LETTERS TO THE EDITOR

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Absolute pitch is associated with a large auditory digit span: A clue to its genesis (L)

Diana Deutsch[a)] and Kevin Dooley
Department of Psychology, University of California, San Diego, La Jolla, California 92093

(Received 18 September 2012; revised 19 January 2013; accepted 24 January 2013)

Auditory and visual digit span tests were administered to a group of absolute pitch (AP) possessors, and a group of AP nonpossessors matched for age, and for age of onset and duration of musical training. All subjects were speakers of English. The AP possessors substantially and significantly outperformed the nonpossessors on the auditory test, while the two groups did not differ significantly on the visual test. It is conjectured that a large auditory memory span, including memory for speech sounds, facilitates the development of associations between pitches and their verbal labels early in life, so promoting the acquisition of AP. © *2013 Acoustical Society of America*. [http://dx.doi.org/10.1121/1.4792217]

PACS number(s): 43.75.Cd [JW] Pages: 1859–1861

I. INTRODUCTION

Absolute pitch (AP)—the ability to name or produce a note of particular pitch in the absence of a reference note—is extremely rare in America and Europe, with its prevalence estimated as less than one in 10 000 (Takeuchi and Hulse, 1993). However, its genesis is unclear, and this has recently been the subject of considerable debate (Deutsch, 2013). Attempts to acquire AP through extensive practice in adulthood have produced negative or unconvincing results (Ward, 1999). Further, the probability of acquiring this ability has been found to be highest for those who had begun musical training at or before age 5, to decrease with increasing age-of-onset of training, and to be extremely low for those who had begun training at age 10 or later (Baharloo *et al.*, 1998; Deutsch *et al.*, 2006, 2009; Gregersen *et al.*, 1999). Indeed, the timetable for acquiring AP is remarkably similar to that for acquiring speech, which suggests that the two capacities are subserved by a common brain mechanism (Deutsch *et al.*, 2004). Further supporting the connection between AP and speech, studies have shown that the prevalence of AP is very high among musicians who are speakers of tone languages such as Mandarin, and so would have learned to associate pitches with verbal labels very early in life (Deutsch, 2013; Deutsch *et al.*, 2006, 2009; Lee and Lee, 2010).

However, the question still remains of why, among speakers of nontone languages such as English, a few individuals with early onset of musical training acquire AP while most others, with equivalent age-of-onset and duration of musical training, do not acquire this ability. A number of studies have pointed to a linkage between AP possession and an unusual neural circuitry underlying speech processing. Of particular importance is the left planum temporale (PT)—a region in the temporal lobe that corresponds to the core of Wernicke's area, and is critically involved in speech. The PT is leftward asymmetric in most human brains (Geschwind and Levitsky, 1968) and this asymmetry is greater among AP possessors than among nonpossessors (Schlaug *et al.*, 1995; Zatorre *et al.*, 1998; Keenan *et al.*, 2001). AP possessors also show enhanced activation in the left PT and surrounding areas while performing a speech processing task (Oechslin *et al.*, 2010). Furthermore, AP possessors have heightened connectivity of white matter between regions in the left temporal lobe that are considered responsible for categorization of speech sounds (Loui *et al.*, 2011). Given these speech-related neuroanatomical differences between AP possessors and nonpossessors, differences in neural circuitry subserving memory for speech sounds might also exist.

Based on these considerations, the present study was designed to test the hypothesis that AP possessors who speak a nontone language have an unusually large auditory memory span, including memory for speech sounds; this could facilitate the development of connections between pitches and their spoken labels early in life, so promoting the acquisition of AP. To test this hypothesis we used the digit span, which measures how many digits a person can hold in memory and immediately recall in correct order. Since other studies have found that musical training is associated with enhanced memory for spoken words (Chan *et al.*, 1998; Ho *et al.*, 2003; Tierney *et al.*, 2008) as well as other cognitive and perceptual aspects of speech processing (Musacchia *et al.*, 2008) the digit spans were tested of both a group of AP possessors and also a control group of AP nonpossessors with equivalent age-of-onset and duration of musical training.

[a)]Author to whom correspondence should be addressed. Electronic mail: ddeutsch@ucsd.edu

 0001-4966/2013/133(4)/1859/3/$30.00

II. METHOD

A. Subjects

Twenty-seven adults grouped as AP possessors and nonpossessors served in the experiment, and were tested individually. These were current or former undergraduates at the University of California, or graduate students at the University of California. All subjects reported that they had normal hearing, and no history of neurological disorders; all spoke English as their primary language, and none spoke a tone or pitch-accent language. They were initially recruited by advertisement and word of mouth, the AP possessors on the basis of self-reporting AP, and the AP nonpossessors on the basis of early onset of musical training. All potential subjects were initially administered the test for AP described below. Seven subjects (6 male, 1 female) scored at least 83% on the test, not allowing for semitone errors; these formed the group of AP possessors. Their average age was 25.4 years (range 20–31), their average age of commencement of musical training was 4.1 years (range 3–6), and they had received an average of 18.6 years (range 10–26) of musical training. A further 20 subjects (7 male, 13 female) scored less than 20% on the test; these formed the group of AP nonpossessors. Their average age was 24.6 years (range 19–34), their average age of commencement of musical training was 5.1 years (range 3–6) and they had received an average of 17.3 years (range 11–25) of musical training. The two groups did not differ statistically in age [$t(25) = -0.40$, $p > 0.05$], onset of training [$t(25) = 2.03$, $p > 0.05$], or duration of training [$t(25) = -0.58$, $p > 0.05$]. The subjects were paid for their participation.

B. AP test

The test for AP was the same as had been employed in the studies of Deutsch *et al.* (2006, 2009). The subjects were presented with the set of 36 notes that spanned the three-octave range between C_3 (131 Hz) and B_5 (988 Hz), and they wrote down the name of each note (C, C#, D, and so on) when they heard it. The notes were presented in quasi-random fashion, the only constraint being that in order to minimize the use of relative pitch as a cue, the successively presented notes were separated by an interval larger than an octave. The stimuli were piano tones that were generated on a Kurzweil K2000 synthesizer tuned to $A_4 = 440$ Hz, recorded onto a Zoom H2 digital audio recorder, and presented to subjects via Sony MDR-7506 dynamic stereo headphones, at a level of approximately 72 dB sound pressure level (SPL). The tones were 500 ms in duration, and were separated by 4.25 s inter-onset intervals. No feedback was provided at any time during the test.

C. Digit span tests

The auditory digit span test was administered first, followed by a break, and then by the visual digit span test. This fixed order was adopted since the hypothesis being tested was that AP possessors would have a larger auditory digit span than nonpossessors, while there was no hypothesis with respect to the visual digit span. Given the small number of AP possessors it was important to exclude any unnecessary source of variance.

In both the auditory and the visual tests, a string of digits was presented on each trial, and the subject attempted to repeat the digits back verbally in the order in which they had occurred. The first two trials consisted of strings of six digits; the next two of strings of seven digits; the next two of strings of eight digits; and so on. The test was ended when the subject made an error on both trials containing the same number of digits.

For both the auditory and the visual tests, the stimuli consisted of strings of digits that were presented at a rate of 1/s. Strings consisting of six to twelve digits were constructed. Within each string, the digits were chosen at random from 0 to 9 without replacement (except that for strings of 11 and 12 digits, one or two digits occurred twice in random positions within the string).

For the auditory test, the digits were recorded by a female speaker into an iMac computer using an AKG C 1000 S microphone placed roughly 8 in. from the speaker's mouth, and saved as WAV files at a sampling rate of 44.1 K. They were adjusted to occur at a rate of 1/s, and normalized for amplitude, using the software package BIAS PEAK PRO version 6.0. They were then transferred onto a Zoom H2 digital audio recorder, from which they were presented to subjects via Sony MDR-7506 dynamic stereo headphones, at a level of approximately 72 dB SPL. For the visual test, the digits were 2 in. × 1 in. in size. They were presented on a 15 in. Macbook Pro monitor, with each successive digit at the center of the screen. Following the digit span tests, the subjects filled out a questionnaire describing their musical training, where they had lived, and the languages that they spoke.

III. RESULTS

For both digit span tests, the subject's score was taken as the largest number of digits that he or she had repeated back correctly at least once. The results are displayed on Fig. 1. It

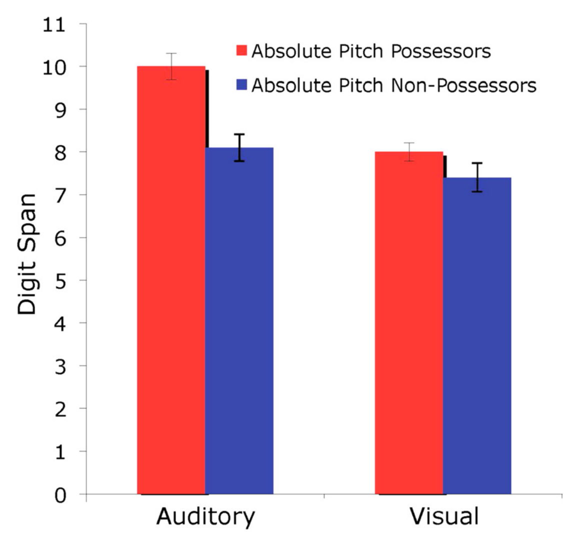

FIG. 1. (Color online) Average scores on the auditory and visual digit span tests, produced by absolute pitch possessors and by nonpossessors, with the two groups matched for age, and for age-of-onset and duration of musical training.

can be seen that for the auditory test, the AP possessors outperformed the nonpossessors on average by almost two digits: While the average digit span for the AP nonpossessors was 8.1, it was 10.0 for the AP possessors. The effect of gender was initially tested and found to be nonsignificant ($F < 1$). A two-way analysis of variance (ANOVA) was performed on the scores from this test, with AP possession and education level (whether or not the subject had an undergraduate degree) as factors. The effect of AP possession was highly significant [$F(1,23) = 12.58$, $p = 0.002$, $\eta^2_{\text{partial}} = 0.35$]. The effect of education level was nonsignificant [$F(1,23) = 1.13$, $p = 0.30$], and the interaction between AP possession and education level was also nonsignificant [$F(1,23) = 1.13$, $p = 0.30$]. For the visual test, the two groups exhibited very similar performance. The effect of gender was initially tested and found to be nonsignificant ($F < 1$). A two-way ANOVA was performed on the scores from this test, with AP possession and education level as factors. Neither effect was significant [AP possession, $F(1,23) = 1.96$, $p = 0.18$; education level, $F(1,23) = 1.61$, $p = 0.22$]; and the interaction between AP possession and education level was also nonsignificant [$F(1,23) = 1.61$, $p = 0.22$].

IV. DISCUSSION

The auditory digit span of a group of AP possessors was here found to be substantially and significantly larger than that of a control group of AP nonpossessors who were very similar in age, and in age-of-onset and duration of musical training. This finding indicates that AP is associated with an unusually large auditory memory span, including memory for speech sounds, and this in turn could facilitate the development of connections between pitches and their spoken labels early in life. The finding could therefore explain why some nontone language speakers acquire AP while most others, with equivalent age-of-onset and duration of musical training, do not do so. Interestingly, the two groups did not differ statistically on the visual digit span test, so the advantage to AP possessors was confined to the auditory modality.

An alternative explanation for our finding of a larger auditory digit span among AP possessors is that this is a result of AP possession, rather than a cause. AP possessors may draw on absolute pitch information in perceiving sounds, and this additional cue could aid in retrieving speech sounds from memory.

We note that tone language speakers were not included as subjects in the present experiment, since it was hypothesized that such persons would have acquired the neural circuitry underlying AP early in life, during the period in which they would have acquired other features of speech (Deutsch *et al.*, 2004); an explanation of AP possession involving a large auditory memory span would therefore for them be redundant. For the same reason, speakers of pitch accent languages such as Japanese were not included. However, it is possible that AP possessors who speak a tone or pitch accent language might also have an enhanced memory for spoken words. We also hypothesize that the unusually large memory span for speech sounds among AP possessors found here might have a genetic basis. Since AP possession is dependent on early musical training, this leads to the conjecture that family members of AP possessors who have not had early and extensive musical training might also have large auditory digit spans. In addition we note that the two subject populations employed in this study were well defined in terms of AP possession and non-possession, with no subjects having partial AP (or quasi-AP; Wilson *et al.*, 2009). It is possible that such rare individuals might exhibit a different pattern with respect to the digit span. These are interesting issues for future research.

ACKNOWLEDGMENTS

The authors contributed equally to this paper. We thank Miren Edelstein for help in recruiting the subjects.

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