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CONCISE REPORT

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# Singing accuracy across the lifespan

Peter Q. Pfordresher

Department of Psychology and Center for Cognitive Science, University at Buffalo, State University of New York, Buffalo, New York, USA

**Correspondence**
Peter Q. Pfordresher, Department of Psychology and Center for Cognitive Science, University at Buffalo, State University of New York, 362 Park Hall, Buffalo, NY 14260, USA.
Email: pqp@buffalo.edu

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## Abstract

Although singing is a nearly universal human behavior, many adults consider themselves poor singers and avoid singing based on self-assessment of pitch matching accuracy during singing (here referred to as singing accuracy), in contrast to the uninhibited singing exhibited by children. In this article, I report results that shed light on how singing accuracy changes across the lifespan, using data from a large online sample, including participants ranging from 6 to 99 years old. Results suggest that singing accuracy improves dramatically from childhood to young adulthood, unperturbed by voice changes during adolescence, and remain at a similarly high level for the remainder of life, exhibiting no strong tendency toward age-related decline. Vocal or instrumental musical training has significant positive effects on singing accuracy, particularly in childhood, though there was no evidence for gender differences. Finally, pitch discrimination varied with age similarly to singing accuracy, in support of views that singing accuracy reflects sensorimotor learning. Taken together, these results are consistent with the view that singing accuracy is a learned motor skill that benefits from engagement and can remain a fruitful endeavor into old age.

KEYWORDS
cognitive aging, lifespan development, music performance, neural plasticity, singing accuracy

## INTRODUCTION

Healthy individuals engage in at least occasional singing for most of their lives. Song-like vocalizations emerge spontaneously from infants and play a role throughout childhood.[1] Even adults who consider themselves inaccurate singers occasionally sing in groups and private settings.[2] However, little is known about how singing abilities change with development,[3] in contrast to the rich existing literature on the development of speech production and language learning.[4] In this paper, I report an analysis of a large online data set to help build this understanding.

Although singing is present at virtually all points in life for virtually all healthy individuals, singing ability is not equally distributed.[5–8] Although there are many dimensions on which singing abilities may vary, the most salient and perhaps most elusive for many singers is pitch accuracy: the ability to match an intended pitch or sequence of pitches with the voice. I refer to this ability here as *singing accuracy*, in keeping with the broader literature, although there are clearly many ways in which singing may be accurate or inaccurate.

Singing accuracy requires the coordination of perception and action via sensorimotor mapping. Cognitively, this mapping may be served by the use of an internal model of the auditory-vocal system,[9] and it may be initiated through auditory imagery (a.k.a. audiation) prior to production.[10] The neural mechanisms for this mapping likely involve white matter tracts connecting auditory and motor centers, possibly mediated by the basal ganglia.[11–13] Individual differences in pitch accuracy may be based on differences in the functioning of auditory perception, motor control, and/or sensorimotor mapping.[14,15] Recent studies suggest that individual differences in sensorimotor mapping may predict singing accuracy.[16,17]

The literature on singing accuracy is dominated by research in music education focusing on singing among elementary school children, dating back several decades, and by recent research from cognitive science on college students.[3,18] Comparisons across these data sets are complicated by different measures used, different recruitment strategies, and different research goals. Moreover, there are salient gaps in the literature, particularly when it comes to the transition from childhood to young adulthood (middle and high school students) and middle and older adulthood. Although there is a sizable literature on older adult vocal production, this research tends to focus on voice disorders as opposed to accuracy in pitch matching.[19–22]

Research reported here was designed to address these shortcomings by analyzing singing behavior from a large online sample with a wide range of ages. All participants completed the same standardized measure, the Seattle Singing Accuracy Protocol (SSAP).[23] Tasks in the SSAP were determined by a team of researchers at a workshop held in Seattle in 2013 and were designed to offer a comprehensive assessment in a minimal timeframe.[24] The online version was launched in 2015 and advertised via social media. The central tasks in the protocol, which I focus on here, involve the vocal imitation of pitches and short melodies based on a vocal model, singing in a key based on a comfortable pitch range for the participant.[25] Other recent test batteries for singing accuracy rely on similar measures.[5,26,27]

A recent article reported the distribution of singing accuracy and correlations with singing accuracy for a large sample of individuals taking the SSAP between 2015 and 2018.[7] The present report includes a deeper analysis of the effects of age, a preliminary analysis of which was reported in that article. The analysis reported here was designed to test whether changes in singing accuracy associated with age cohere with general theories of plasticity during early years[28–30] and age-related deficits later in life.[31,32] In addition, associations between singing accuracy and related tasks in the SSAP may be used to test fluctuations in the differentiation or dedifferentiation of cognitive processes, given that neural (though possibly not behavioral) dedifferentiation is proposed to be a source of cognitive decline.[33–35]

Following an analysis designed to chart the trajectory of singing accuracy with age for the whole sample, further analyses are presented that are designed to address in greater detail the association of age-related changes in singing accuracy with musical training, gender, pitch discrimination, and self-assessment. Previous research suggests that practice may have considerable effects on singing accuracy among children[36] and young adults,[37] but, to my knowledge, no point of comparison across age groups has been made with respect to the effects of experience. Likewise, previous evidence suggests girls take part in singing more than boys past early childhood in many cultures due to the effects of gender stereotyping,[38] but to date, no broad-based study to my knowledge has assessed gender differences in singing accuracy.

## METHOD

### Participants

Participants were 632 volunteers who completed the online SSAP between September 2015 and April 13, 2018, as was also reported in Ref. 7. All recordings were checked for basic recording quality and appropriate compliance of participants with instructions. The sample was global in scope, with the largest groups coming from the United States and Denmark ($n$ = 411 and 127, respectively). Participants self-reported the gender of their singing voice as male or female to determine the best vocal model ($n$ = 383 females, $n$ = 249 males, 61% female), although all participants under the age of 12 were given a female vocal model, which is best suited to child voices of either gender (and was appropriate for eight male participants in this sample who fit this category based on an assessment of vocal timbre and comfortable range). Participants reported years of formal musical training, which ranged widely (0–55 years, M = 5.37, SD = 8.47), although nearly half of the participants reported no formal training ($n$ = 292, 46%). Likewise, ages ranged widely for the sample (6–99 years, M = 30.83, SD = 16.31), although a large subset fell within the years generally associated with college education (18–22 years, 29% of the sample).

### Procedure

The SSAP includes five subtests: (1) vocal warmup and comfortable key selection, (2) imitative pitch matching and melody production, (3) singing of familiar songs, (4) adaptive pitch discrimination, and (5) self-report measures. I focus on analyses of (2), which is the most critical section for measuring singing accuracy, and its relationship to demographic measures in subtest (5) related to age, gender, musical background, and self-assessments.

Pitch imitation trials incorporated a call-and-response procedure in which the participant would first hear a target stimulus and then see a visual cue (a flashing image of the word “record”) directing the participant to start imitating that sequence using the syllable “doo” for each note. The participant terminated recording on each of these trials by hitting enter. Target sequences were of three types: imitation of single vocal pitches, imitation of single piano pitches, and imitation of four-note melodies based on vocal pitch. The vocal pitch models were based on recordings of two music performance majors (one male and one female) from Northwestern University’s Bienen School of Music, who produced tones without vibrato. Piano tones were recorded by Sean Hutchins at the Royal Conservatory of Canada. More details on the SASP tests are provided elsewhere.[25]

Participation was voluntary and occurred at a time and place of the individual’s choosing; participants were encouraged to complete tasks in a private, quiet environment. The protocol only works on computers (not smartphones or tablets), using browsers that allow use of the computer microphone for voice recognition: Chrome, Firefox, and Opera. The SSAP performs automated scoring of singing and pitch discrimination tasks, and presents results to each participant after completion of the protocol. Personal identifiers, such as names, date of birth, and computer IP address, were not collected. This procedure was done with the ethical approval of the Institutional Review Boards of the University at Buffalo and Northwestern University.

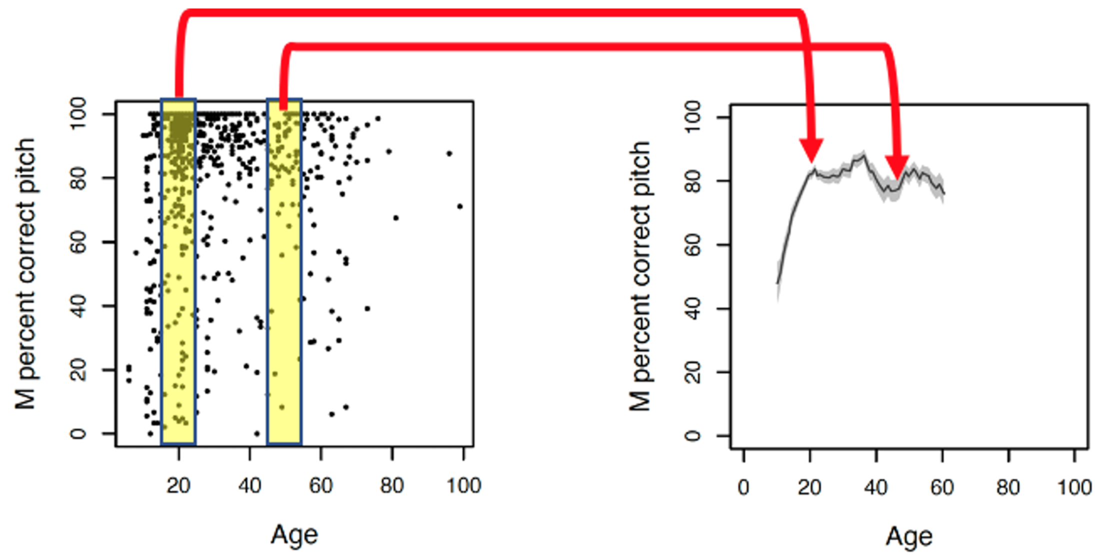


**FIGURE 1** Association between pitch accuracy in singing (*y*-axis) and age (*x*-axis), illustrating the analysis process. Left panel: The initial data set, with a datapoint for every participant. Shaded areas highlight two 10-year windowed regions (one centered at age 20, one at age 50). Right panel: Solid line shows the moving average for a 10-year period plotted for the age midpoint of each window (*x*-axis) and the mean percent of correctly imitated pitches (*y*-axis) for participants in the window. The shaded region displays the standard error of the mean for each window. Red arrows show means and standard errors corresponding to shaded areas in the left panel.

## Data analysis

The dependent variable used here was the proportion of correctly matched pitch in the imitation subtest of the SSAP. The automated procedure for this analysis runs using custom-made programs in Matlab. First, the trajectory of the fundamental frequency ($f_0$) over time was extracted using the function Yin.[39] Artifacts in pitch extraction that lead to octave errors were detected and corrected based on sudden transitions between adjacent samples of more than a half octave. For trials involving the imitation of four-note melodies, tone onsets were determined based on fluctuations in the amplitude envelope associated with syllable onsets. Sung pitches within boundaries were based on the median $f_0$ for the middle quartile of sampled pitches; sung pitches were categorized as correct if they fell within +/− 50 cents (a half semitone) of the target pitch based on equal-tempered tuning, or as an error if they fell outside these boundaries.

The primary goal of this study was to address how singing accuracy changes across the lifespan, and how these changes may be mediated by environmental factors related to musical training (years of private lessons on any instrument and/or voice) and gender. An analysis of singing accuracy by age was reported previously;[7] however, the large and variable sample made it hard to visualize the underlying relationship. Analyses reported here, therefore, adopted a moving window procedure to represent the relationship more clearly.

The window was based on a 10-year range; initial analyses suggested that this size provided the optimal reduction of noise while still showing changes in the relationship with optimal precision. For each center age, the mean and standard error across all participants within that window are computed. Figure 1 illustrates the process relating the raw scatterplot (left panel) to means and standard errors from the moving window (right panel), with two windows highlighted for illustrative purposes. Note that the end points of the moving window analysis do not span the entire range of ages in the original sample in order to ensure reasonable sample sizes at each point.

# RESULTS

Figure 2A illustrates the change in singing accuracy with age, adjusting *x*- and *y*-axis limits in order to see the relationship clearly. There was a dramatic improvement in singing accuracy with age from childhood until young adulthood. After this point, accuracy appears to reach a plateau, with only modest fluctuations in singing accuracy for the remainder of years sampled. Two points worth noting from this result are the absence of decrements associated with the onset of adolescence, and only minimal evidence for age-related decline. Sample sizes differed across means, as shown in Figure 2B. As noted above, the largest group in this sample comprised college-aged participants. However, reasonably large sample sizes were associated with all windows. The smallest sample was for the youngest group, midpoint age = 10, with $n = 22$. The second smallest sample was for a midpoint age = 60, with $n = 43$.

A major goal of this work is to address the interaction between maturational processes associated with age and more strongly environmental factors, such as acquired musical training. The role of training is an obvious question when interpreting the results in

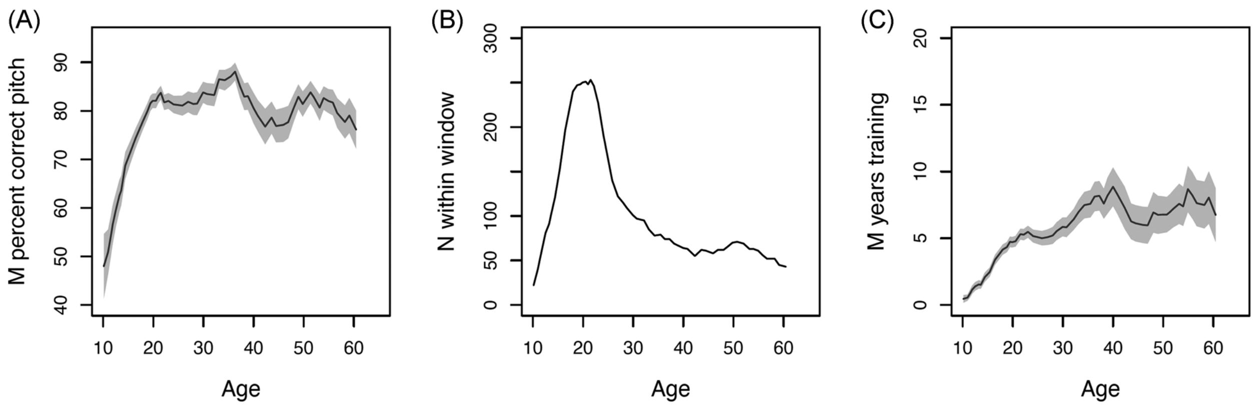


**FIGURE 2** (A) Association between pitch accuracy in singing (*y*-axis) and age (*x*-axis) based on a moving window as in Figure 1 (left). (B) Sample size for each mean in the moving window. (C) Association between mean years of training (*y*-axis) by age (*x*-axis), subjected to the same moving window analysis.

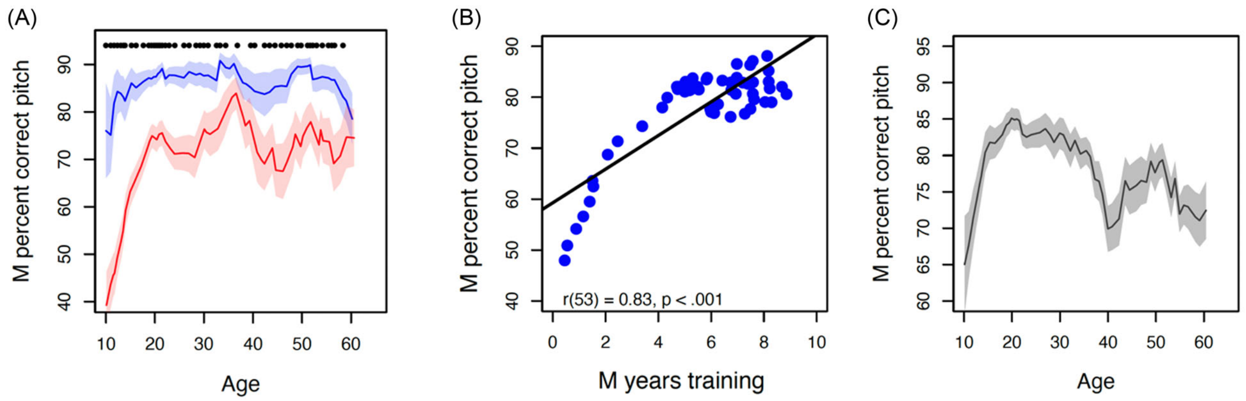


**FIGURE 3** (A) Association between pitch accuracy in singing (*y*-axis) and age (*x*-axis) based on a moving window for participants reporting no formal musical training (red), and those reporting at least 1 year of musical training (blue). Black dots at top of panel highlight windows associated with a significant difference between groups ($p < 0.05$, two-tailed). (B) The association between mean years of training and singing accuracy across all participants, midpoint age of the moving window is the parameter. (C) Association between pitch accuracy and age for all participants, after the relationship in panel B is removed from pitch accuracy via linear detrending.

Figure 2A because the years exhibiting dramatic improvement are also years associated with early musical development. Figure 2C plots a moving window analysis applied to years of formal musical training across age, which can be compared directly to the results in Figure 2A. In contrast to the relationship between age and singing accuracy, the relationship between age and years of formal training exhibited a more gradual pattern of increase, with a shallower slope in early years than is evident for singing accuracy. Nevertheless, there may be a considerable contribution from musical training to singing accuracy, as well as age, and I turn to analyses that pursue this question further.

First, I separated participants in the sample who reported no formal training (here defined as private lessons on an instrument or in voice) to those reporting one or more years of training, which led to fairly equal subsets as described in the Participants section. Figure 3A displays moving window plots of the relationship between singing accuracy and age separately for each group. As can be seen, the dramatic increase was present for participants with no formal musical training. In fact, the presence of musical training considerably reduced the rate of improvement in childhood because singing accuracy in this group was comparable to that of young adults. Although the benefits of training were most apparent early in life, the difference across groups remained consistent for virtually every subset in the moving window analysis, and the difference across groups was significant for almost every window. A subsequent analysis verified that an advantage of training can also found for young adults and older adults when the musically trained sample is limited to those who consider themselves primarily instrumentalists rather than vocalists and have only instrumental formal training, although vocal (as opposed to strictly instrumental) training had the strongest impact on performance. See the Supplementary Results (available online) for details of these analyses.

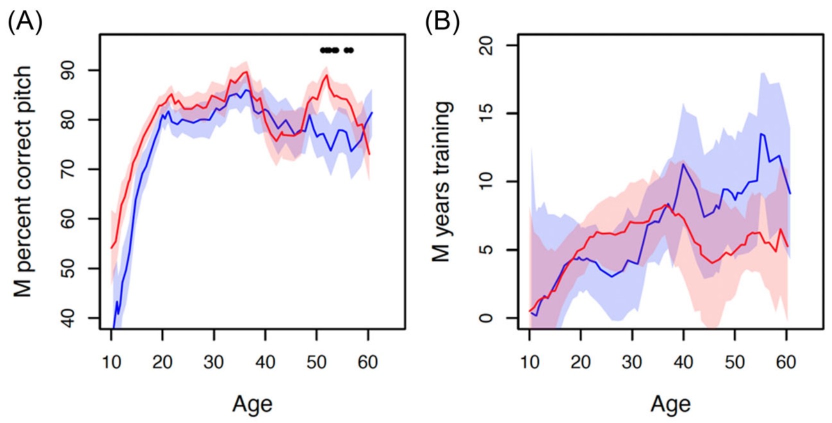


**FIGURE 4** Comparison between self-reported male participants (blue) and self-reported female participants (red). (A) Association between pitch accuracy in singing (*y*-axis) and age (*x*-axis) based on a moving window. Black dots at top of panel highlight windows associated with a significant difference between groups ($p < 0.05$, two-tailed). (B) Association between mean years of training and age, for those participants reporting at least 1 year of instrumental training.

I further addressed the mediating effect of musical training across all participants using regression analyses. Figure 3B shows the association between musical training and singing accuracy, where age for the moving window midpoint is the parameter. Detrended singing accuracy scores were computed by taking the residuals from the regression line and adding the grand mean for singing accuracy to each datapoint. The adjusted means and standard errors are shown in Figure 3C. This plot represents the relationship between age and singing accuracy that is independent of the linear association with training. As can be seen, the steep increase in singing accuracy from childhood to young adulthood was still present, and accuracy remained high through adulthood. However, accuracy diminished considerably in middle age and older adulthood, in contrast to Figure 2A, suggesting that musical training plays a part in sustained high singing accuracy for these age groups.

I also addressed whether differences in accuracy may be found for participants identifying as male versus female. Differences as a function of gender are displayed in Figure 4A. Although a slight advantage for girls seems to be present at early childhood, none of these differences were statistically significant, and the only significant differences were found for a few windows among older adults. As can be seen in Figure 4B, musical training was highly variable in each gender group, with no significant differences. Thus, in this sample, there seem to be no reliable differences across genders, and both groups follow similar age-related trajectories.

The SSAP also includes an adaptive pitch discrimination test that generates an estimate of an individual's pitch discrimination threshold, a measure of perceptual resolution. Previous studies have shown modest correlations across individuals between pitch discrimination and singing accuracy that are often nonsignificant for relatively small samples,[6,40] but significant for larger samples.[16,41] Figure 5A shows changes in pitch discrimination with age for each window, as in other analyses. Similar to singing accuracy, dramatic improvements (lowering of threshold) occurred early in life, followed by a plateau through adulthood. There was no apparent age-related decline. Changes in pitch discrimination with age are strongly correlated with changes in singing accuracy, $r(53) = -0.91$, $p < 0.001$ (Figure 5D), largely due to the correlated dramatic changes before adulthood. This correlation, where age is the parameter, was far stronger than correlations reported in which participant is the parameter (e.g., Ref. 16).

Previous research also suggests that individual self-assessment of musical talent (as conceptualized by the participant) and singing ability correlates with singing accuracy across individuals;[7,42] the associations of these self-report measures with age are shown in Figure 5B,C, respectively. In contrast to pitch discrimination, the pattern of change in self-report measures with age did not follow a similar trajectory to singing accuracy, and each showed a drop for older adults that contrasts with singing accuracy. It is not surprising then that correlations of these measures with singing accuracy, shown in Figure 5E,F, were nonsignificant. Thus, unlike individual differences, differences associated with age in self-report were not associated with changes in singing accuracy.

Of course, each datapoint in the scatterplots shown in Figure 5D–F represents an average of *n* paired measurements. Correlations, therefore, may be assessed within each datapoint and are informative in their own right. As discussed in the Introduction, lifespan development theories suggest a pattern of change with increasing specialization from childhood to young adulthood, leading to lower correlations, followed by dedifferentiation in older adulthood, leading to higher correlations. These changes may be reflected in a pattern of change in correlations across ages. Figure 6 plots correlation coefficients for paired data within each window as a function of the mean age for that window. Note that each coefficient that is plotted is parameterized by individual (i.e., each dot reflects the correlation for *n* individuals within a window). Filled circles in each panel represent significant correlations ($p < 0.05$). Correlations between pitch discrimination and age (Figure 6A) were significantly negative (as is the case across age), but diminished in magnitude, becoming nonsignificant, for older adults, leading to a significant positive correlation between coefficient values and age, $r(53) = 0.64$, $p < 0.001$. Note that this association is not consistent with theories of dedifferentiation in older adults, which should lead to significant associations for that age group. Similar analyses on the two self-report measures also yielded changes in the magnitude of correlation with age, but in different directions (correlation of singing accuracy with self-assessed talent, $r(53) = -0.32$, $p = 0.018$; with self-assessed singing, $r(53) = 0.73$, $p < 0.001$). Moreover, all correlations were significant. Ultimately, it appears that self-report measures vary with singing accuracy by individual, but do not exhibit reliable associations as a function of age.

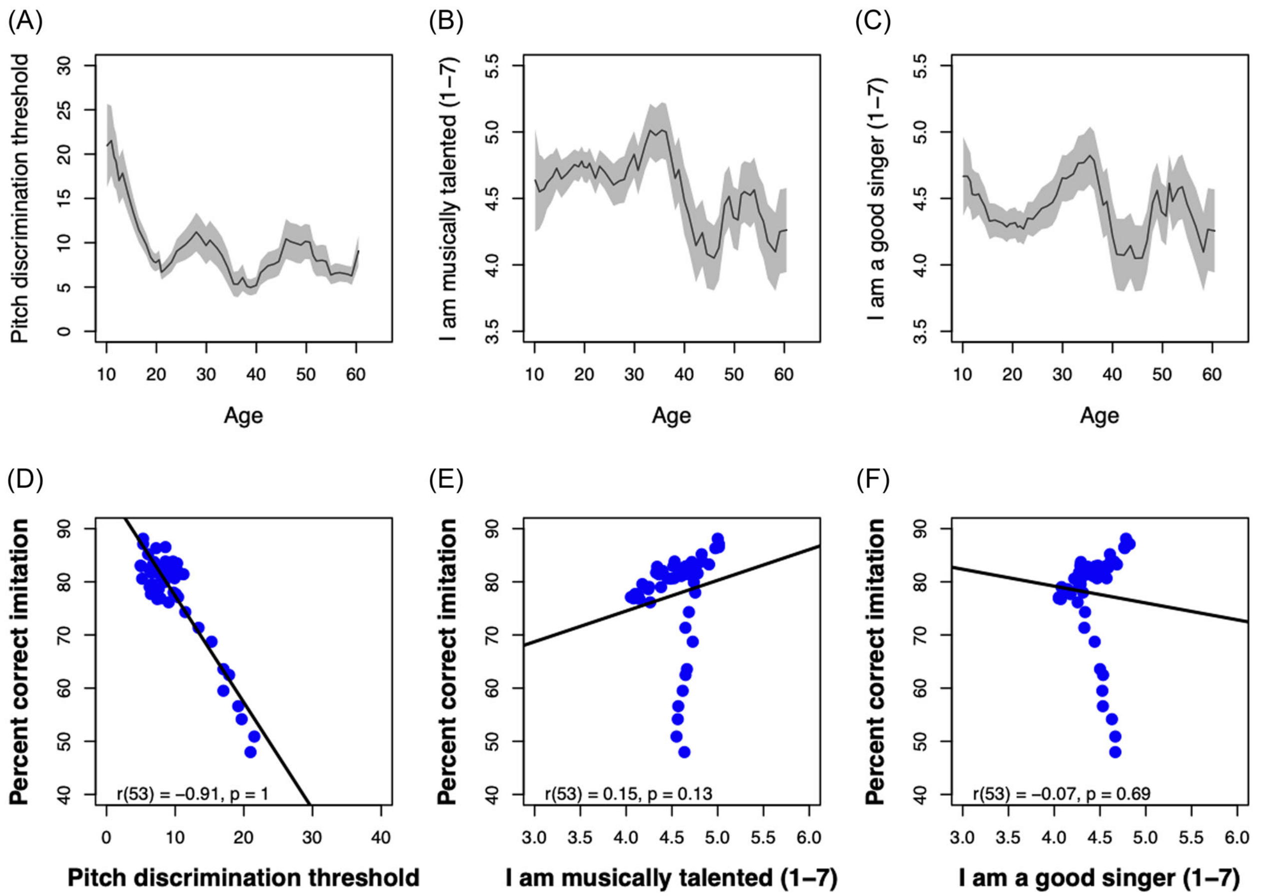


**FIGURE 5** (A–C) Moving window analyses for pitch discrimination thresholds (A), self-report of musical talent (B), and self-report for belief that one is a good singer (C), structured as in Figure 1A. (D–F) Scatterplots showing the regression of singing accuracy (from Figure 1A) and the ordinate measure from the corresponding column of the upper row. Age window is the parameter in each regression.

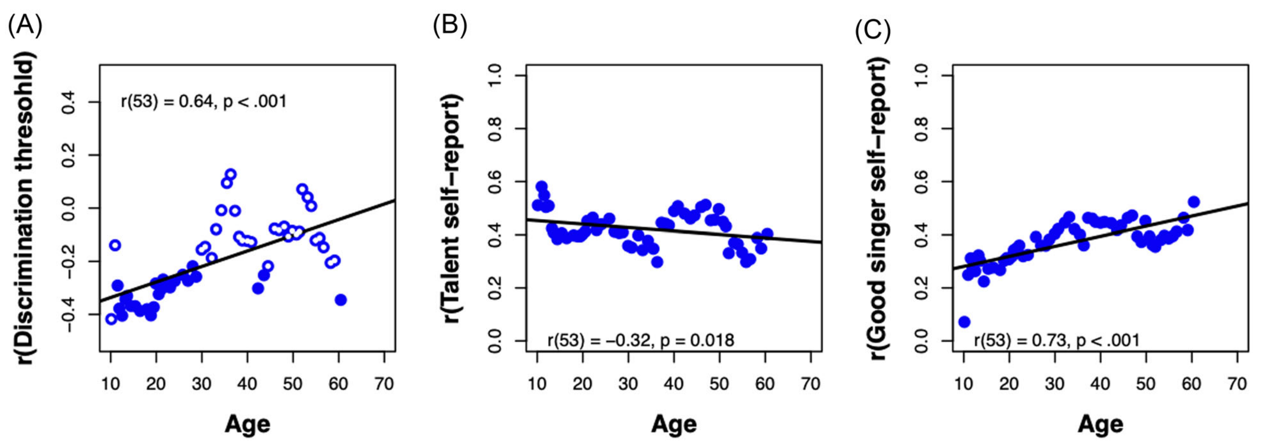


**FIGURE 6** Plots showing correlation coefficients based on individual differences within each window, as a function of age. Degrees of freedom for each point are based on the sample size shown in Figure 2B. Filled circles represent significant correlations at $p < 0.05$, two-tailed.
(A) Correlations between singing accuracy and pitch discrimination threshold. (B) Correlations between singing accuracy and self-assessment of musical talent. (C) Correlations between singing accuracy and self-assessment of good singing.

## DISCUSSION

The analyses reported here shed new light on how the accuracy of pitch matching via singing ("singing accuracy") changes across the lifespan. Data from a large sample with ages spanning 6–99 years old who completed a standardized test battery (the Seattle Singing Accuracy Protocol, SSAP) were analyzed using a moving window with a 10-year width in order to estimate the underlying developmental trajectory. Dramatic increases in accuracy were apparent from early childhood until early adulthood (around age 20), with accuracy from that point effectively reaching a plateau into later adulthood. Neural plasticity in childhood was thus apparent in these data, though not age-related decline. Musical training was associated with consistently high performance across the lifespan, with particularly dramatic effects for children, and may have had some role in staving off effects of age-related decline. No evidence of gender differences was apparent.

Age-related changes in pitch discrimination and self-assessed ability, also part of the SSAP, were submitted to a similar moving window analysis and yielded diverging results. Pitch discrimination thresholds changed with age in a manner similar to singing accuracy, with dramatic improvement up to young adulthood and reliably consistent accuracy from that point. In contrast, self-assessments of musical talent and singing ability formed a pattern of change across age that was independent of singing accuracy, with older adults reporting lower assessments than those younger, but no strong pattern of change through childhood. Thus, in contrast to significant correlations between self-assessment and singing accuracy across individuals, these variables do not follow similar age-related trajectories.

These results are consistent with models of singing that emphasize sensorimotor learning and associations between perception and action,[10,14,43] as opposed to models that emphasize the role of muscle coordination.[15,44] Three characteristics of the results are critical in this respect. First is the absence of any disruptive effects during the time of adolescent voice change, or the loss of vocal muscle control in older adulthood. Both of these periods yield noticeable effects on vocal timbre, and difficulty regulating vocal motor control, but little effect on accuracy of pitch matching according to the present data, even among occasional (untrained) singers. Second, the fact that training had large effects on accuracy, while gender had negligible effects, is likewise consistent with prior accounts based on sensorimotor learning. Third, the association with pitch discrimination replicates other data sets that have been interpreted as supportive of sensorimotor accounts.[16] Clearly, more needs to be done to understand the relative contribution of vocal motor control. I am not here denying the importance of this complex ability, though the present data suggest that other factors may play a more important role in age-related changes.

The lack of age-related deficits in singing accuracy contrasts sharply with performance in other cognitive domains.[32] Although the present data do not speak directly to these differences, possible explanations exist that may be pursued in subsequent research. First, the fact that music production is based on regular, rhythmic timing may cause music production to remain accurate into adulthood. Previous work on sensorimotor synchronization suggests that temporal deficits found in speeded tasks may not generalize to synchronization tasks based on one's optimal period.[45] Second, the engaging and emotionally arousing nature of music may lead to relatively better spared recall of musical stimuli. For instance, other studies suggest that older adults with dementia may not exhibit similar deficits for musical recall.[46]

This is the first study I know of to address changes in singing accuracy across the lifespan with a standardized measure, and as such, there is room for improvement in subsequent research in many respects. First, although the online measure provided a way to include participants from around the world, there was considerable bias in which cultures participated. The most prevalent countries in the data set were the United States and Denmark, both highly industrialized and wealthy Western nations. A better effort to broaden the scope of this investigation, along with materials that are more accessible across cultures, would provide more generalizable data. Second, the fact that this sample volunteered to participate probably led to higher performance than a more random sample. A recent comparison between college students completing the SSAP for course credit and participants from similar ages who took the SSAP voluntarily found higher performance in the latter sample that went beyond effects of musical training.[7] Finally, the inclusion of other cognitive measures as a basis for comparison with measures included in the SSAP would allow a deeper consideration of the association between music ability and other cognitive functions across the lifespan, and could provide tools for music educators seeking to facilitate performance among child singers who struggle with accuracy.

Ultimately, the present results support a view that singing accuracy develops as a form of sensorimotor learning that is influenced by maturational and environmental factors early in life. Unlike other skilled behaviors, singing accuracy may remain relatively stable later in life, which may be part of the reason why singing can be such a rewarding activity for older adults.[47]

### ACKNOWLEDGMENT

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### COMPETING INTERESTS

The author declares no competing interests.

### PEER REVIEW

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## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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