Research Article

GOOD PITCH MEMORY IS WIDESPREAD

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Abstract—*Here we show that good pitch memory is widespread among adults with no musical training. We tested unselected college students on their memory for the pitch level of instrumental soundtracks from familiar television programs. Participants heard 5-s excerpts either at the original pitch level or shifted upward or downward by 1 or 2 semitones. They successfully identified the original pitch levels. Other participants who heard comparable excerpts from unfamiliar recordings could not do so. These findings reveal that ordinary listeners retain fine-grained information about pitch level over extended periods. Adults' reportedly poor memory for pitch is likely to be a by-product of their inability to name isolated pitches.*

Absolute pitch (AP; also called *perfect pitch*) is often viewed as a marker of musical giftedness (Takeuchi & Hulse, 1993; Ward, 1999), with an estimated incidence of 1 in 10,000. AP refers to the ability to identify or produce isolated tones in the absence of contextual cues or reference pitches. Upon awakening, for example, AP possessors can label or sing middle C (262 Hz) or concert A (440 Hz). In other words, they have long-term memory for musically relevant pitches, and they remember those pitches by name (Levitin, 1994). AP is thought to differ from other human abilities in its bimodal distribution (Takeuchi & Hulse, 1993): Either you have it or you do not. For people who do not, memory for isolated pitches is thought to fade quickly with the passage of time (Burns, 1999). According to Krumhansl (2000), "pitch memory is approximately equal for possessors and nonpossessors of AP for delays up to one minute, but only AP possessors perform above chance for longer delays" (p. 167). AP possessors do not differ from other musicians in their memory for tone frequencies that are musically irrelevant (e.g., tones outside the musical range, mistuned tones), nor do they differ in their ability to discriminate pitches or in most other musical abilities (Ward, 1999). In short, the uniqueness of AP possessors is restricted to their rapid and effortless identification and production of isolated tones.

AP is found almost exclusively among individuals who began music lessons in early childhood (Takeuchi & Hulse, 1993), which implies a *critical period* for its acquisition. In one large sample of musicians, 40% of those who began musical training before 4 years of age had AP, compared with 27% who began between ages 4 and 6 years, and 8% who began between ages 6 and 9 years (Baharloo, Johnston, Service, Gitschier, & Freimer, 1998). Although early training is the best predictor of AP, it does not guarantee AP. Genetic factors also make important contributions. For example, individuals with AP are considerably more likely than those without AP to have siblings with AP, even when amount of musical training and age of onset are taken into account (Baharloo, Service, Risch, Gitschier, & Freimer, 2000).

For normally developing children, relative pitch processing is thought to replace absolute pitch processing during the preschool years (Saffran & Griepentrog, 2001; Takeuchi & Hulse, 1993), with only a small minority (i.e., AP possessors) retaining both modes of processing. Relative pitch processing—a widespread skill—lies at the heart of music and its appreciation. For example, identifying a familiar tune (e.g., "The Star Spangled Banner"), whether it is performed at a high pitch level (e.g., sung by a soprano, played on a piccolo) or at a low pitch level (e.g., sung by a baritone, played on a tuba), depends on the listener's knowledge of pitch relations. Whereas non-AP musicians share AP possessors' explicit knowledge of musical note names and pitch intervals (i.e., relations between musical notes), they do not share AP possessors' accurate memory for individual pitches (Benguerel & Westdal, 1991). Nevertheless, given one musical tone, such as C, non-AP musicians can use their knowledge of intervals to identify or generate other musical tones, such as F or G (5 or 7 semitones from C). AP possessors tend to approach such tasks on a tone-by-tone basis, reflecting their bias for absolute over relative processing. As a result, they name intervals more slowly and less accurately than do non-AP musicians, which implicates AP as a nonmusical mode of processing (Miyazaki, 1995).

In contrast to musicians with or without AP, nonmusicians cannot name any musical intervals or tones. Nonetheless, they can identify familiar melodies presented at novel pitch levels, and they notice when such melodies are performed incorrectly (Drayna, Manichaikul, de Lange, Snieder, & Spector, 2001), which confirms the accuracy of their implicit memory for pitch relations. There is speculation that the higher-than-usual incidence of AP in autistic and developmentally delayed populations (Heaton, Hermelin, & Pring, 1998; Heaton, Pring, & Hermelin, 1999; Lenhoff, Perales, & Hickok, 2001a, 2001b; Mottron, Peretz, Belleville, & Rouleau, 1999; Young & Nettlebeck, 1995) stems from deficient relational processing (Ward, 1999). These atypically developing individuals may fail to generalize song-defining pitch relations across pitch levels (e.g., the first four tones of "Twinkle Twinkle Little Star" can be CCGG, DDAA, EEBB, and so on, with the last two tones being 7 semitones higher than the first two).

Our goal in the present investigation was to demystify the phenomenon of AP by documenting adults' memory for pitch under ecologically valid conditions. We hypothesized that the reportedly poor pitch memory of ordinary adults is an artifact of conventional test procedures, which involve isolated tones and pitch-naming tasks. Isolated tones are musically meaningless to all but AP possessors, and pitch naming necessarily excludes individuals without musical training. Much recent research focuses on knowledge acquired without explicit awareness (e.g., Goshen-Gottstein, Moscovitch, & Melo, 2000; Reber & Allen, 2000; Tillman, Bharucha, & Bigand, 2000). Thus, the absence of explicit memory for pitch level does not preclude relevant implicit knowledge. We also expected that implicit memory for pitch, like most other human abilities, would be normally distributed rather than bimodally distributed.

Previous indications that nonmusicians retain in memory some sensory attributes of music arise from studies that have included meaningful test materials (Bergeson & Trehub, 2002; Halpern, 1989; Levitin & Cook, 1996; Palmer, Jungers, & Jusczyk, 2001; Schellenberg,

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Iverson, & McKinnon, 1999). For example, college students with limited musical training can identify familiar recordings of popular songs (i.e., songs heard previously at the same pitch level, tempo, and timbre) from excerpts as short as 100 ms (Schellenberg et al., 1999). Such brief excerpts preclude the use of relational cues, forcing listeners to rely on absolute features from the overall timbre or frequency spectrum. When adults sing hit songs from recordings heard repeatedly, almost two thirds of these productions are within 2 semitones of the recorded versions (Levitin, 1994), and their tempo (speed) is within 8% of the originals (Levitin & Cook, 1996). Adults show similar consistency in pitch level and tempo when they sing familiar songs from the folk repertoire (e.g., "Yankee Doodle") on different occasions, even though they would have heard these songs at several pitch levels and tempi (Bergeson & Trehub, 2002; Halpern, 1989).

Although the song-production data (Bergeson & Trehub, 2002; Halpern, 1989; Levitin, 1994) imply accurate pitch memory, the contributions of cognitive and motor factors are inseparable in these studies. For example, movement patterns associated with song production (i.e., motor memory) may be implicated. Moreover, the limited pitch range of musically untrained individuals may generate pitch consistency that has little to do with memory. Nonetheless, the findings highlight the potential of familiar materials to reveal nonmusicians' memory for acoustic features.

We tested memory for the pitch level of musical recordings heard frequently at one pitch level only. We expected that contextually rich materials would reveal the generality of long-term memory for pitch and the normal distribution of this ability. In Experiment 1, adult listeners heard excerpts from highly familiar recordings. On each trial, the same instrumental excerpt was presented twice, once at the original pitch level and once shifted upward or downward in pitch by 1 or 2 semitones. Participants attempted to identify which excerpt (the first or the second) was presented at the correct pitch level, that is, the only pitch level at which they had heard the recording previously. Experiment 2 was identical except that a different group of listeners made judgments about unfamiliar recordings that were pitch-shifted by 2 semitones. In other words, it was a "control" experiment designed to ascertain whether factors other than pitch memory (e.g., the audio manipulation, composers' use of particular keys) contribute to successful identification.

EXPERIMENT 1

Method

Participants

The participants in Experiment 1 were 48 college students. Recruitment was limited to students familiar with the six television programs from which the stimuli were excerpted. The skewed distribution of musical training (i.e., years of music lessons) was typical of college populations, with a mean of 5.1, a median of 3, and a mode of zero. None of the participants reported having AP.

Stimuli and apparatus

The recordings were instrumental excerpts from six popular television programs: "E.R.," "Friends," "Jeopardy," "Law & Order," "The Simpsons," and "X-Files" (keys of B minor, A major, E-flat major, G minor, C-sharp major, and A minor, respectively). Each recording had multiple instruments, each with multiple pure-tone components. The selection criteria were as follows: (a) popularity with undergraduates, as estimated in a pilot study, and (b) a musical theme with at least 5 s of instrumental music. The theme music was saved as CD-quality sound files on an iMac computer. For five of the six programs, the 5-s instrumental excerpt was from the beginning of the program. For "Jeopardy," the excerpt was from Final Jeopardy. In all cases, the excerpt was selected to be maximally representative of the overall recording.

The excerpts were shifted in pitch by 1 or 2 semitones with Pro Tools (DigiDesign) digital-editing software, which is used commonly in professional recording studios.[1] Pitch shifting had no discernible effect on tempo (speed) or overall sound quality. Within each semitone condition, the "incorrect" excerpt for a given musical selection was always shifted in one direction (upward for three, downward for three), to eliminate the option of selecting the middle pitch level and to ensure that correct and incorrect excerpts were presented equally often; the participants were divided into two equal groups, and the direction of pitch shifts was reversed for the two groups. Pitch shifts involved multiplying (for upward shifts) or dividing (for downward shifts) all frequencies in an excerpt by a factor of 1.12 for 2-semitone shifts and 1.06 for 1-semitone shifts. For example, a 2-semitone upward shift involved a change from 262 Hz to 294 Hz.

To eliminate potential cues from the electronic manipulation, we also shifted the pitch level of the correct excerpts. The original excerpts were shifted upward and then downward by 1 semitone (all frequencies multiplied and subsequently divided by 1.06) in the 2-semitone condition and by half a semitone (frequencies multiplied and divided by 1.03) in the 1-semitone condition. The monaural excerpts were presented binaurally over lightweight headphones while participants sat in a sound-attenuating booth. (Sample stimuli are available on the Web at www.erin.utoronto.ca/~w3psygs.)

Procedure

Participants were tested in two test sessions on different days no more than 1 week apart. The incorrect excerpts were shifted by 2 semitones in one session and by 1 semitone in the other, with order of sessions counterbalanced. The 2-semitone pitch shifts were orthogonal to the 1-semitone shifts, such that the direction of shift was reversed for half of the excerpts across sessions. Each session consisted of five blocks of six trials. Each block had one trial for each excerpt, with trials presented in random order. The first block served as a practice block. On each trial, listeners heard one version of a 5-s excerpt at the original pitch level and another version at the altered (upward or downward) pitch, with the two excerpts separated by 2 s. Order (original-altered or altered-original) was counterbalanced. Participants were told that they would hear two versions of the same theme song on each trial, with one version at the correct pitch and the other version shifted higher or lower. Their task was to identify the excerpt (first or second) at the correct (i.e., usual) pitch level. They received no feedback for correct or incorrect responses. Participants also completed a brief questionnaire about their musical background, and they provided cumulative viewing estimates for each program (i.e., lifetime viewing estimates).

1. A free version of the software (Pro Tools Free) that includes the pitch-shifting function can be downloaded from the Internet (http://www.digidesign. com).

Results

The outcome measure was the percentage of correct responses. Because order of presentation (1- or 2-semitone change first) and stimulus set (i.e., excerpts shifted upward or downward) did not affect performance or interact with other variables, they were excluded from further consideration. Performance exceeded chance levels (50% correct) for the 1-semitone comparisons (58% correct), $t(47) = 4.00$, $p < .001$, and for the 2-semitone comparisons (70% correct), $t(47) = 9.40$, $p < .001$, with superior performance on the larger shifts, $t(47) = 4.46$, $p < .001$ (see Fig. 1). (This finding was replicated with different listeners and a slightly different task: yes/no judgments for single excerpts rather than selection of one of two alternatives. Performance remained significantly above chance and commensurate with the levels in the main study reported here.) Performance on the first trial of each excerpt significantly exceeded performance on subsequent trials, which implies that increasing exposure to pitch-shifted excerpts interfered with memory for the original pitch level.

For subsequent analyses, performance was calculated across the 1- and 2-semitone conditions. As can be seen in Figure 2, the frequency distribution for performance accuracy approximated a normal curve. Performance was far from perfect, but it was remarkably consistent, with only 3 of 48 participants performing below 50% correct (binomial test, $p < .001$). Performance was not significantly correlated with musical training, $r = -.242$, $p = .952$ (one-tailed).

Differences in performance among the six excerpts were examined with a one-way repeated measures analysis of variance. The analysis revealed that some musical excerpts were identified better than others, $F(5, 235) = 5.59$, $p < .001$, with performance at 60% correct or below for some excerpts ("The Simpsons"—57%; "E.R."—60%) and above 70% for others ("Friends"—71%, "X-Files"—71%). Pair-wise comparisons revealed better performance for "Friends" and "X-Files" than for the other four excerpts, $ps < .03$, but no differences between other pairs of excerpts. For all six excerpts, performance exceeded chance levels, $ps < .03$.

Lifetime-viewing estimates for the TV programs are summarized in Table 1. For each program, the distribution of estimates was positively skewed because some individual estimates for particular programs were extremely high. (For example, "Friends" and "The Simpsons" are broadcast several times daily.) We evaluated the possibility that viewing estimates for a particular TV program predicted performance for that excerpt better than for the other five excerpts. Although the six within-program correlations (e.g., exposure to "X-Files" and pitch memory for "X-Files") were low (highest $r = .372$, $p = .005$, for "The Simpsons"; lowest $r = .074$, $p > .5$, for "Law & Order"), they were significantly higher than the 30 cross-program correlations (e.g., exposure to "X-Files" and pitch memory for "Friends"), $p = .010$ (Mann-Whitney test).

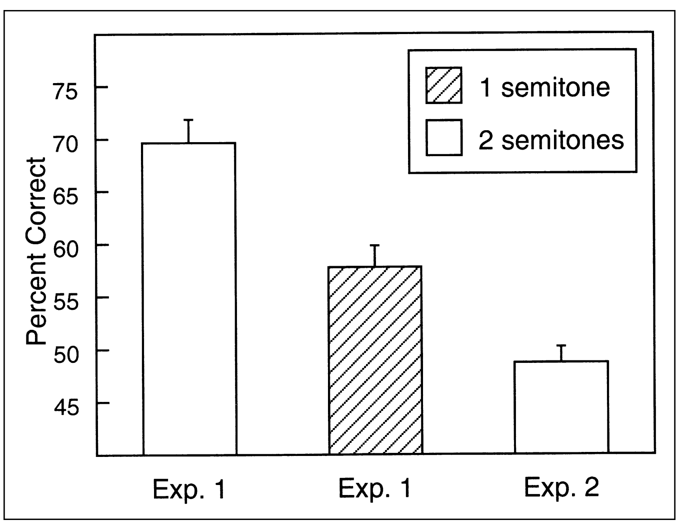

Fig. 1. Performance on excerpts pitch-shifted by 1 or 2 semitones (chance = 50%). The excerpts were familiar in Experiment 1 and unfamiliar in Experiment 2. Error bars represent standard errors.

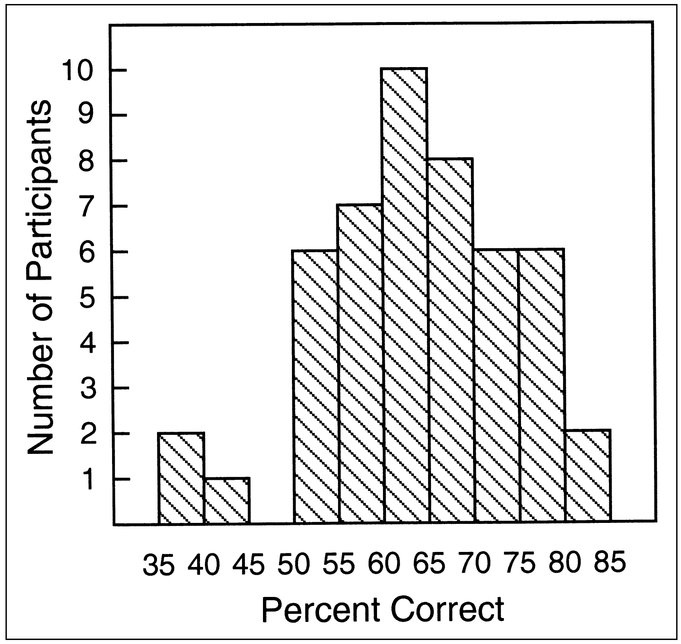

Fig. 2. Distribution of performance levels in Experiment 1 collapsed across 1- and 2-semitone pitch shifts. The distribution, which is centered markedly to the right of chance levels (50% correct), approximates the normal curve (mean = 64%, median = 65%). Scores at the boundary between two categories were grouped in the higher category.

EXPERIMENT 2

We conducted a further experiment to rule out the possibility that the results of Experiment 1 were due to singularly appropriate pitch levels for the original excerpts or to obscure electronic cues from the pitch-shifting manipulation. If either of these factors accounted for adults' ability to identify the familiar recordings in Experiment 1, then similar findings should be obtained with unfamiliar recordings.

Table 1. *Mean estimates of total number of episodes viewed for the television programs in Experiment 1*

Program	Viewing estimate
E.R.	55 (114)
Friends	337 (631)
Jeopardy	370 (1,137)
Law & Order	319 (824)
The Simpsons	1,094 (2,258)
X-Files	127 (226)

Note. Standard deviations are in parentheses.

Method

The participants were 48 college students who did not take part in Experiment 1. Recruitment was limited to students who were familiar with the six programs from the previous experiment. The method was the same as in Experiment 1 with two exceptions: (a) Musical excerpts were taken from unfamiliar recordings, and (b) there was a single test session in which excerpts at the original pitch level were paired with excerpts pitch-shifted upward or downward by 2 semitones. Participants were told that they would hear a series of trials in which a musical excerpt would be played twice, once at the original pitch level and once shifted upward or downward in pitch. Their task was to identify the correct, unshifted excerpt (first or second).

In two cases, we replaced the familiar recording from Experiment 1 with an unfamiliar recording by the same composer: The theme from "Silk Stalkings" (in C minor), an HBO police drama from the 1980s, replaced the theme from "Law & Order"; and the theme from "Gremlins" (E-flat major), a 1984 film, replaced the theme from "The Simpsons." In the other instances, the unfamiliar recordings retained the style and instrumentation of the original. A pop song, "Circle of Friends" (A major, by Better Than Ezra), replaced music from "Friends"; theme music from "Match Game" (C major), a game show from the 1980s, replaced the "Jeopardy" theme; music from Ninja Gaiden (B-flat minor), a Nintendo video game, replaced the "E.R." theme; and music from Tenchu Stealth Assassin (E-flat minor), from SONY PlayStation, replaced the theme from "X-Files."

Results

Overall performance did not differ from chance levels (49% correct) and was significantly poorer than performance in the 2-semitone condition of Experiment 1, $t(94) = 8.18$, $p < .001$ (see Fig. 1). Performance ranged from 40.1% to 55.7% correct across excerpts but did not exceed chance levels for any excerpt (ps $> .2$). Clearly, the pitch-shifting procedure did not generate cues that enabled listeners to distinguish unfamiliar, pitch-shifted excerpts from the original versions. Moreover, there was no indication that any pitch level or key, including common keys (e.g., C major, A major), was considered more appropriate than any other.

DISCUSSION

Our results provide unequivocal evidence that adults with little musical training remember the pitch level of familiar instrumental recordings, as reflected in their ability to distinguish the correct version from versions shifted upward or downward by 1 or 2 semitones. Their failure to identify the correct pitch level of unfamiliar musical recordings rules out contributions from potential artifacts of the pitch-shifting process. Long-term memory for pitch that permits successful identification of 1-semitone alterations is especially interesting for two reasons. First, musicians with AP often make 1-semitone errors (Lockhead & Byrd, 1981; Miyazaki, 1988), which raises the possibility that ordinary adults' memory for the pitch level of highly familiar music is similar to AP possessors' memory for isolated pitches. Second, 1 semitone is the smallest meaningful difference in Western music, as well as the smallest difference specified in standard musical notation. Performers may use smaller pitch deviations for expressive purposes, but no musical culture makes systematic use of intervals smaller than a semitone (Burns, 1999).

Thus, contrary to scholarly wisdom, adults with little musical background retain fine-grained information about pitch level over extended periods. This finding advances the case that music listeners construct precise memory representations of music that include absolute as well as relational features (Dowling, 1999). It also demystifies aspects of AP such as its rarity, its bimodal distribution, and the reported critical period for AP acquisition. Once pitch-naming or reproduction requirements are eliminated and familiar materials are used, memory for specific pitch levels seems to be widespread and normally distributed. It is likely that pitch naming rather than pitch memory underlies much about AP, including its apparent bimodal distribution. Pitch naming may be an all-or-none ability, but pitch memory is not. Similarly, the unique pattern of cortical activity in AP possessors (Hirata, Kuriki, & Pantev, 1999; Ohnishi et al., 2001) may reflect distinctive auditory-verbal associations—a consequence of naming—rather than distinctive pitch processing (Zatorre, Perry, Beckett, Westbury, & Evans, 1998).

Although our findings are consistent with some previous accounts, they are notable for demonstrating considerably greater accuracy in pitch memory. For example, Levitin (1994) reported that 44% of adults' sung performances were within 2 semitones of the original recording on both of two test trials. He quantized responses to the nearest semitone, however, which means that 44% of his participants were within 2.5 semitones of the original pitch. He also ignored pitch height (e.g., Cs in different octaves were considered equivalent), such that performance could deviate from the original by no more than 6 semitones. In effect, more than half of his participants were performing at chance levels (deviations of 3 semitones or more) on at least one of two trials. Our more sensitive measure of pitch memory avoids these and other limitations of production tasks.

If repeated exposure to a recording enhances memory for its pitch level, what accounts for the weak associations between exposure and pitch memory? First, self-reports of television viewing may be inaccurate. Second, individual differences associated with amount of television viewing (e.g., motivation) would complicate matters, as would factors that influence performance on standard AP tasks, such as timbre, pitch register, and pitch class (Takeuchi & Hulse, 1993). The complex association between exposure and pitch memory is exemplified by results for "The Simpsons," which had greater exposure than any other program (Table 1), the strongest association between accuracy and individual differences in exposure, and the poorest overall levels of performance. "The Simpsons" differs from the other familiar programs in that its theme music incorporates upward and downward pitch shifts (transpositions) in 2-semitone steps, which could obscure differences between the original pitch and shifts of 2 semitones or less.

We are not suggesting that the pitch-perception skills of typical college students are equivalent to those of musicians with or without AP. In general, pitch memory and the perception of pitch relations are a function of musical experience (Krumhansl, 2000). Musical training results in enhanced representation of musical features, which is reflected not only in superior performance on tests of explicit musical knowledge (e.g., naming tones, intervals, or keys; playing an instrument), but also in differential neural processing (Ohnishi et al., 2001; Pantev et al., 1998; Schneider et al., 2002). For tasks that do not depend on explicit knowledge, however, nonmusicians' abilities are surprisingly similar to those of musicians. As unfamiliar melodies unfold, trained and untrained listeners have similar expectancies about which tones will follow (Schellenberg, 1996), as do listeners of different ages (Schellenberg, Adachi, Purdy, & McKinnon, 2002). Our measure of memory for pitch level appears to be another test of implicit musical knowledge that is unrelated to musical training.

The hypothesized shift from absolute to relative pitch processing in early childhood (Saffran & Griepentrog, 2001; Takeuchi & Hulse, 1993) is at odds with our results and with considerable evidence of relative-pitch processing in infancy (Trehub, 2000). The discrepancy in experimental results could stem from the divergent procedures used for evaluating pitch processing in children and adults. Aside from the criteria for AP being applied less stringently to children than to adults, isolated pure tones—the stimuli of choice for adults—are used rarely with children. For example, children's reproduction of songs at a consistent pitch level is often offered as evidence of AP (Takeuchi & Hulse, 1993), but similar adult skills (Bergeson & Trehub, 2002; Halpern, 1989) are regarded as *residual AP* or *pseudo-AP* (Takeuchi & Hulse, 1993; Ward, 1999) rather than genuine AP. In short, the absolute-to-relative shift in pitch processing may be exaggerated or absent altogether.

On the one hand, adults outperform children on relative-pitch tasks (Schellenberg & Trehub, 1996), and adults with AP identify musical tones more accurately than do children with AP (Miller & Clausen, 1997). On the other hand, preschoolers outperform older children and adults on the acquisition and retention of labels for specific pitches (Crozier, 1997). In this respect, preschoolers are more like older autistic or developmentally delayed individuals whose cognitive inflexibility, language limitations, or focus on local rather than global details may facilitate the acquisition of pitch labels (Heaton et al., 1998, 1999). The prolonged critical period for the acquisition of AP among developmentally delayed children (Lenhoff et al., 2001b) could stem from similar factors. It is intriguing that the critical period for acquiring AP among normally developing children (before age 6 or 7) is the optimal age range for achieving nativelike phonological proficiency in a second language (Flege & Fletcher, 1992). The attentional and cognitive profile of young children may be ideally suited to rote learning, sound reproduction, and the acquisition of word-object or pitch-name associations. Why some children with early musical training acquire AP, as usually defined, and others do not may stem from genetic variations in associative abilities and from unidentified environmental factors.

In conclusion, adults with little explicit knowledge of music differ from musicians with AP, who can label isolated tones, and from musicians without AP, who can label isolated intervals. Nonetheless, the average person has rich representations of familiar music that include implicit memory for pitch level.

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REFERENCES

Baharloo, S., Johnston, P.A., Service, S.K., Gitschier, J., & Freimer, N.B. (1998). Absolute pitch: An approach for identification of genetic and nongenetic components. *American Journal of Human Genetics*, *62*, 224–231.

Baharloo, S., Service, S.K., Risch, N., Gitschier, J., & Freimer, N.B. (2000). Familial aggregation of absolute pitch. *American Journal of Human Genetics*, *67*, 755–758.

Benguerel, A.-P., & Westdal, C. (1991). Absolute pitch and the perception of sequential musical intervals. *Music Perception*, *9*, 105–120.

Bergeson, T.R., & Trehub, S.E. (2002). Absolute pitch and tempo in mothers' songs to infants. *Psychological Science*, *13*, 72–75.

Burns, E.M. (1999). Intervals, scales, and tuning. In D. Deutsch (Ed.), *The psychology of music* (2nd ed., pp. 215–264). San Diego, CA: Academic Press.

Crozier, J.B. (1997). Absolute pitch: Practice makes perfect, the earlier the better. *Psychology of Music*, *25*, 110–119.

Dowling, W.J. (1999). Development of music perception and cognition. In D. Deutsch (Ed.), *The psychology of music* (2nd ed., pp. 603–625). San Diego, CA: Academic Press.

Drayna, D., Manichaikul, A., de Lange, M., Snieder, H., & Spector, T. (2001). Genetic correlates of musical pitch recognition in humans. *Science*, *291*, 1969–1972.

Flege, J.E., & Fletcher, K.L. (1992). Talker and listener effects on degree of perceived foreign accent. *Journal of the Acoustical Society of America*, *91*, 370–389.

Goshen-Gottstein, Y., Moscovitch, M., & Melo, B. (2000). Intact implicit memory for newly formed verbal associations in amnesic patients following single study trials. *Neuropsychology*, *14*, 570–578.

Halpern, A.R. (1989). Memory for the absolute pitch of familiar songs. *Memory & Cognition*, *17*, 572–581.

Heaton, P., Hermelin, B., & Pring, L. (1998). Autism and pitch processing: A precursor for savant musical ability? *Music Perception*, *15*, 291–305.

Heaton, P., Pring, L., & Hermelin, B. (1999). A pseudo-savant: A case of exceptional musical splinter skills. *Neurocase*, *5*, 503–509.

Hirata, Y., Kuriki, S., & Pantev, C. (1999). Musicians with absolute pitch show distinct neural activities in the auditory cortex. *NeuroReport*, *10*, 999–1002.

Krumhansl, C.L. (2000). Rhythm and pitch in music cognition. *Psychological Bulletin*, *126*, 159–179.

Lenhoff, H.M., Perales, O., & Hickok, G. (2001a). Absolute pitch in Williams syndrome. *Music Perception*, *18*, 491–503.

Lenhoff, H.M., Perales, O., & Hickok, G. (2001b). Preservation of a normally transient critical period in a cognitively impaired population: Window of opportunity for acquiring absolute pitch in Williams syndrome. In C.A. Shaw & J.C. McEachern (Eds.), *Toward a theory of neuroplasticity* (pp. 275–287). Philadelphia: Psychology Press.

Levitin, D.J. (1994). Absolute memory for musical pitch: Evidence from the production of learned melodies. *Perception & Psychophysics*, *56*, 414–423.

Levitin, D.J., & Cook, P.R. (1996). Memory for musical tempo: Additional evidence that auditory memory is absolute. *Perception & Psychophysics*, *58*, 927–935.

Lockhead, G.R., & Byrd, R. (1981). Practically perfect pitch. *Journal of the Acoustical Society of America*, *70*, 387–389.

Miller, L.K., & Clausen, H. (1997). Pitch identification in children and adults: Naming and discrimination. *Psychology of Music*, *25*, 4–17.

Miyazaki, K. (1988). Musical pitch identification by absolute pitch possessors. *Perception & Psychophysics*, *44*, 501–512.

Miyazaki, K. (1995). Perception of relative pitch with different references: Some absolute-pitch listeners can't tell musical interval names. *Perception & Psychophysics*, *57*, 962–970.

Mottron, L., Peretz, I., Belleville, S., & Rouleau, N. (1999). Absolute pitch in autism: A case study. *Neurocase*, *5*, 485–501.

Ohnishi, T., Matsuda, H., Asada, T., Aruga, M., Hirakata, M., Nishikawa, M., Katoh, A., & Imabayashi, E. (2001). Functional anatomy of musical perception in musicians. *Cerebral Cortex*, *11*, 754–760.

Palmer, C., Jungers, M.K., & Jusczyk, P.W. (2001). Episodic memory for musical prosody. *Journal of Memory and Language*, *45*, 526–545.

Pantev, C., Oostenveld, R., Engelien, A., Ross, B., Roberts, L.E., & Hoke, M. (1998). Increased auditory cortical representation in musicians. *Nature*, *392*, 811–814.

Reber, A.S., & Allen, R. (2000). Individual differences in implicit learning: Implication for the evolution of consciousness. In R.G. Kunzendorf & B. Wallace (Eds.), *Advances in consciousness research: Vol. 20. Individual differences in conscious experience* (pp. 227–247). Amsterdam: John Benjamins.

Saffran, J.R., & Griepentrog, G.J. (2001). Absolute pitch in infant auditory learning: Evidence for developmental reorganization. *Developmental Psychology*, *37*, 74–85.

Schellenberg, E.G. (1996). Expectancy in melody: Tests of the implication-realization model. *Cognition*, *58*, 75–125.

Schellenberg, E.G., Adachi, M., Purdy, K.T., & McKinnon, M.C. (2002). Expectancy in melody: Tests of children and adults. *Journal of Experimental Psychology: General*, *131*, 511–537.

Schellenberg, E.G., Iverson, P., & McKinnon, M.C. (1999). Name that tune: Identifying popular recordings from brief excerpts. *Psychonomic Bulletin & Review*, *6*, 641–646.

Schellenberg, E.G., & Trehub, S.E. (1996). Children's discrimination of melodic intervals. *Developmental Psychology*, *32*, 1039–1050.

Schneider, P., Scherg, M., Dosch, H.G., Specht, H.J., Gutschalk, A., & Rupp, A. (2002). Morphology of Heschl's gyrus reflects enhanced activation in the auditory cortex of musicians. *Nature Neuroscience*, *5*, 688–694.

Takeuchi, A.H., & Hulse, S.H. (1993). Absolute pitch. *Psychological Bulletin*, *113*, 345–361.

Tillman, B., Bharucha, J.J., & Bigand, E. (2000). Implicit learning of tonality: A self-organizing approach. *Psychological Review*, *107*, 885–913.

Trehub, S.E. (2000). Human processing predispositions and musical universals. In N.L. Wallin, B. Merker, & S. Brown (Eds.), *The origins of music* (pp. 427–448). Cambridge, MA: MIT Press.

Ward, W.D. (1999). Absolute pitch. In D. Deutsch (Ed.), *The psychology of music* (2nd ed., pp. 265–298). San Diego, CA: Academic Press.

Young, R.L., & Nettlebeck, T. (1995). The abilities of a musical savant and his family. *Journal of Autism and Developmental Disorders*, *25*, 231–248.

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

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