive function. In sum, while there is a growing interest regarding the potential benefits of amateur singing on cognitive functioning in aging, the current empirical evidence is heterogeneous and too limited to conclude about short-term and long-term potential benefits.

The general objective of the current study was to examine auditory discrimination and four components of executive functions in the auditory modality – selective attention, inhibitory control, processing speed and working memory– in a sample of carefully matched healthy amateur singers and non-singers that included young, middle-aged, and older adults. The first specific objective was to explore age and group differences in auditory discrimination and executive functions. The first hypothesis was that performance in all domains would be lower in older compared to younger adults. The second hypothesis was that singing would show a positive association with auditory discrimination and executive functions, with an interaction between Age and Group, consistent with the *differential preservation hypothesis* (Salthouse, 2006). Specifically, we expected to find a negative relationship between executive functions and age, and that this relationship would be stronger in non-singers than singers. A third hypothesis was that evidence of a near-transfer effect associated with singing (i.e., better auditory discrimination in singers) would be stronger than evidence of far transfer (i.e., better selective attention, inhibitory control, processing speed and working memory in singers).

The second specific objective was to examine the impact of singers' characteristics on auditory discrimination and executive functions. Consistent with the *differential preservation hypothesis*, it was expected that singers who were more actively engaged in their practice would show less age-related decline in executive functions than singers who were less actively engaged in their practice. Specifically, our fourth hypothesis was that singers who began singing at an early age, had several years of practice, frequently practised, and received formal singing training would have better preserved executive functions, as illustrated by a significant interaction between Age and Practice.

2. Method

2.1. Participants

A total of 153 healthy adults (mean age 52.88 ± 20.18; 20–98 years, including 87 females and 66 males) were recruited through emails, Facebook posts, posters and flyers distributed in the general community and at Université Laval and through emails and Facebook posts targeting choirs in the Quebec City area. The study was approved by the *Comité d'éthique de la recherche sectoriel en neurosciences et santé mentale, Institut Universitaire en Santé Mentale de Québec* (#192–2017). All participants provided informed consent. The inclusion criteria were to be right-handed according to the *Edinburgh Handedness Inventory* (Oldfield, 1971), non-smokers, native speakers of Canadian French, to have normal or corrected-to-normal vision, no self-reported speech, voice, swallowing, uncontrolled acid reflux and no respiratory disorder (these and the non-smoking criteria were used because the study included voice assessments and magnetic resonance imaging, not reported here), no diagnosed language or psychological disorder, and no neurological or neurodegenerative disorder.

Further, participants had to fit within one of the two groups: amateur singers and non-singers. Non-singers were defined as individuals not involved in any form of group singing. Singers were defined as individuals involved in a choir for at least 2 years and with a weekly choral practice of ≥60 consecutive minutes. Age of onset was documented but it was not used as an inclusion criterion because of the typical high variability of age of onset in amateur group singers. Professional musicians and regular instrument players were excluded in order not to confound the results. While singing and instrument playing are alike in many ways, they also differ on several key dimensions. For example, the memorization of lyrics —or verbal content— is specific to singing, as is the use of the vocal cords and articulatory system. In contrast, the ability to read music is essential in an orchestra but is not required in many if not most amateur choirs. Though empirical evidence awaits to determine whether the association between cognitive aging and musical activities depends on the type of activity (singing vs. instrument playing), here we were interested in studying amateur singers specifically because of the universality of choir singing and its easy access at all ages.

All participants answered a questionnaire on past and present musical experiences to determine whether they fit these criteria and to document their practice. Seven participants were excluded because they did not meet one or more inclusion or exclusion criteria.

The final sample ($N = 147$) was divided into 75 non-singers (mean age 52.5 ± 20.3; 20–98 years, 39 females) and 72 singers (mean age 55.5 ± 19.2; 21–87 years, 45 females). The presence of depression symptoms was assessed using the 30-item version of the Geriatric Depression Scale (GDS) (Yesavage et al., 1982). No participant exhibited signs of major depression. General cognitive functioning was assessed using the Montreal Cognitive Assessment (MoCA) (Nasreddine et al., 2005). The GDS and the MoCA questionnaires were not used as exclusion criteria.

Singers started singing on average at age 38.58 ± 18.38 years (range: 7–84.5 years). About a third of the singers (22/72) had received formal singing training. The singers had an average of 16.9 ± 14.2 years of singing experience (range: 2–62 years). Given that participants varied in age, a "Singing experience ratio" was calculated by dividing the number of years of experience by age. In addition to their weekly choir, most participants rehearsed at home (65/72) and/or sang in their spare time (68/72). To quantify the amount of singing practice, a composite singing frequency variable was calculated across all singing-related activities (i.e., choir, home rehearsing, and leisure). The detail of each singer's experience is reported in supplementary material 1.

Singers and non-singers did not differ in biological sex, age, pure tone hearing, education, general cognitive functioning (MoCA), number of spoken languages, depression (GDS), and self-perceived health (all $p > .17$). A summary of participants' information is provided in Table 1.

2.2. Procedure

The experiment took place in a double-walled sound-attenuated room at the Speech and Hearing Neuroscience Laboratory in Quebec City, Canada. The visit had a duration of 3 h and included several breaks. It was well tolerated by all participants. The tasks included an audiometric evaluation, the Test of Attention in Listening (TAiL) (Zhang, Barry, Moore, & Amitay, 2012) and the Running span (Pollack, Johnson, & Knaff, 1959). Participants were seated facing a 24-in. computer monitor and were wearing headphones (DT 770 Pro, Beyerdynamic Inc. US). All tests were run on a Lenovo ThinkPad W510 computer. For the TAiL and the Running span, the volume was adjusted to a comfortable level prior to beginning each task to ensure that performance was not affected by hearing. The tasks detailed here represent a subset of a larger project. Other components of the project have been published elsewhere: a speech perception in noise task and structural imaging data (Perron, Theaud, Descoteaux, & Tremblay, 2021; Perron, Vaillancourt, & Tremblay, 2022) and a standardized passage reading task (Marczyk et al., 2022; Marczyk, O'Brien, Tremblay, Woisard, & Ghio, 2022).

2.2.1. Audiometric evaluation

Pure-tone thresholds in dB HL were measured with a calibrated clinical audiometer (AC40, Interacoustic, Danemark) for the following frequencies: 0.5, 1 and 2 kHz, in each ear separately. These measurements were used to compute a better ear (i.e., lowest thresholds between the two ears) pure tone average (PTA). The average better ear PTA was 9.5 ± 9.3 dB HL. Singers and non-singers did not differ in better ear PTA ($p = .42$), or inter-aural difference ($p = .50$) (Table 1). Because normal age-related hearing impairment in adults can affect performance in auditory cognitive tasks, hearing (better ear PTA) was included as a covariate in our statistical model. Though it has been shown that including higher frequencies in the calculation of a PTA provides a better proxy for hearing loss (Lin & Reed, 2020), the current PTA still provides a significant amount of control given a sample presenting with no hearing complaint and no diagnosed hearing disorder.

2.2.2. Auditory selective attention, inhibitory control and speed of processing

A French version of the test of Attention in Listening (TAiL) (Zhang et al., 2012) was used to measure auditory selective attention, inhibitory control and speed of processing. The TAiL is a Windows-based computer program that measures two aspects of auditory attention (involuntary orienting and conflict resolution) in addition to auditory speed of information processing; it was designed to identify and quantify the contribution of attention to auditory performance. The TAIL is based on Posner's Attention System view (Petersen & Posner, 2012; Posner & Petersen, 1990) and the Load Theory of attention (Lavie, Hirst, de Fockert, & Viding, 2004).

To measure these different executive abilities, the listener is required to assess the relationship between two sequentially presented tones, with respect to either their location (same or different ear), or their frequency (same or different frequency) in three tasks. Each task involves the diotic presentation of 40 pairs of two pure tones varying in two dimensions: pitch (range was 476 to 6188 Hz with the constraint

Table 1
Participant's characteristics.

	Controls $N = 75$ (52% F)				Singers $N = 72$ (62.5% F)				Welch Two Sample *t*-test	
Characteristics	M	SD	min	max	M	SD	min	max	t	p
Age	52.52	20.32	20	98	55.47	19.23	21	87	−0.90	0.37
Education (years)[a]	15.11	2.79	9	21	14.86	2.51	6	23	0.56	0.58
Nb languages[b]	2.25	1	1	7	2.21	0.6	1	4	0.33	0.74
MoCA[c] (/30)	27.37	2.15	21	30	27.08	2.69	17	31	0.72	0.47
GDS[d] (/30)	2.84	2.99	0	14	2.42	3.2	0	19	0.83	0.41
Self-reported health[e]	5.26	0.89	3	7	5.04	1.1	1	7	1.32	0.19
Right ear PTA[f]	13.61	11.49	−5	56.67	12.06	9.52	−1.67	36.67	0.90	0.37
Left ear PTA[f]	11.91	10.93	−3.33	46.67	9.62	9	−6.67	36.67	1.39	0.17
Better ear PTA[g]	10.13	9.91	−5	38.33	8.88	8.58	−6.67	30	0.82	0.41
Inter-aural difference	1.7	8.05	−16.67	41.67	2.43	4.57	−6.67	15	−0.68	0.50

Note. M = mean, SD = standard deviation of the mean, N = number of participants per group, F = number of female participants.
[a] Education = Standardized number of years of education based on the highest level reached.
[b] Number of spoken languages.
[c] MoCA = Montreal Cognitive Assessment. Higher scores indicate better cognitive functions.
[d] GDS = Geriatric Depression Scale. The GDS includes 30 yes/no questions. Each "negative" answer is worth one point; thus, a higher score indicates a more depressed state. For example, question one asks whether the person is globally satisfied with his/her life. A "no' answer is worth one point, whereas a "yes" answer is worth no point. Participants with scores between 0 and 9 are considered normal, while scores between 10 and 19 indicate a light depression, and scores between 20 and 30 indicate a severe depression. No participant scored above 19.
[e] Self-reported health = self-reported general health status on a scale of 0 to 7 (0 being lowest health level).
[f] PTA = pure tone average thresholds measured in decibels at 0.5, 1 and 2 kHz for each ear.
[g] Better ear PTA = pure tone average thresholds (PTA) at 0.5, 1, and 2 kHz for the better ear, measured in decibels (dB).

that the spectral gap between any two tones was at least 2.1 equivalent rectangular bandwidths) and location (right ear, left ear). The first task (Cued RT) evaluates participants' ability to detect the signal (speeded reaction time) by pressing a key on a computer keyboard as quickly as possible when the second sound is presented, independently of frequency and location. In the other two tasks (attend frequency or AF and attend location or AL), participants are asked to indicate as quickly as possible whether two pure tones have the same Frequency or Location (depending on the task) while the other dimension (Frequency or Location) is ignored. A summary of the conditions and associated outcome measures is presented in Supplementary Material 2.

Before each task, a practice of 5 trials was used to familiarize the participants with the task. The average reaction time (RT) on correct trials and the error rate are calculated for each task. Trials with RTs longer than 2 s or shorter than 100 ms were excluded. In addition to this measure of processing speed, two composite scores are provided (Involuntary orienting and Conflict resolution). The *involuntary orienting* score is a measure of distractibility which describes the effect of an incongruence in the unattended dimension on performance (for example, the effect of a difference in tone location when the listener attends to frequency). A higher value indicates an increased in the cost of dealing with distracting information (increased distraction). The *Conflict resolution* score is a measure of inhibitory control that considers differences between trials with tones varying in one (attended or unattended) dimension (conflict) and trials in which tones agree on both or neither dimension (no conflict). A higher value indicates an increased in the cost for resolving conflict.

2.2.3. Frequency discrimination

To determine whether there was a group difference in auditory frequency discrimination, we calculated a sensitivity (d') score based on the signal detection theory framework (Macmillan & Creelman, 1991). Discrimination was calculated from the Attention in Listening (TAiL) Specifically, we used the trials in the attend frequency (AF) task (see Section 2.2.2), which includes 40 trials in which two pure tones are presented. In this case, d' measures the ability to correctly recognize whether the pairs have the same or a different pitch. The formula used was: Z(hit rate) − Z(false alarm rate), where hit rate is the proportion of identical trials to which participants responded identical and false alarm rate is the proportion of identical trials to which participants responded different. A high value of d' indicates a good auditory frequency discrimination capacity.

2.2.4. Auditory working memory

A French version of the Running Span task (Pollack et al., 1959) included in the Cognitive Psychology Experiment IV pack (version 2), which is part of the Presentation® software package (Neurobehavioral Systems, Inc., Berkeley, CA, www.neurobs.com), was used to measure auditory working memory. The stimuli (digits 0 to 9) were recorded by a Quebec French speaker. Before each trial began, a countdown was shown on the screen. Immediately after the countdown, a series of spoken digits was presented with an inter-stimulus interval of 500 ms, after which participants were asked to recall *n* items from the end of the list. The number of items to be recalled ranged from 2 to 7, resulting in 6 different conditions (i.e., 6 different spans). The sequence of digits to be recalled was shown on the screen with blank spaces at the end of each list. Participants were asked to write down the recalled digits using a computer keyboard. Each condition (each span) included five trials, for a total of 35 trials. The order of the conditions was randomized across participants. For each condition, accuracy (i.e., the percentage of lists with correct recall) was extracted. A global span score was calculated, consisting in highest span level (2,3,4,5,6,7) at which performance reached 50% accuracy.

2.2.5. Statistical analyses

Data were analyzed using R version 4.0.3 (Team, 2019). For each variable of interest, first, outliers, defined as values above or below the interquartile range (IQR) were removed (Q1–1.5 × IQR or above Q3 + 1.5 × IQR). Next, the cleaned data were visually inspected using histograms to ensure that the distributions were normally or relatively normally distributed. For each domain (auditory attention, frequency discrimination, auditory working memory), two sets of analyses are reported. The first set (main analysis) focuses on group differences (singers vs. non-singers) (Objective 1). The second set focuses on the impact of singing-related factors on performance in the singers (Objective 2).

For each analysis, the same statistical approach was used unless otherwise stated. Data were analyzed using a generalized linear mixed effect (LME) approach. Each LME model was fit using the buildmer package version 1.9 (Voeten, 2020) and the lme4 package version 1.1.23 (Bates, Maechler, Bolker, & Walker, 2015). The buildmer package starts with the full model and determines the order of the random and fixed effects in the model that explain the most variance (Barr, 2013). The effects are then systematically reduced with backward stepwise elimination based on likelihood ratio tests to arrive at the final converging model with the best fit. The bound optimization by quadratic approximation optimizer (bobyqa) was used. LME results were illustrated using the r package ('sjPlot') (Lüdecke, 2021) for reporting and plotting model results (marginal means and regression lines). Detailed information on each statistical model is presented in the next two sections.

2.2.5.1. Analysis of the TAiL. Three outcome measures were analyzed: a measure of baseline performance (i.e., speed of processing), for each of the three tasks (Cued, AF, AL), as well as involuntary orientation (selective attention) and conflict resolution (inhibitory control) for the AF and AL tasks. For the analysis of baseline performance, the dependent variable was RT. The full model for the main analysis included the within-subject fixed factors Task (Cued RT, AF, AL), the between-subject factors Age and Group (Control, Singer), several between-subjects continuous covariates (sex, GDS score, better ear PTA, MoCA score and education) and a maximal random effects structure. For the analysis of the singers only, the full model included the within-subject fixed factors Task (Cued RT, AF, AL), four singing-related variables (singing onset, singing experience, singing training, and singing frequency), and the sensitivity score (see Section 2.2.2) and a maximal random effects structure. For the analyses of involuntary orienting (RT and error rate) and Conflict resolution (RT and error rate), the full models included the within-subject fixed factors Task (AF, AL), the between-subject factors Age and Group (Controls, Singers), several between-subjects continuous covariates (sex, GDS score, better ear PTA, MoCA score and education) and a maximal random effects structure. For the analysis of the singers only, the full model included the within-subject fixed factors Task (AF, AL), four singing-related variables (singing onset, singing experience, singing training, and singing frequency), the sensitivity score (see Section 2.2.3) and a maximal random effects structure. The maximal models for all analyses are reported in supplementary material 3.

2.2.5.2. Analysis of the running span. Two outcome measures were analyzed for the running span: accuracy and span. For accuracy, removing outliers did not make the data normally distributed in spans 2 and 3 (i.e., strong ceiling effect), and 6 and 7 (i.e., strong floor effect). No transformation could make these distributions normal, therefore, only data for spans 4 and 5 were analyzed. The full analytical model for the main analyses included the within-subject factors Span (4, 5), the between-subject factors Age and Group (Controls, Singers), several between-subjects continuous covariates (sex, GDS score, better ear PTA, MoCA score and education) and a maximal random effects structure. For the analysis of the singers only, the full model included the within-subject factors Span, four singing-related variables (singing onset, singing experience, singing training, and singing frequency), a reduced number of continuous covariates based on the main analyses (age, better ear PTA, MoCA score) and a maximal random effects structure.

For the analysis of the span variable, due to the non-continuous nature of the variable, a cumulative link model for ordinal regressions (Christensen, 2018) was used instead of a LMM. The full analytical model for the main analyses included the between-subject factors Age and Group (Controls, Singers), and several between-subjects continuous covariates (sex, GDS score, better ear PTA, MoCA score and education). The maximal models for all analyses are reported in supplementary material 3.

3. Results

3.1. Group comparison

3.1.1. Frequency discrimination

Here we investigated auditory frequency discrimination measured as sensitivity (d') in the AF condition of the TAiL (see Section 2.2.2) as a proxy for musical ability. Results revealed that singers had better frequency discrimination compared to controls (Fig. 1A), and that younger adults had better frequency discrimination (Fig. 1B). The details of the analysis can be found in Table 2 and the estimated marginal means in supplementary material 4.

3.1.2. TAiL

Here we investigated three variables: baseline performance (RT only), involuntary attention (RT and error rate) and conflict resolution (RT and error rate).

The results show that, in the baseline condition, older participants were slower than younger ones, an effect that was stronger in the non-singers compared to the singers (Fig. 2A). The AL task was less influenced by participants' age than were the AF and cued RT tasks (Fig. 2B). The singers were faster than the controls in the Cued RT task ($\beta = 0.0803$, $SE = 0.0180$, $p < .001$, $d = 0.775$), and faster in the AF task ($\beta = 0.0348$, $SE = 0.0175$, $p = .0477$, $d = 0.336$) (Fig. 2C). The details of the analysis can be found in Table 3 and the estimated marginal means in supplementary material 5A.

Next, we examined involuntary attention (i.e., distractibility). The results show that older adults were more distracted compared to the younger ones, with higher cost in RT (Fig. 2D). Distractibility was also higher in older adults compared to younger ones in terms of error rate cost, but only in the singers (Fig. 2F). Distractibility was higher in the AF compared to the AL task, in terms of RT cost (Fig. 2E) and error rate cost (Fig. 2G). Singers were slightly but significantly more distracted (reflected in higher RT cost) than the Controls in the AF task ($\beta = -0.0519$, $SE = 0.0166$, $p = .002$, $d = -0.624$). The groups did not differ in the AL task (Fig. 2E). The details of the analysis can be found in Table 4 and the estimated marginal means are reported in full in supplementary material 5B.

Finally, we investigated conflict resolution. The results reveal that older adults, regardless of their group, paid a higher price for resolving auditory conflict, in terms of RT (Fig. 2H) and error rate. For error rate, as shown in Fig. 2J, the age effect was only significant in the AF task ($\beta = 0.26$, $SE = 0.07$, $p \leq .001$) but not in the AL task ($\beta < -0.0001$, $SE = 0.02$, $p = .993$). For RT, in contrast, this effect was found in both the AF and the AL task. Still, there was evidence that AF task was harder than the AL task, with higher RT cost for resolving conflict in the AF compared to the AL task ($\beta = 0.022$, $SE = 0.01$, $p = .027$, $d = 0.29$), regardless of age. Finally, as shown in Fig. 2J, the cost of resolving conflict in terms of error rate was higher for controls than singers ($\beta =$

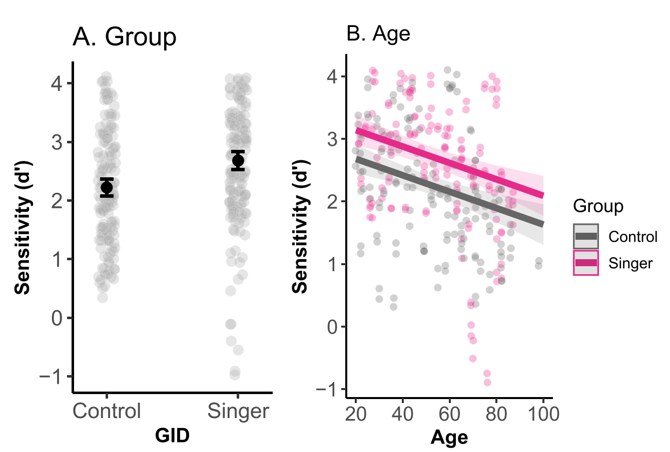

Fig. 1. Frequency discrimination results (predicted values). A. The scatterplot displays the significant difference between Group on frequency discrimination. B. The scatterplot displays the significant relationship between Age and sensitivity. The shaded area around the lines represents the confidence interval of the regression line.

Table 2
Frequency discrimination measured as d'.

Predictors	*β*	*SE*	*CI*	*p*
(Intercept)	−0.37	0.76	−1.87–1.13	0.627
MoCA	0.11	0.02	0.07–0.16	**<0.001**
Age	−0.01	0	−0.02 to −0.01	**<0.001**
Group [Singers]	0.46	0.1	0.25–0.67	**<0.001**
Sex [Female]	0.23	0.11	0.02–0.44	**0.033**
Observations	294			
R^2 / R^2 adjusted	0.232 / 0.221			
AIC	772.563			

Note. B = estimate*;* SE = standard error of the estimate; CI: confidence interval of the estimate.

3.44, $SE = 1.48$, $p = .021$, $d = 0.28$). The details of the analysis can be found in Table 5 and the estimated marginal means are reported in full in supplementary material 5C.

3.1.3. Auditory working memory

For working memory, the analyses focus on two measures of performance: accuracy and span. The results revealed no difference between groups and no interaction with the group for either accuracy or span. There was, however, an interaction between Age and Span on accuracy, shown in Fig. 3A, which revealed a negative association between age and accuracy in the most difficult condition (span 5) ($\beta = -0.003$, $SE = 0.0008$, $p < .001$), but not in the easy condition (span 4) ($\beta = -0.0013$, $SE = 0.0008$, $p < .117$). There was also a negative effect of age on span (Fig. 3B). The details of the analysis can be found in Table 6 and the estimated marginal means are reported in supplementary material 6.

3.2. Singer characteristics

In this section we analyzed only the singers and included four singing-related variables in the analyses to examine their relationship to performance: singing onset, singing experience, singing training, and singing frequency. The sensitivity score was also included as a proxy for musical skills. As detailed in Table 7, singing training and singing frequency were not associated with performance on any measure. As shown in Fig. 4, frequency discrimination was associated with baseline performance (those with better auditory frequency discrimination responded faster) (Fig. 4A), distractibility (those with better auditory frequency discrimination had lower overall error rates (Fig. 4B), that is, lower distraction) and span (those with better auditory frequency discrimination had higher span) (Fig. 4C). Age of onset was associated with frequency discrimination (those with earlier onset had better discrimination) (Fig. 4D) and with working memory accuracy (those with earlier onset had a better accuracy) (Fig. 4E). Finally, years of experience was associated with baseline performance (those with less experience responded faster) (Fig. 4F) and with working memory accuracy (those with less experience had a better accuracy) (Fig. 4G).

4. Discussion

The current study explored age-related differences in auditory frequency discrimination and executive functions in groups of adult amateur singers and non-singers carefully matched for demographic and health variables, to explore normal cognitive aging and as a (non-causal) test for the mental exercise hypothesis. Specifically, we examined processing speed, selective attention, inhibitory control, and working memory – four core components of executive functions reflecting largely (though not entirely) separable processes. It was expected that executive functions would be lower in older adults. This hypothesis was supported by our findings, in terms of speed of processing, selective attention, inhibitory control and working memory. Our main hypothesis was that singing would show a positive association with executive functions, with an interaction between Age and Group, consistent with the *differential preservation hypothesis* (Salthouse, 2006). Specifically, we expected to find a negative relationship between executive functions and age, and that this relationship would be stronger in non-singers than singers. This hypothesis received limited support, with only speed of processing exhibiting the expected pattern (see Fig. 5 for a summary of the main outcomes).

A third hypothesis was that evidence of a near-transfer effect associated with singing (i.e., better auditory discrimination in singers) would be stronger than evidence of far transfer (i.e., better selective attention, inhibitory control, processing speed and working memory in singers). This hypothesis was supported by our results. The second objective of the study was to examine the impact of singers' characteristics on executive functions. Consistent with the differential preservation hypothesis, we expected less age-related decline in singers who began singing at an early age, had several years of practice, frequently practised, and received formal singing training. This hypothesis received some support, with age of onset associated with performance in some, but not all, cognitive tests. Overall, our results are more consistent with the *preserved differentiation hypothesis* than with the *differential preservation hypothesis* (Salthouse, 2006; Salthouse et al., 1990), and suggest a limited transfer effect of amateur singing on executive functions in the auditory modality, with a positive association between singing and conflict resolution.

4.1. Preserved differentiation or maintained preservation?

Executive functions play a critical role in everyday life, allowing individuals to plan, initiate and inhibit actions, focus their attention, monitor their performance, and switch between different tasks. Executive functions are key to maintaining independence in older age, and have been associated with improved self-reported quality of life in older adults (Davis, Marra, Najafzadeh, & Liu-Ambrose, 2010). It is therefore crucial to further our understanding of how executive skills change across the adult lifespan, and whether singing – as well as other activities – is associated with better maintained executive functions, as this could help develop training interventions, including singing-based interventions, to maintain functioning in older ages. Evidence that choir singing could have a positive impact on executive functions in healthy aging, and more generally on cognition, is relatively scarce. Evidence in support of the *differential preservation hypothesis* is even more limited. One longitudinal cohort study found better speech in noise perception after singing training, but there was no change in auditory working memory or inhibitory control (Dubinsky et al., 2019). Other studies have found an impact of singing on verbal fluency (phonological and animal semantic) and immediate word recall but not delayed word recall (Fu et al., 2018), and in verbal flexibility, but not working memory, processing speed or inhibition (Pentikainen et al., 2021). One cluster-randomized trial conducted at 12 senior centres in the United States reported no cognitive benefit at all (episodic memory, inhibition and executive function measured by the TMT test) after 44 weeks of a choir intervention that was designed to impact cognition (Johnson et al., 2020). Overall, the effect of choral singing on executive function appears to be selective rather than broad. The results of the present study are consistent with the literature in that we showed only associations between specific areas of executive function and singing, some positive and other negative, revealing a complex interaction between singing and cognitive aging. Several factors may account for the heterogeneity in the literature, including the nature of the singing training program (e.g., duration, style, number of trainees, etc.), and the characteristics of the participants. Further, the type and modality of the tasks used to evaluate cognitive and executive functions can also affect the results. Specifically, it has been proposed that the benefits of music practice on cognition are stronger on more complex or cognitively demanding tasks (Blain, Talamini, Fornoni, Bidet-Caulet, & Caclin, 2022; Dittinger et al., 2016). In sum, although it remains to be determined to what extent and

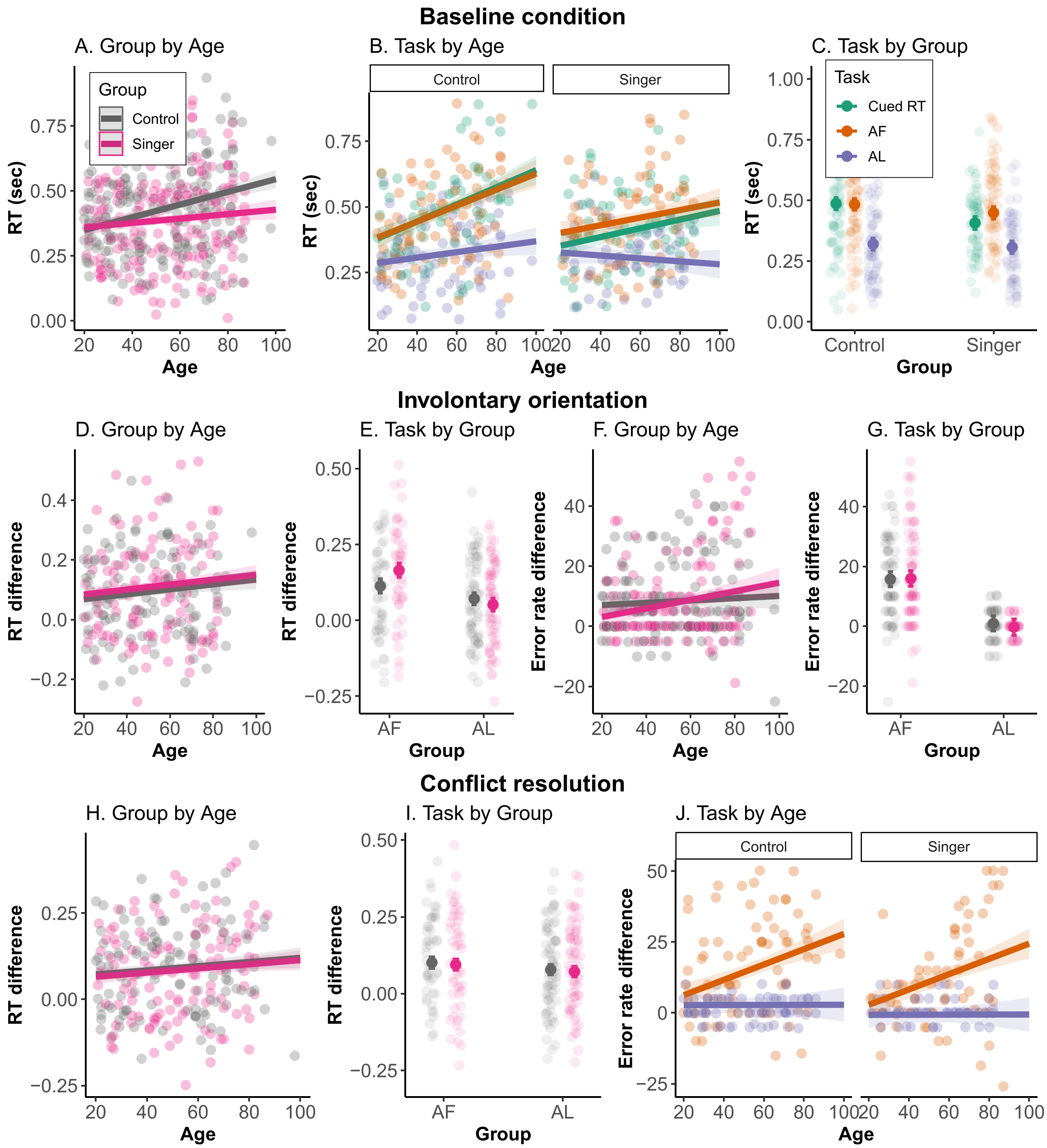

Fig. 2. TAiL main results (predicted values) for the baseline (first row), involuntary attention (second row) and conflict resolution (third row). A. The scatterplot displays the interaction between Group and Age on overall baseline RT. The shaded area around the lines represents the confidence interval of the regression line. B. The scatterplot displays the interaction between Condition (Cued RT, AF, AL) and Age on RT, separately for each group. C. The plot displays the interaction between Task (Cued RT, AF, AL) and Group on RT. The error bars represent the confidence interval. D. The scatterplot displays the relationship between Age and RT difference separately for each group. E. The boxplots display the interaction between Group (Control, Singer) and Task (AF, AL) on RT difference. F. The scatterplot displays the interaction between Age and Group (control, singer) and error rate difference G. The boxplots display the significant effect of Task (AF, AL) on error rate difference, separately for each group. H. The scatterplot displays the relationship between Age and RT difference for conflict resolution, separately for each group. I. The boxplots display the significant effect of Task (AF, AL) on RT difference separately for each group. J. The scatterplot displays the interaction between Age and Task (AF, AL) on error rate difference, separately for each group.

under what conditions choral singing has a positive effect on cognition, the literature indicates that singing has a positive effect on specific aspects of executive functions.

One issue, however, is that because most studies only included older participants, it is not clear if the effect of choral singing can be explained by the preserved differentiation hypothesis or differential preservation hypothesis. The current study was designed to investigate this by including participants of all ages. Importantly, our sample included not only younger and older adults but also middle-aged adults, which is important to examine aging trajectories. Studies of the impact of age on executive functions have largely focused on comparing young and older adults (Ferguson, Brunsdon, & Bradford, 2021). The current study therefore makes a unique contribution to the literature by demonstrating that, contrary to our prediction, there was only limited evidence in support of the *differential preservation hypothesis,* that is, the association between age and executive functioning was largely similar in singers and non-singers. The only evidence of a reduced association was found in the baseline condition of the TAiL (cued RT), which provides a baseline measure of information processing under minimal attention control (i.e., when neither frequency nor location differences were

Table 3
Result of the linear mixed model analysis for the TAiL: Baseline RT.

	RT			
Predictors	*β*	*SE*	*CI*	*p*
(Intercept)	0.310	0.030	0.26–0.37	**<0.001**
Condition [AF]	0.010	0.040	−0.07–0.08	0.833
Condition [AL]	−0.050	0.040	−0.12–0.03	0.200
Age	0.000	0.000	0.00–0.00	**<0.001**
Group [Singers]	0.000	0.030	−0.06–0.07	0.887
Condition [AF] * Age	0.000	0.000	−0.00–0.00	0.740
Condition [AL] * Age	0.000	0.000	−0.00 to −0.00	**0.001**
Age * Group [Singers]	0.000	0.000	−0.00 to −0.00	**0.003**
Condition [AF] * Group [Singers]	0.050	0.030	-0.00–0.09	0.071
Condition [AL] * Group [Singers]	0.070	0.030	0.02–0.12	**0.008**
Observations	409			
R^2 / R^2 adjusted	0.396 / 0.382			
AIC	−682.036			

Note. B = estimate*;* SE = standard error of the estimate; CI: confidence interval of the estimate.

relevant to the task). There, singers showed evidence of a faster processing speed and a lower rate of decline with age compared to controls. The impact of amateur singing on speed processing has not been investigated extensively. Our finding is inconsistent with a recent cross-sectional study that reported no impact of choral singing on processing speed (Pentikainen et al., 2021). However, it is consistent with studies on instruments playing that reported music-related benefits on auditory processing speed (Bugos, Perlstein, McCrae, Brophy, & Bedenbaugh, 2007; Hanna-Pladdy & MacKay, 2011). Further evidence is therefore needed to test the robustness of our finding in an independent sample.

With the exception of processing speed, singing, in the present study, was not associated with a difference in the rate of decline of executive functions with normal aging. Though our study was not experimental in nature, its results suggest that the *differential preservation hypothesis* may not be an appropriate model to explain the relationship between singing and cognitive aging. Instead, our results suggest that the differences between singers and non-singers are stable throughout life, consistent with the differential preservation hypothesis. This suggests that at any age, adult singers will perform significantly better than non-singers on specific tests (frequency discrimination and auditory conflict resolution), which may still offer some advantage as they age. Alternatively, it is also possible that a stronger protective effect could have been found in professional singers, in people who sing more often, in those with formal musical training or in those who started singing earlier (Cf. Section 4.3). Admittedly, our sample was heterogeneous and included several singers with only limited singing experience. Most singers started singing late in life. Further, we did not collect a measure of singing proficiency other than a very indirect proxy (auditory frequency discrimination); it is therefore impossible to determine how proficient singers really were, which could explain the limited benefits. Yet, we do believe that our sample was representative of choral singers, at least in Canada, where many people start singing late in life. Moreover, from a rehabilitation perspective, only amateur singing is a realistic model, as professional singing is not universally accessible. Evidence from large-scale trials with measures of singing proficiency is needed to confirm these findings.

Besides limited positive associations between singing and executive functions, we also found negative associations between singing and involuntary orientation, with singers being more distracted compared to non-singers, specifically when the dimension to be ignored was incongruent, and with distractibility increasing with age in singers. One hypothesis that might explain this unexpected result is that, during choral practice, singers must pay attention to the acoustic environment (e.g., the performance of the other members of their choir, the choral master, and the instrumentalists when present) in order to control and adapt their own performance. Thus, incongruent acoustic events could have a greater impact on their attentional control since they are more likely to detect them in the background compared to non-singers. It would be

Table 4
Results for involuntary attention (TAiL).

	A. RT				B. Error rate			
Predictors	*β*	*SE*	*CI*	*p*	*β*	*SE*	*CI*	*p*
(Intercept)	0.07	0.02	0.04–0.11	**<0.001**	14.52	3.43	7.77–21.26	**<0.001**
Task [AL]	−0.04	0.02	−0.07 to −0.01	**0.007**	−16.44	4.87	−26.02 to −6.86	**0.001**
Age	0.000	0.0000	0.00–0.00	**0.005**	0.02	0.06	−0.10–0.14	0.712
Group [Singers]	0.05	0.02	0.02–0.08	**0.002**	−12.12	5.16	−22.27 to −1.97	**0.019**
Task [AL] * Group [Singers]	−0.07	0.02	−0.11 to −0.03	**0.001**	12.15	7.48	−2.58–26.89	0.106
Task [AL] * Age	–	–	–	–	0.03	0.09	−0.14–0.20	0.72
Age * Group [Singers]	–	–	–	–	0.23	0.09	0.06–0.41	**0.01**
Task [AL] * Age * Group [Singers]	–	–	–	–	−0.26	0.13	−0.52–0.00	0.053
Observations	235				278			
R^2 / R^2 adjusted	0.220 / 0.206				0.386 / 0.370			
AIC	−495.095				2113.76			

Note. B = estimate*;* SE = standard error of the estimate; CI: confidence interval of the estimate.

Table 5
Results for conflict resolution (TAiL).

	A. RT				B. Error rate			
Predictors	*β*	*SE*	*CI*	*p*	*β*	*SE*	*CI*	*p*
(Intercept)	0.070	0.010	0.04–0.10	**<0.001**	0.870	3.000	−5.04–6.79	0.772
Age	0.001	0.000	0.00–0.00	**0.026**	0.270	0.050	0.17–0.37	**<0.001**
Task [AL]	−0.020	0.010	−0.04 to −0.00	**0.028**	1.850	4.340	−6.70–10.39	0.671
Group [Singers]	–	–	–	–	−3.440	1.480	−6.35 to −0.53	**0.021**
Task [AL] * Age	–	–	–	–	−0.270	0.080	−0.42 to −0.12	**0.001**
Observations	237				276			
R^2 / R^2 adjusted	0.036 / 0.028				0.278 / 0.267			
AIC	−546.066				2173.811			

Note. B = estimate*;* SE = standard error of the estimate; CI: confidence interval of the estimate.

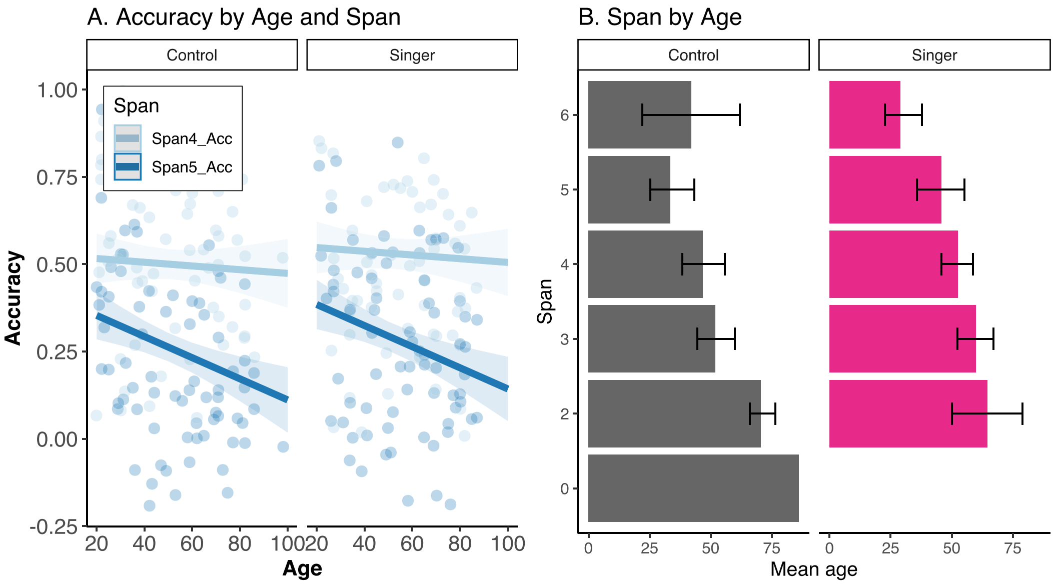

Fig. 3. Results for the Running span. A. The scatterplot displays the relationship between Age and accuracy, for the easy (span 4) and hard (span 5) conditions, separately for each group. The shaded area around the lines represents the confidence interval of the regression line. B. The bar plot illustrates the mean age of participant with different average span, separately for each group. The error bars represent the confidence intervals.

Table 6
Results for the Working Memory Test (Running span).

A. Accuracy					B. Span			
Predictors	*β*	*SE*	*CI*	*p*	*Predictors*	*OR*	*CI*	*p*
(Intercept)	0.040	0.170	−0.30–0.38	0.82	2|3	0.01	0.00–0.02	**<0.001**
Span [Hard]	−0.110	0.070	−0.25–0.02	0.108	3|4	0.07	0.03–0.18	**<0.001**
MoCA	0.020	0.010	0.01–0.03	**0.002**	4|5	0.45	0.18–1.12	0.086
Age	0.000	0.000	−0.00–0.00	0.616	5|6	2.23	0.78–6.41	0.136
Span [Hard] * Age	0.000	0.000	−0.00 to −0.00	**0.04**	Age	0.95	0.94–0.97	**<0.001**
Observations	272				Sensitivity	N/A	N/A	N/A
R^2 / R^2 adjusted	0.348 / 0.339				Observations	146		
AIC	−101.276				R^2 Nagelkerke	0.215		

Note. B = estimate*;* SE = standard error of the estimate; CI: confidence interval of the estimate. OR = odds ratio. CI: confidence interval of the odds ratio.

interesting to compare amateur group and solo singers in future studies to test this hypothesis, as we would expect only group singers to show this pattern. Alternatively, it is possible that people who join choirs are more distracted. Given the lack of randomization, this hypothesis cannot be verified here.

4.2. Cognitive transfer

Transfer can be defined as a learning effect that goes beyond the primary effect of practice. Transfer can be near, intermediate, or far, depending on the distance between the trained and the untrained task. Transfer can be explained by postulating that the by-product of learning specific cognitive tasks consists in general cognitive skills (Taatgen, 2016), such as working memory. Because people characteristically do not learn new skills in isolation, any new task that is learnt is affected by prior learning. While there is no doubt that specific cognitive training improves performance directly linked to the trained task and even to tasks within the same domain (i.e., near and intermediate transfer), whether training in one task can improve performance in tasks that are seemingly remote from the trained activity (i.e., far transfer) remains highly controversial to this day (Melby-Lervag, Redick, & Hulme, 2016; Sala & Gobet, 2019).

As one might expect, taking music lessons is associated positively with performance on a wide variety of musical and non-musical listening tasks. For singing, the primary effect of practice should include a better vocal control, better vocal projection, and the ability to sing on key. These are very specific skills. But learning to sing also trains executive functions such as working memory and selective and divided attention: singers must learn lyrics, read words and music at the same time, while paying attention to the choir conductor as well as to group dynamics. If singing practice resulted in better executive performance, this would constitute evidence of a far transfer effect of singing. To test this hypothesis (though non-causally), in the present study, we examined auditory cognitive capabilities in carefully matched groups of amateur singers and non-singers. Singers had better auditory discrimination at all ages, which is evidence of near transfer. Evidence supporting far transfer, in contrast, was limited: singers did not show superior overall auditory cognition compared to non-singers. Their processing speed was higher in the cued RT task, and their ability to resolve conflict was also slightly better (in terms or error but not RT). There was no positive association with distractibility and working memory. These findings suggest significant but selective transfer of singing to executive functions, consistent with the results of cognitive training studies showing no far transfer effects (Melby-Lervag et al., 2016; Sala & Gobet, 2019, 2020; Sala, Tatlidil, & Gobet, 2021).

Our findings do not signify that no far transfer effect can result from amateur singing. It is possible that other cognitive or executive skills are more strongly associated with amateur singing, such as verbal fluency, which is perhaps more directly trained by choral singing than any other executive function. It is also possible that our results were influenced by

Table 7
Results for the singers only.

A. Frequency discrimination (d')					B. TAiL: Baseline RT			
Predictors	*β*	*SE*	*CI*	*p*	*β*	*std. Error*	*CI*	*p*
(Intercept)	4.53	0.63	3.28–5.78	**<0.001**	0.27	0.05	0.16–0.37	**<0.001**
Age	0.02	0.02	−0.02–0.05	0.344	0.00	0.00	0.00–0.00	**0.008**
Age of onset	−0.06	0.03	−0.11 to −0.00	**0.039**	N/A	N/A	N/A	N/A
Singing experience	−2.68	1.53	−5.74–0.37	0.084	0.15	0.05	0.06–0.24	**0.001**
Frequency discrimination	N/A	N/A	N/A	N/A	−0.02	0.01	−0.05 to −0.00	**0.034**
Observations	72				211			
R^2 / R^2 adjusted	0.185 / 0.149				0.233 / 0.214			
AIC	203.57				−201.495			
C. TAiL: Involuntary attention								
	RT				**ER**			
Predictors	*β*	*SE*	*CI*	*p*	*β*	*SE*	*CI*	*p*
(Intercept)	0.17	0.01	0.14–0.19	**<0.001**	17	4.83	7.45–26.55	**0.001**
Task [AL]	−0.11	0.02	−0.14 to −0.08	**<0.001**	−16.35	1.97	−20.24 to −12.46	**<0.001**
Age	N/A	N/A	N/A	N/A	0.11	0.06	0.00–0.22	**0.047**
Frequency discrimination	N/A	N/A	N/A	N/A	−2.6	1.02	−4.62 to −0.57	**0.012**
Observations	114				132			
R2 / R2 adjusted	0.275 / 0.268				0.413 / 0.400			
AIC	−223.484				1018.465			
D. TAiL: Conflict resolution								
	RT				**ER**			
Predictors	*β*	*SE*	*CI*	*p*	*β*	*SE*	*CI*	*p*
(Intercept)	0.06	0.02	0.02–0.10	**0.008**	0.28	3.53	−6.70–7.27	**0.936**
Task [AL]	−0.03	0.01	−0.06 to −0.01	**0.021**	−9.55	2.17	−13.84 to −5.26	**<0.001**
Age	0.00	0.00	0.00–0.00	**0.041**	0.19	0.06	0.08–0.31	**0.001**
Observations	117				133			
R2 / R2 adjusted	0.071 / 0.055				0.203 / 0.190			
AIC	−261.791				1052.699			
E. Running span results								
	Accuracy				**Span**			
Predictors	*β*	*SE*	*CI*	*p*	*Predictors*	*OR*	*CI*	*p*
(Intercept)	0.73	0.08	0.57–0.89	**<0.001**	2|3	0.01	0.00–0.11	**<0.001**
Span [Hard]	−0.22	0.04	−0.29 to −0.15	**<0.001**	3|4	0.2	0.02–1.88	0.161
					4|5	1.59	0.19–13.57	0.672
					5|6	7.89	0.85–73.60	0.07
Age	N/A	N/A	N/A	N/A	Age	0.95	0.93–0.98	**<0.001**
Age of onset	0	0	−0.01 to −0.00	**0.001**	Age of onset	N/A	N/A	N/A
Singing experience	−0.22	0.11	−0.44 to −0.00	**0.049**	Singing experience	N/A	N/A	N/A
Frequency discrimination	N/A	N/A	N/A	N/A	Frequency discrimination	1.76	1.10–2.84	**0.019**
Observations	134				Observations	72		
R^2 / R^2 adjusted	0.272 / 0.256				R^2 Nagelkerke	0.325		
AIC	−38.776				AIC	N/A		

Note. B = estimate*;* SE = standard error of the estimate; CI: confidence interval of the estimate.

the choice of tests: more demanding tasks could have led to more evidence of transfer (Coffey, Mogilever, & Zatorre, 2017), consistent with previous findings in auditory processing (Parbery-Clark, Skoe, & Kraus, 2009; Parbery-Clark, Skoe, Lam, & Kraus, 2009) and speech in noise (Wong et al., 2009). Yet, previous studies have found no executive advantage for singers using tests assessing some of the dimensions assessed by the TAiL (inhibitory control), such as the Trail making test (Bialystok & Depape, 2009; Fu et al., 2018; Johnson et al., 2020; Pentikainen et al., 2021) and the flanker task (Dubinsky et al., 2019; Johnson et al., 2020). Only one study of classically trained vocalist found an advantage in an auditory Stroop test for the pitch conflict condition (Bialystok & Depape, 2009). Together these findings suggest limited impact of amateur singing on inhibitory control. Regarding working memory, in previous studies, researchers have used the digit span task, which is easier than the running span test that we used, and found a group difference (Mansens et al., 2018), while others have used tasks of comparable difficulty, such as the listening span (Dubinsky et al., 2019), and spatial span (Bialystok & Depape, 2009), and, consistent with our finding, have reported no group difference. These findings suggest that participants characteristics may be affecting the results more so than the task. Thus, the impact of singing on selective attention, inhibitory control and working memory appear to be modest, but this finding needs to be tested using tasks varying in difficulty level, in singers with various proficiency levels and age of onset. And finally, our study cannot replace the much-needed randomized controlled studies.

4.3. Singing characteristics

The second objective of the present study was to examine the impact of singers' characteristics on executive functions. Our analyses show a moderately positive association between age of onset and cognition, and a moderately negative association with years of experience. There was no association with formal training or frequency of singing.

Unsurprisingly, age of onset was found to be a positive moderator of the relationship between singing and frequency discrimination, with earlier onset associated with better discrimination. Importantly, age of onset was also positively associated with working memory, with earlier onset associated with better working memory. In our study, age of onset was not used as an inclusion criterion. Singers started singing on average at age 38.58 ± 18.38 years, but the range was high (7–84.5 years), and everyone started at the age of 7 or later. We chose not to use age of onset as an inclusion criterion, because our experience with amateur singers is that, in this population, age of onset varies widely, and often people pick up singing in adulthood or in late adulthood, reflecting the accessibility of this musical activity at any age. Age of onset has been associated with music-induced neuroplasticity (for a review, see e.g. Merrett, Peretz, & Wilson, 2013) and earlier age of onset for music training in childhood was found to be associated with enhancement of specific musical skills (Ireland, Iyer, & Penhune, 2019) and rhythm synchronization (Bailey &

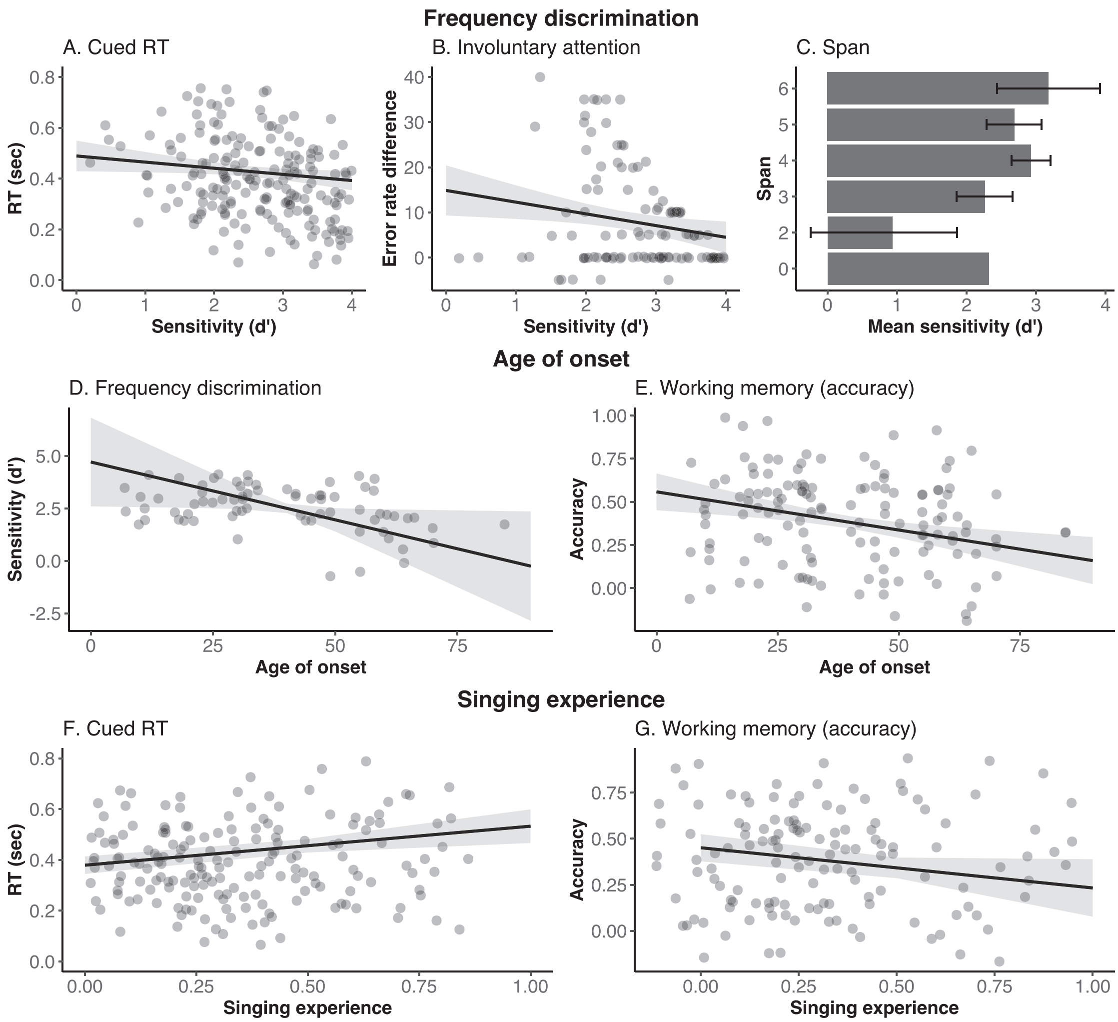

Fig. 4. Results for the analyses of singing characteristics. First row: relationship between performance and frequency discrimination for the baseline RT (A), involuntary orientation (B) and Span (C). B. The scatterplot displays the significant interaction between singing experience (Year of experience / Age) and baseline RT. C. Second row: relationship between performance and age of onset for Frequency discrimination (D) and working memory accuracy (E). Third row: relationship between performance and singing experience for baseline RT (F) and working memory accuracy (G).

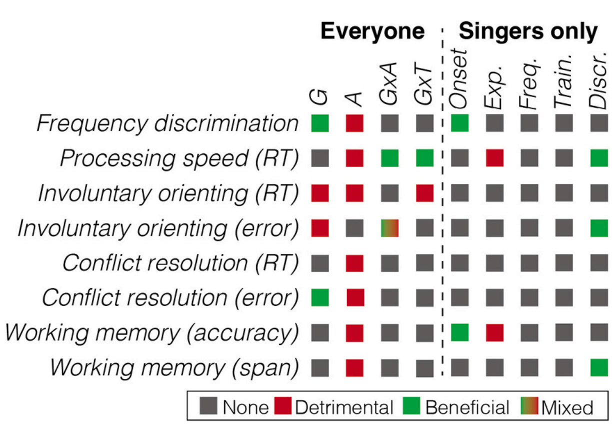

Fig. 5. Summary of the main results. G = group; A = Age or Task by Age; G X A = Group X Age interaction; G X T = Group by task interaction. Onset = age of singing onset; Exp = years of experience (ratio); Freq = frequency of practice; Training = singing training; Discr = frequency discrimination skill.

Penhune, 2010; Bailey & Penhune, 2012). It has been suggested that learning music within the first seven to nine years of life may be associated with maximal benefits in auditory-motor synchronization skills, with a non-linear relationship across the lifespan (Bailey & Penhune, 2013). Our results suggest that, even in those who started singing late in life, a relationship with performance can be observed, at least on working memory. It is also possible that this relatively specific cognitive benefit is related to the fact that participants started singing outside of this maximally sensitive period.

Perhaps more surprisingly, experience was negatively associated with processing speed and working memory. Singers in our study had an average of 16.9 ± 14.2 years of singing experience ranging from 2 to 62 years. This was expected because they were aged between 21 and 87 years, with an average age of 55 ± 19 years. To measure the relationship between experience and performance independent of age, experience was converted into a ratio variable (number of years of experience / age). So, how can the slightly negative impact of experience be explained? It has been suggested that, the longer you train a specific skill, the more you become proficient in that particular skill, and in task components that are highly specific to that particular skill (Dege, 2020). This very expertise might therefore limit the potential of transfer due to the high specificity of the processes -or operators in the PRIMs model (Taatgen, 2016)- involved. As discussed by Schellenberg: "*Findings of* *positive associations between duration of music training and intelligence imply that professional musicians should be geniuses, which is patently untrue*" (Schellenberg, 2011, p. 285). Though developed to explain developmental data, this argument seems relevant to explain the present results with middle-aged and older adults. This "*curse of specificity*" has been defined as one of the basic elements in a model of human cognition (Sala & Gobet, 2019). In this view, more years of singing practice would not necessarily lead to enhanced cognition. Given the nature of choir singing, it is also possible that, in the present study, those with a longer experience were not more skilled singers. Consistent with these notions, Duke, Simmons, and Cash (2009) showed that, among a sample of 17 adult pianists, the strategy employed during practice was more predictive of their retention test performances than was how much or how long they practiced. In sum, the present finding suggests that, to reach their optimal transfer potential, singing activities would not have to last for decades. Form a rehabilitation perspective, this is important, as long-lasting interventions have reduced applicability.

Another interesting finding of the present study is that frequency discrimination was positively associated with three of the four cognitive domains tested: processing speed, selective attention and working memory. Only conflict resolution was not associated with frequency discrimination. It is possible that better discrimination capacities free up cognitive resources leading to better performance in auditory cognitive tasks. It is also possible that frequency discrimination may be a proxy for musical proficiency, which was not directly measured in the present study, and which is, unfortunately, not typically reported in studies on music-induced transfer. The present finding suggests that measuring musical skills directly may be important to understanding potential transfer effects.

5. Conclusion

While the present study does not generally support the differential preservation hypothesis and provides only limited evidence of far transfer from amateur singing to auditory cognition, it raises new questions worth investigating in future research. First, the finding that age of onset was only moderately positively associated with only specific measures of auditory cognition (as opposed to having a broad impact) is important for those interested in the impact of amateur singing, and musical activities more broadly, in adulthood and late adulthood, and in its curative potential, as it suggests that transfer may be possible late in life. Second, the results suggest that the level of musical proficiency could be a more important factor than the amount of experience in predicting far transfer in a healthy adult population. This is an important finding to guide future studies, given that most studies do not include indexes of musical proficiency. Despite the limited evidence of singing-induced executive benefits in the present study, given the established benefits of singing on well-being, the next step forward is to conduct the much needed randomized controlled training studies with middle-aged and older adults to measure with more precision the impact of singing activities on cognition, using theory-based, goal-oriented singing programs and including measure of musical proficiency before and after training, in addition to measuring a large range of cognitive abilities.

CRediT authorship contribution statement

Pascale Tremblay: Conceptualization, Funding acquisition, Methodology, Investigation, Formal analysis, Visualization, Supervision, Resources, Project administration, Writing – original draft, Data curation. **Maxime Perron:** Methodology, Investigation, Writing – review & editing.

Data availability

The authors do not have permission to share data.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cognition.2022.105311.

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