Review TRENDS in Cognitive Sciences Vol.9 No.1 January 2005
Full text provided by www.sciencedirect.com
SCIENCE DIRECT

# Absolute pitch: perception, coding, and controversies

**Daniel J. Levitin and Susan E. Rogers**

Department of Psychology and Center for Interdisciplinary Research in Music, Media and Technology, McGill University, Montreal, Quebec, Canada

**Recent findings in cognitive neuroscience and cognitive psychology are converging to shed light on the nature of processing, categorization and memory for pitch in humans and animals. Although most people are unable to name or place pitch values in consistent, well-defined categories, as they do for color, stable long-term memory for pitch has been shown in certain animal species, in infants, and in both adult musicians and non-musicians. 'Absolute pitch', the rare ability to label pitches without external reference, appears to require acquisition early in life, and involves specialized brain mechanisms, now partially identified. Research on pitch coding strategies informs wider theories in cognitive science of semantic memory, and the nature of perceptual categories.**

## Introduction

The study of the memory codes used for musical pitch is one of the oldest in experimental psychology, beginning with Helmholtz, Fechner, Stumpf and Wundt. Indeed, the Gestalt psychology movement was launched with the following question: how is it that a melody composed of specific musical pitches retains its identity despite transposition and when none of the original pitches are present? A related question is that of why some people are able to label all the notes of the musical scale as effortlessly as most of us label colors – a phenomenon known as absolute pitch (AP). Recent findings from neuroimaging, psychophysics, developmental psychology and cognitive science are converging to create a critical mass of knowledge on which to build new theories and experiments.

Research on absolute pitch has grown exponentially over the past 120 years. Defined as the ability either to *identify* the chroma (pitch class) of a tone presented in isolation or to *produce* a specified pitch without external reference [1–3], AP occurs in 1 in 10 000 people [2]. People with AP presumably possess an internal template to map musical tones to linguistic labels. Sometimes regarded as a mark of musicianship, AP is in fact largely irrelevant to most musical tasks. Being unable to turn it off, many possessors of AP perform dramatically poorer at judging whether a melody and its transposed counterpart are the same, a task that non-AP musicians accomplish with ease [4,5].

Comparisons are often made between color labelling in most humans and pitch labelling in AP possessors [2], because AP possessors categorize and label pitches quite effortlessly and automatically. However, the human visual system is constructed in such a way as to allow discrete categories to emerge readily: information about color is separated into three (or sometimes four) streams by cones in the retina [6], and remains separated up to the cortex. By contrast, information from the cochlea and peripheral auditory system is much more continuous and lacks the one-to-one mapping between excitation patterns and percepts [7]. Accordingly, pitch and color perception are phenomenologically different: colors are experienced as belonging to categories; pitches are experienced (by most of us) as continuous. The fact that some individuals place pitches into categories requires an explanation of what is different about these individuals in their development or neural architecture.

## Absolute pitch versus relative pitch

AP should not be confused with relative pitch (RP), an ability all trained musicians learn that allows them to identify or produce musical 'intervals', or relations between pitches (see Box 1). A trained musician presented with the tones *A* and *C* will identify the musical interval as a 'minor third' without being able to name either component tone. Told that the first note was an *A*, she will use her learned knowledge of musical scales to report that the second note was a *C*. Interestingly, if we tell the musician that the first note was *G*, she will report that the second note was a *Bb* – the note a minor third above *G* – and not know that she had been deceived. The *absolute* labels for notes are typically not attended to by RP possessors except when performing music from a score. Indeed, most musical training in the classical, jazz and popular traditions emphasizes the ability to play musical patterns and scales equally well in all keys.

In general, RP information is used to recognize and produce melodies, but some residual AP information might also be coded (see Box 2). This issue relates to a longstanding debate in the animal literature about the extent to which learning and internal representations are relational or absolute, and whether the function of memory is to preserve the details of experience or rather, to form abstractions and preserve the *gist* of experience [8].

*Corresponding author:* Levitin, D.J. (daniel.levitin@mcgill.ca).
Available online 8 December 2004

www.sciencedirect.com 1364-6613/$ - see front matter © 2004 Elsevier Ltd. All rights reserved. doi:10.1016/j.tics.2004.11.007

**Box 1. Categories of pitch: scales and intervals**

Musical practice subdivides the auditory frequency continuum into discrete pitches, forming the basis of scales. All musical cultures have scales based on frequency ratios of 2:1, the 'octave' [13]. Western musical tradition further subdivides the octave into 12 (logarithmically) equally spaced pitch classes. These repeat cyclically throughout the range of useable musical tones. An 'interval' is the distance between two tones. The smallest of these in the Western system is the semitone (1/12th of an octave), equivalent to adjacent keys on the piano. Tones an octave apart share certain perceptual features, and are often confused with one another; such 'octave equivalence' is a musical universal. The cyclical repetition, and the equal spacing of scale tones, enables 'transposition', the ability to play and recognize melodies regardless of their starting tone – it is the *pattern* of interval distances between the tones that defines the melody, not its absolute pitches. An exception is that the memory schemas for melodies held by AP possessors evidently include an integrated representation of absolute pitch levels that is impossible to separate from the interval information.

Many cultures and traditions have scales with fewer than 12 tones. Western classical music typically uses only seven of the 12 at a time (the 'diatonic scale') and a five-note ('pentatonic') scale is the basis of blues and rock music. No known cultures, however, have scales with *more* than 12 tones, perhaps because of cognitive processing limits [9,13].

'Tuning' refers to the precise relationship between the frequencies of a given tone and a standard, or between two tones of a nominal interval class. Orchestral musicians 'tuning up' before a performance are synchronizing the tuning of their instruments (which naturally drifts as the wood, metal, strings and other materials expand and contract as a result of temperature and humidity changes) to a standard frequency. Expert musicians often alter musical intervals for expressive purposes while they are playing (except of course on a keyboard instrument); sounding a note slightly lower or higher than its nominal value can impart emotion when done skillfully.

Although it has been claimed that Indian and Arab–Persian music uses 'microtuning', close analysis reveals that their scales also rely on only 12 tones and the others are simply expressive variations, glissandos and momentary passing tones [13], similar to the American blues tradition of sliding into a note for emotional purposes.

The existence of a small number of individuals who have learned to label upwards of 70 musical frequencies appears to contradict the oft-quoted $7\pm2$ limit of information processing [9]. Therefore, the study of pitch memory in general (and AP in particular) is relevant for theories of information processing, the accuracy and nature of long-term memories [8], and the ways in which perceptual stimuli are (or are not) coded into mental categories [10,11].

## AP: phenomenology

The mental codes used to represent color invoke categories (e.g. red, green, blue). For AP possessors, pitch categories are as fixed and familiar as color categories are for the rest of us, although category width can be idiosyncratic from person to person [10] (Figure 1). When AP possessors hear a familiar piece of music played in the wrong key (either when it is transposed, or when an instrument has been tuned to a different standard), they often become agitated or disturbed. To get a sense of what it is like, imagine going to the produce market and finding that, because of a temporary disorder of visual processing, the bananas all appeared orange, the lettuce yellow, and the apples purple.

**Box 2. Does everyone have absolute pitch to some extent?**

The human auditory system encodes absolute frequency information, but until recently, many assumed that this information was discarded by non-AP possessors. Because AP information is not required to recognize melodies or voices, it was deemed irrelevant information that a parsimonious system need not retain. But growing evidence suggests that many people might have stable, long-term auditory memories for pitch – one of the components of true AP ability, termed 'pitch memory', the other being 'pitch labelling' [62].

When people without AP are asked to identify a pitch [18] or musical key, the modal response is to answer correctly (see Figure I). Even in the absence of explicit labelling, pitch memory is stable across time: everyday speech is apparently coupled to absolute pitch memory [63,64], and the mean pitch of one's speech correlates with perceptual judgments made in the 'tritone paradox' [42], an ambiguous auditory pattern. Asked to sing popular songs that exist in only one key and thus have an objectively correct pitch, most people sing at or very near the correct pitches [62]. People might indeed be capable of labelling pitches to some degree, but rather than using the specialized labels that musicians learn (such as *C, D, Bb*, or *Do, Re, Te*) they use ad hoc codes tied to the lyrics of the melody (many experimental participants know, for example, that the word *hotel* in 'Hotel California' is to be sung on *G*). This finding was replicated in a production task [65], and a new paradigm for testing pitch memory for isolated tones in non-musicians was recently introduced [66].

Taken together, these findings are consistent with other research showing that people remember visual experience with astonishing accuracy [67], and they suggest that elementary attributes of the auditory stimulus including pitch, tempo and timbre [30,43,65,68] might be stored in a memory system that is connected to the perceptual representation system [69]. If accurate memory for low-level features of the stimulus exists alongside an abstract memory for higher-level features (the sequence of relative pitches that allows for melody identification) then this constitutes evidence for 'mulmultiple-trace memory models' [8,69], which are rapidly gaining support among cognitive scientists.

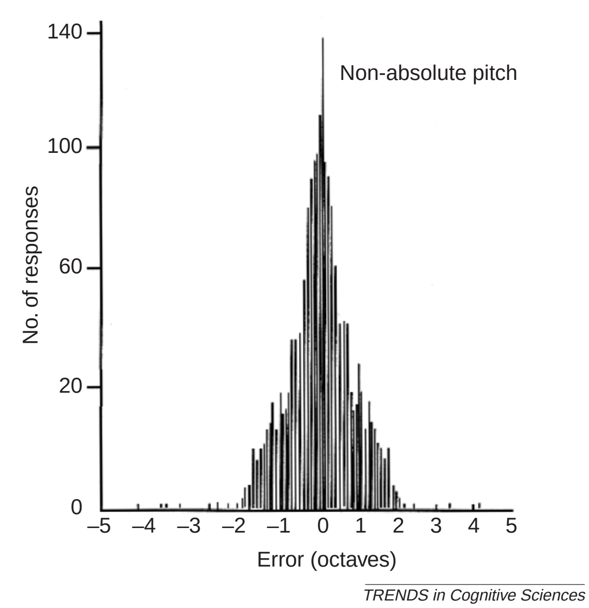


**Figure I.** Errors made by non-AP possessors. When asked to label a tone, even those without AP do so with surprising accuracy, and their modal response is to give the correct answer. However, their variance is far greater than that for true AP possessors. These results suggest that even individuals not normally identified as AP possessors do possess something akin to AP. Data redrawn with permission from [18].

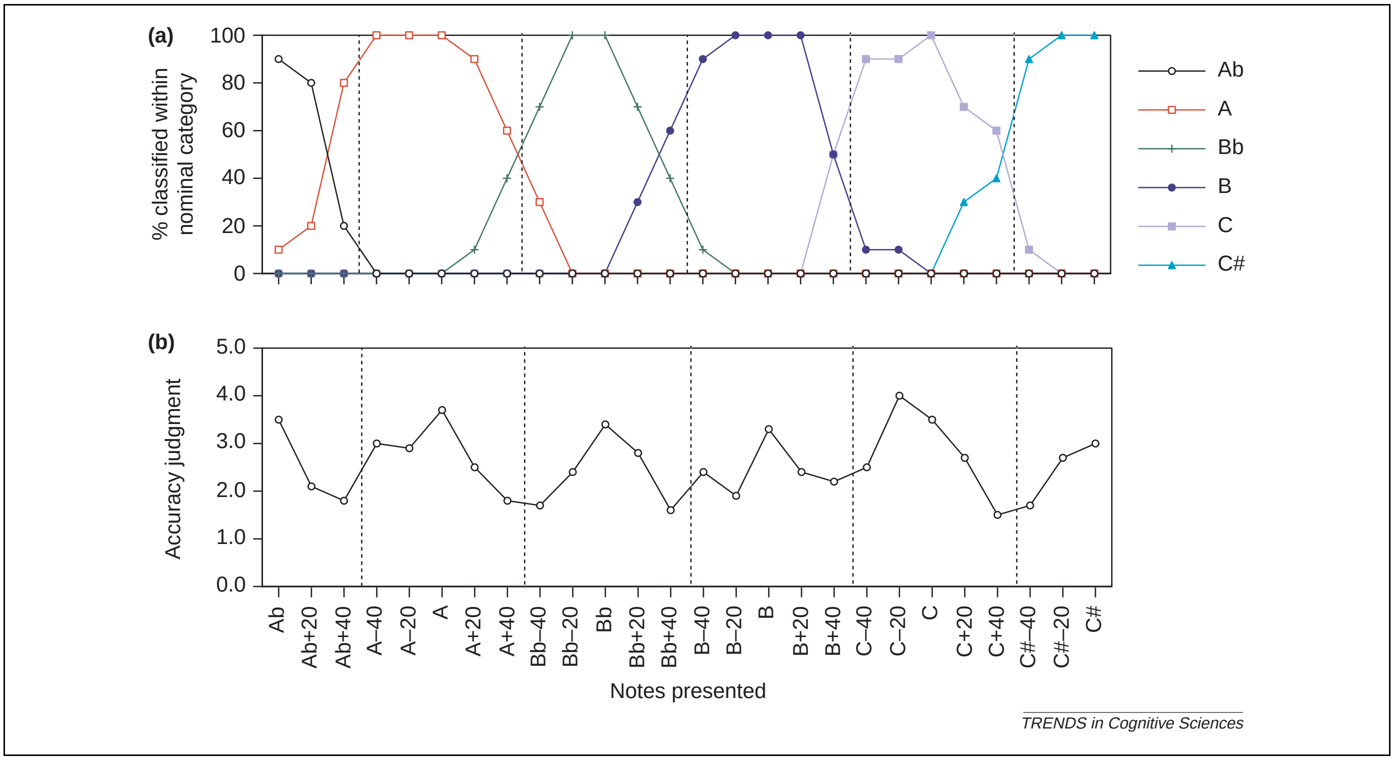


**Figure 1.** Classification functions for a typical AP possessor. The participant was presented with tones randomly drawn from the interval 207 Hz (*Ab*) to 277 Hz (*C#*), some of which were in tune and some of which were out of tune in 1/5th semitone (20 cent) increments. The task was first to identify the tone by name, and second, to rate how good an exemplar of its category the tone was. **(a)** AP possessors tend to place tones in categories with very little error, and to place even mistuned tones in their nominal categories. **(b)** Evidence that AP possessors do not have 'categorical perception' – perceiving all members of a nominal category as equivalent – comes from their judgment of accuracy, or the goodness function. The 'scalloped' shape of the goodness function, which is monotonically decreasing as the tone becomes more out of tune, reveals that this participant had a well-refined ability to detect differences among members of the same nominal category.

Some researchers believed that AP possessors had 'categorical perception' for pitch [12], as for color, exhibiting heightened discrimination for tones that cross category boundaries compared with tones within a category. This was subsequently refuted: AP possessors do treat pitches categorically, in that they place tones in nominal categories, but that category structure does not affect their *perception* of pitch [10,11], only their ability to label. Although all musicians treat intervals categorically (e.g. minor third, perfect fifth etc) [13] only AP possessors treat *isolated pitches* categorically.

AP is automatic, qualifying as a form of 'perceptual expertise' [14]: categorization occurs without deliberation [15], is accompanied by marked differences in speed of performance compared with non-experts, and experts can engage in other tasks while making judgments [16].

## Absolute pitch is not 'perfect' pitch

It is important to emphasize that AP possessors do *not* have an exceptional pitch acuity. Absolute pitch is neither 'absolute' nor 'perfect' in the ordinary uses of those words; 'absolute' refers to judgments established independently, rather than by comparison. The terms 'absolute' and 'perfect' both imply in the lay mind a level of precision not typically present in AP possessors, who frequently make octave errors (confusing tones that are half or double the frequency), and semitone errors (confusing tones that are 6% apart) [17–19]. Like most human traits, AP is not an all-or-none ability, but rather, exists along a continuum [10,17,20,21]. Self-identified AP possessors score well above chance (which would be 1 out of 12, or 8.3%) on AP tests, typically scoring between 50 and 100% correct [19], and even musicians *not* claiming AP score up to 40% [18]. Still, even those who score better than 90% show similar discrimination thresholds to, and are typically no better than, other musicians at noticing when one tone is out of tune with respect to another [11,17]. Clearly, there is nothing 'perfect' about AP; rather AP is the ability to place or produce tones within nominal categories.

Some people with AP can only label tones produced by one particular instrument. Because this instrument is often the piano, this has been termed 'absolute piano' [18]. This phenomenon suggests that their internal template for pitch is bound up with the timbre of that particular instrument, and the individual is consulting those multiple cues contained in the instrument's unique spectrum to encode pitch labels.

Some people have AP for only a single tone – often their tuning note – and fail to show the automatic and rapid identification found in true AP possessors (hence, this is termed 'quasi-AP'). They are able to obtain high scores on standard AP tests by calculating tone names from their one internal referent. It is only when reaction times are collected that they can be distinguished from true AP possessors.

Occasionally, someone develops AP on an instrument that is mistuned with respect to pitch standards (e.g. the commonly used $A=440$ Hz), as when a child grows up with an old piano that had been tuned down a semitone. This child will make consistent semitone errors on

**Box 3. A genetic basis for absolute pitch?**

A reasonable explanation for the unequal distribution of AP in the general population is that there exist genetic predispositions towards some of the underlying traits necessary for its development. A significant association between siblings who *claim* AP has been shown [60], although AP status was not confirmed in that report. Other evidence is an ethnicity cluster for AP; that is, a higher rate of AP among Asians [34] that is not attributable to sociocultural variables, because the elevated rate is also found in Americans of Asian descent. Speaking a tonal language cannot alone account for this finding, as not all Asian languages are tonal [70].

A genetic predisposition might be necessary but clearly is not sufficient: tone labels must still somehow be learned. When the type of musical training received was compared across ethnic groups, Asians were significantly more likely to have received 'fixed pitch training' (i.e. reinforcing tone/name associations), such as the Suzuki method, compared with Caucasians (29% versus 6%) [34]. This is predicted by the 'unlearning theory' [2], which posits that all children are born with AP but musical-interval training causes them to unlearn it.

The most convincing evidence for a genetic basis for AP would be to compare adopted children with their biological and adoptive parents, or to study monozygotic twins reared apart (MZA), as has been successfully done for several traits, including religiosity, honesty and phobias. However, the number of MZA and AP possessors both being rare might render this approach impractical.

The search for a genetic component of AP may be inherently doomed [10] because of the difficulty in separating genes from environment in a skill that certainly must be taught, learned and nurtured. By analogy, most parents who speak French raise French-speaking children, but one need not invoke a genetic explanation – French is simply what those children are taught. Most importantly, one must ask what such putative genes would be coding for, and what the possible evolutionary value would be. Whereas pitch labelling might not confer any obvious value, a good pitch memory would, enabling those with it to detect subtle pitch changes in the voice of friends and foes, changes that might indicate anger, pleasure, stress or illness. The link between good pitch memory and pitch labelling is not yet clear, but the former would seem to be a prerequisite for the stable category formation associated with AP.

standardized tests (owing to no fault of his own), and yet might perform with near zero variance. The *best* AP possessor is therefore not necessarily the one with the fewest errors, but with the lowest variance [2].

## Origins of AP: phylogeny and ontogeny

Many animals show preferential processing for absolute qualities of stimuli over relational information; it is a cornerstone of learning theory that relational processing requires greater cognitive sophistication. With regard to pitch procesing, rats and wolves have been shown to use AP information, in the latter to identify members of their own pack. Starlings and rhesus monkeys first attempt to solve pitch tasks with AP, and if that fails, can resort to RP as a secondary strategy [22]. Monkeys but not songbirds show 'octave equivalence' (treating two tones an octave apart as the same; see Box 1), indicating that this form of RP developed after the divergence between birds and mammals [23].

The natural predisposition for pitch production and perception in human infants is an area of active research [24–26] (see Box 3). During the first few months of life, the fundamental frequency of infants' cries stabilizes to a fairly constant pitch, a given infant showing a variation of less than one semitone [27]. This suggests the existence of an auditory–motor control feedback network that attends to absolute pitch values. Two experiments found AP to be the dominant perceptual mode of processing for 8-month olds [24,28], followed by a developmental shift towards RP. However, RP information can be elicited by (AP) infants in certain tasks [29], and one study concluded that AP information is *not* available to 6-month olds [30,31], so the picture is not clear as yet. Task demands and stimulus configuration clearly influence the types of results obtained and further work in this area is being actively pursued.

## Critical periods

Studies suggest that AP is acquired before the age of 9 [32–34], and no case exists of an adult successfully acquiring it [2]. This has led to conjecture that, like grammar and phonology in spoken [35] and signed languages [36], AP must be acquired during a 'critical period' or maturational stage before the development of other cognitive skills that might undo it. Indeed, the existence and high incidence of late-acquiring AP possessors among developmentally delayed populations such as Williams Syndrome [37] and autism [38] supports the maturational stage idea. The discovery of a small number of individuals who apparently acquired AP outside the critical window [38,39] does not, of course, contradict the critical-period hypothesis, given the statistical properties of biological distributions [40] (see Figure 2).

Further evidence in favor of a critical period for AP is that many AP possessors are better at identifying or producing the white notes of the keyboard, those tones

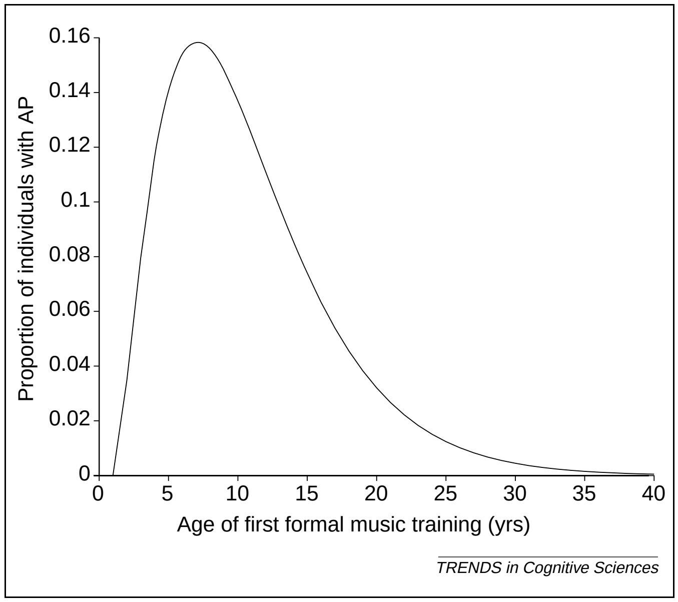


**Figure 2.** Data from retrospective reports on age of acquistion of AP, as modeled by a Gamma function. This suggests the possible existence of a critical period for AP acquisition. Gamma functions are consistent with a number of biological, developmental processes, because they are constrained at zero. The modal age of acquisition is around 7 years old. The existence of individuals beyond the mode should not be taken as evidence against the critical period hypothesis; a small number of individuals in the tails of the distribution are to be expected on statistical grounds. Redrawn with permission from [40].

that are generally learned first during music lessons, than they are the black notes [19]. In additional, speakers of tonal languages, like Mandarin Chinese, are more likely to have AP than speakers of non-tonal languages, suggesting that an early attentional focus on the pitch attribute of the auditory stream creates a better climate for AP acquisition [41,42].

Pitch labelling can be trained more successfully in children than in adults. With one week of training, adults learned to attach a label to a *single* tone and to produce or identify that tone well above chance [43]. Children of 5–6 years of age and adults were similarly trained for single-tone AP [44], and the accuracy of the 5–6 year-old group far exceeded that of the adult group and a group of younger children, strongly supporting the critical period hypothesis, at least for single-tone acquisition.

## AP: neuroanatomy

AP possessors show neuroanatomical differences and different results on neural tests from non-possessors, especially in working memory and associative memory systems [3], although cause and effect have not yet been teased apart. When listening to transposed tone sequences non-possessors show a mismatched negativity and an attentive P3 evoked response potential (ERP), indicating the activation of working memory [45,46], whereas AP possessors appear to use long-term memory instead [47]. This is presumably because AP possessors need not use working memory to keep a mental representation of pitch active; they can recode the tone to a verbal label [3,48].

Anatomically, regions of right superior temporal cortex and planum temporale (PT) are smaller in AP possessors than non-possessors [49,50]. That AP is fundamentally a *labelling* ability and not a difference in perception, as is often argued, is best illustrated by two findings. First (as already noted), AP possessors and non-possessors have equivalent acuity and perceptual thresholds for pitch differences [10]. Second, in fMRI studies, when asked to name tones or intervals, AP possessors show focal activation in posterior dorsolateral frontal cortex (an area implicated in conditional associative learning), whereas RP possessors activate this same region *only* when naming intervals [51] (see Figure 3). That is, each group, naming that pitch attribute at which they are highly competent, recruits a neural region with known involvement in labelling, with no significant neural differences in primary auditory cortex (where pitches are initially processed).

Tracking brain activations in non-AP musicians during pitch-memory tasks over time [52] reveals early left-lateralized activation of superior temporal gyrus and the PT, and bilateral dorsolateral frontal regions (0–2 s post stimulus). This is followed by continued activation in the left lateral superior temporal plane and of the *right* PT, activation in the left frontal operculum and adjacent left mid-dorsal prefrontal cortex (3–4 s), and of the PT bilaterally (5–6 s). Throughout the 6-s post-stimulus period, the cerebellum is significantly activated bilaterally, consistent with other studies of tonal processing revealing a role for the cerebellum beyond motor control [53–55].

It has been claimed that persons blinded early in life (younger than 2 years) outperform late-blind and sighted people when reporting the direction (up or down) of pitch change between two successive tones [56]. However, their initial discrimination thresholds might be all that is better; their overall thresholds (deduced from the percent correct data) are actually worse than trained normals. Early-blind musicians are far more likely to possess AP than sighted ones, with nearly 60% of one sample reporting AP, compared with less than 20% of sighted musicians [57]. This has been attributed to the recruitment of unused neural resources from the visual cortex [58], although one study found that the same cortical networks were activated in a blind AP possessor as in sighted AP musicians [59].

## How is AP acquired?

Controversy exists as to whether AP acquisition requires explicit training [32,40] or can result merely from incidental exposure to music [38,60]. Most possessors report having acquired the ability without remembering when or how it occurred [32]; all report having had music instruction. The failure to remember the learning episode can be taken as evidence that AP is a form of 'semantic memory' but does not necessarily imply that the learning was incidental.

Our own view is that AP is probably acquired just like other labels in the developing child's vocabulary. The acquisition of pitch categories might parallel that of color categories, for both of which the child must learn to distinguish one perceptual quality (pitch chroma, or hue) from several other perceptual attributes as a prerequisite to creating the correct mappings between tone (or color) and its linguistic label [10]. How and why these associations are formed in a relatively automatic way in AP possessors is still unknown, but the most parsimonious explanation is simply that most children are not taught pitch labels (but are taught color labels). Active practice is necessary to produce plastic alterations in the cortex [61], lending support to the musical training argument.

A two-component model proposes that AP consists of 'pitch memory', which is widespread in the population (see Box 2), and 'pitch labelling', which is possessed exclusively by persons with AP [62]. AP and RP both rely on long-term memory (LTM) but in distinctive ways. At lower levels of processing, virtually all listeners extract the pitch component from a complex tone, separating it from other features such as loudness, timbre, and so on. The AP possessor then – automatically, for this is a hallmark of AP – compares the pitch of the tone with a stored LTM representation or 'pitch template' associated with a linguistic label. The RP possessor might hold the tone in working memory long enough to compare it with unlabelled temporally adjacent tones and then compare these intervals with a stored 'interval template' that is associated with linguistic labels, but few RP musicians report that they label intervals automatically. Rather, it requires conscious effort. In this sense, tonal processing among all but AP possessors may be analogous to 'gist memory' for speech [43], retaining the meaning without

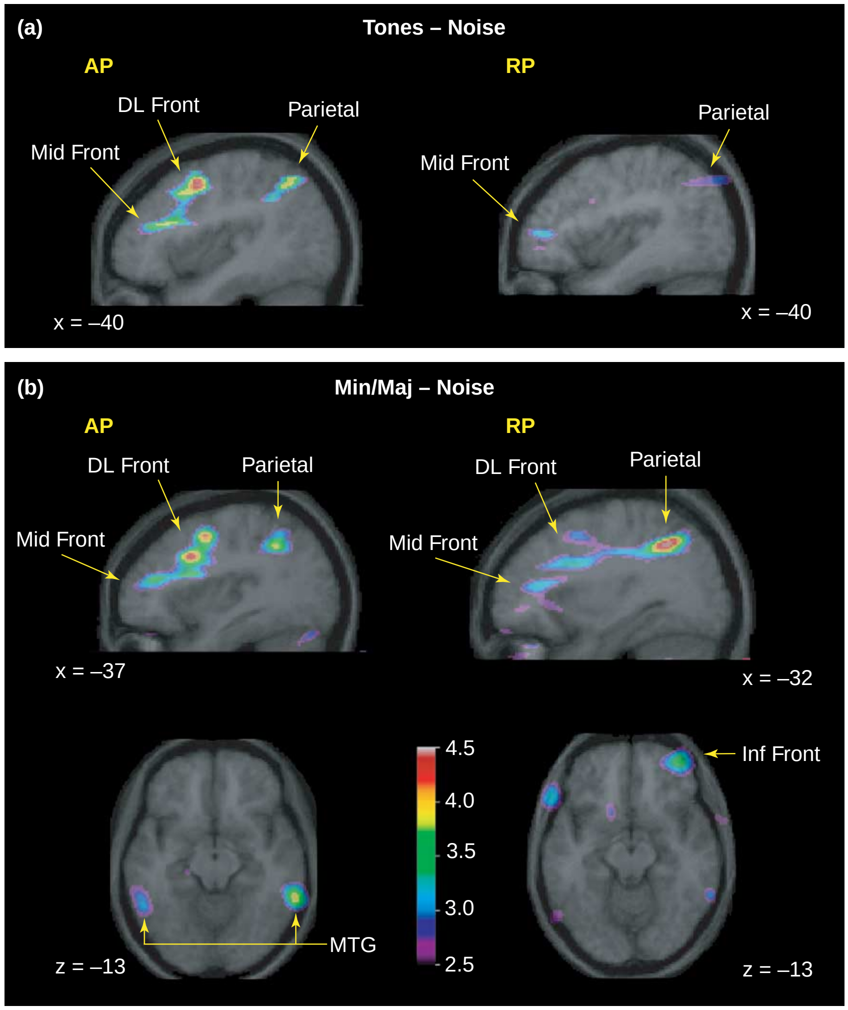


**Figure 3.** Data from a PET study of AP and RP possessors, who labelled **(a)** isolated tones and **(b)** intervals. The Blood Oxygenated Level Dependent (BOLD) signal for the task in comparison with broadband noise is illustrated. When naming tones, AP but not RP possessors recruit structures in left posterior dorsolateral prefrontal cortex ('DL Front' in figure), a region implicated in conditional associative learning (i.e. associated with object labelling). Both groups show activation in that region in response to labelling an interval as major or minor. This same region is recruited by non-musicians, once they are taught to label chords. Thus, it seems that for as yet unknown reasons, the associative function of DLPFC is enhanced or facilitated in AP possessors to help them form tone–label associations automatically. Reproduced with permission from [51] Copyright (1998) National Academy of Sciences, USA.

the stimulus details. On the other hand, the long-term memory representation for well-known songs might combine both absolute and relative pitch cues, suggesting a hybrid model and supporting the notion of accurate and stable 'pitch memory' distinct from labelling [59,62].

### Box 4. Questions for future research

- Why do some AP possessors learn to generalize tone identification across instruments (and even to sinewave tones) whereas others do not?
- Why do some develop AP for only a single tone?
- What are the relative contributions of genetics and environment in developing AP?
- Assuming there exists a critical period for AP acquisition, what are the necessary and sufficient conditions?
- How is the planum temporale involved in AP? In general, are the observed neuroanatomical differences between possessors and non-possessors a cause or an effect of AP?
- What might be the evolutionary value, if any, for AP?
- The nature of pitch encoding in mammals has not been fully explored. It is unknown whether dogs, cats, pigs or primates could use both AP and RP information if given the right task and rewards.

## Conclusions

A small percentage of the population has direct access to pitch information in the form of linguistic codes that they can apply to pitches. Research in this area suggests that access to some of this information might exist in a much larger proportion of the population. Infants appear to be born with the capacity to attend to and make use of absolute pitch information in melodic recognition tasks, although general development or musical training causes a strategic shift towards relative pitch processing in most normally developing (as opposed to developmentally delayed) individuals. Those who do acquire absolute pitch most probably do so within a critical period of development; they might have a genetic or neural predisposition to do so (Box 3), but some form of systematic training appears to be necessary (see also Box 4). Neuroanatomical studies have confirmed differences between AP possessors and non-possessors, although cause and effect have not been distinguished. New work on the neuroanatomy of pitch memory may yield additional clues. Understanding both the nature of absolute pitch, and why it occurs in some individuals and not others, might tell us more about how humans process melodies and pitch, and has already informed work on perceptual expertise and memory, and theories about cognition, perception, and the interaction between the two.

**Acknowledgements**

The preparation of this report was supported by an FCAR/FQRNT Strategic Professor Award and the Bell Canada Chair in the Psychology of Electronic Communication to DJL, by grants from NSERC (228175–00), SSHRC (410–2003–1255), and VRQ (2201–202) to DJL, and a CIRMMT doctoral fellowship to SER. We thank Giulia de Prophetis, Catherine Guastavino, Hadiya Nedd-Roderique, and Regina Nuzzo for help with the figures. We are grateful to Evan Balaban, Ed Burns, Tina Chin, Caroline Palmer, Gottfried Schlaug, Jenny Saffran, Robert Zatorre, the TICS editor Shbana Rahman, and the merciless anonymous reviewers for helpful comments on a previous draft; any errors remaining were probably pointed out to us by them and are our fault for inadvertently (or stubbornly) failing to repair them.

## References

1 Parncutt, R. and Levitin, D.J. (2001) Absolute pitch. In *The New Grove Dictionary of Music and Musicians* (Sadie, S. ed.), pp. 37–39, Grove
2 Ward, W.D. (1999) Absolute pitch. In *The Psychology of Music* (Deutsch, D. ed.), pp. 265–298, Academic Press
3 Zatorre, R.J. (2003) Absolute pitch: A model for understanding the influence of genes and development on neural and cognitive function. *Nat. Neurosci.* 6, 692–695
4 Miyazaki, K. and Rakowski, A. (2002) Recognition of notated melodies by possessors and nonpossessors of absolute pitch. *Percept. Psychophys.* 64, 1337–1345
5 Miyazaki, K. Recognition of transposed melodies by absolute pitch possessors. *Jpn. Psychol. Res.* (in press)
6 Bimler, D.L. *et al*. (2004) Quantifying variations in personal color spaces: Are there sex differences in color vision? *Color Research and Application* 29, 128–134
7 Imaizumi, K. *et al*. (2004) Modular functional organization of cat anterior auditory field. *J. Neurophysiol.* 92, 444–457
8 Goldinger, S.D. (1998) Echoes of echoes? An episodic theory of lexical access. *Psychol. Rev.* 105, 251–279
9 Miller, G.A. (1956) The magical number seven plus or minus two: Some limits on our capacity for processing information. *Psychol. Rev.* 63, 81–97
10 Levitin, D.J. (2004) L'oreille absolue. *L'Anneé Psychologique* 104, 103–120
11 Burns, E.M. and Campbell, S.L. (1994) Frequency and frequency-ratio resolution by possessors of absolute and relative pitch: Examples of categorical perception? *J. Acoust. Soc. Am.* 96, 2704–2719
12 Siegel, J.A. and Siegel, W. (1977) Categorical perception of tonal intervals: Musicians can't tell sharp from flat. *Percept. Psychophys.* 21, 399–407
13 Burns, E.M. (1999) Intervals, scales, and tuning. In *The Psychology of Music* (Deutsch, D. ed.), pp. 215–264, Academic Press
14 Palmeri, T.J. *et al*. (2004) Computational approaches to the development of perceptual expertise. *Trends Cogn. Sci.* 8, 378–386
15 Johanson, M.K. and Palmeri, T.J. (2002) Are there representational shifts during category learning? *Cogn. Psychol.* 45, 482–553
16 Gauthier, I. and Tarr, M.J. (2002) Unraveling mechanisms for expert object recognition. *J. Exp. Psychol. Hum. Percept. Perform.* 28, 431–446
17 Levitin, D.J. (1999) Absolute pitch: Self-reference and human memory. *International Journal of Computing Anticipatory Systems* 4, 255–266
18 Lockhead, G.R. and Byrd, R. (1981) Practically perfect pitch. *J. Acoust. Soc. Am.* 70, 387–389
19 Miyazaki, K. (1988) Musical pitch identification by absolute pitch possessors. *Percept. Psychophys.* 44, 501–512
20 Deutsch, D. (2002) The puzzle of absolute pitch. *Curr. Dir. Psychol. Sci.* 11, 200–204
21 Vitouch, O. (2003) Absolutist models of absolute pitch are absolutely misleading. *Music Perception* 21, 111–117
22 Wright, A.A. *et al*. (2000) Music perception and octave generalization in rhesus monkeys. *J. Exp. Psychol. Gen.* 129, 291–307
23 Hauser, M.D. and McDermott, J. (2003) The evolution of the music faculty: A comparative perspective. *Nat. Neurosci.* 6, 663–668
24 Saffran, J.R. (2003) Absolute pitch in infancy and adulthood: The role of tonal structure. *Dev. Sci.* 6, 35–47
25 Saffran, J.R. (2003) Mechanisms of musical memory in infants. In *The Cognitive Neuroscience of Music* (Peretz, I. and Zatorre, R.J. eds), pp. 32–41, Oxford University Press
26 Trehub, S.E. (2003) Musical predispositions in infancy. In *The Cognitive Neuroscience of Music* (Peretz, I. and Zatorre, R.J. eds), pp. 3–20, Oxford University Press
27 Wermke, K. *et al*. (2002) Developmental aspects of infant's cry melody and formants. *Med. Eng. Phys.* 24, 501–514
28 Saffran, J.R. and Griepentrog, G.J. (2001) Absolute pitch in infant auditory learning: Evidence for developmental reorganization. *Dev. Psychol.* 37, 74–85
29 Saffran, J.R. Changing the tune: The structure of the input affects infants' use of absolute and relative pitch. *Dev. Sci.* (in press)
30 Plantinga, J. and Trainor, L.J. Memory for melody: Infants use a relative pitch code. *Cognition* (in press)
31 Plantinga, J. and Trainor, L.J. (2003) Long-term memory for pitch in six-month-old infants. *Ann. N. Y. Acad. Sci.* 999, 520–521
32 Chin, C.S. (2003) The development of absolute pitch: A theory concerning the roles of music training at an early developmental age and individual cognitive style. *Psychology of Music* 31, 155–171
33 Costa-Giomi, E. *et al*. (2001) Absolute pitch, early music training and spatial abilities. *Ann. N. Y. Acad. Sci.* 930, 394–396
34 Gregersen, P.K. *et al*. (2000) Early childhood music education and predisposition to absolute pitch: Teasing apart genes and environment. *Am. J. Med. Genet.* 98, 280–282
35 Kuhl, P.K. (2003) Language, mind, and brain: Experience alters perception. In *The New Cognitive Neurosciences* (Gazzaniga, M.S. ed.), pp. 99–115, MIT Press
36 Newman, A.J. *et al*. (2002) A critical period for right hemisphere recruitment in American Sign Language processing. *Nat. Neurosci.* 5, 76–80
37 Lenhoff, H.M. *et al*. (2001) Absolute pitch in Williams Syndrome. *Music Perception* 18, 491–503
38 Brown, W.A. *et al*. (2003) Autism-related language, personality, and cognition in people with absolute pitch: Results of a preliminary study. *J. Autism Dev. Disord.* 33, 163–167
39 Brown, W.A. *et al*. (2002) Early music training and absolute pitch. *Music Perception* 19, 595–597
40 Levitin, D.J. and Zatorre, R.J. (2003) On the nature of early training and absolute pitch: A reply to Brown, Sachs, Cammuso and Foldstein. *Music Perception* 21, 105–110
41 Deutsch, D. *et al*. (2004) Absolute pitch, speech, and tone language: Some experiments and a proposed framework. *Music Perception* 21, 339–356
42 Deutsch, D. and Henthorn, T. (2004) Speech patterns heard early in life influence later perception of the tritone paradox. *Music Perception* 21, 357–372
43 Levitin, D.J. (2002) Memory for musical attributes. In *Foundations of Cognitive Psychology: Core Readings* (Levitin, D.J. ed.), pp. 295–310, MIT Press
44 Russo, F.A. *et al*. (2003) Learning the 'special note': Evidence for a critical period for absolute pitch acquisition. *Music Perception* 21, 119–127
45 Fujioka, T. and Trainor, L.J. A comparison of automatic melodic contour and interval encoding in musicians and nonmusicians. *J. Cogn. Neurosci.* (in press)
46 Shahin, A. *et al.* Enhancement of neuroplastic P2 and N1c auditory evoked potentials in musicians. *J. Neurosci.* (in press)
47 Hirose, H. *et al*. (2002) People with absolute pitch process tones with producing P300. *Neurosci. Lett.* 330, 247–250
48 Zatorre, R.J. and Beckett, C. (1989) Multiple coding strategies in the retention of musical tones by possessors of absolute pitch. *Mem. Cogn.* 17, 582–589
49 Keenan, J.P. *et al*. (2001) Absolute pitch and planum temporale. *Neuroimage* 14, 1402–1408
50 Zatorre, R.J. (1998) Functional specialization of human auditory cortex for musical processing. *Brain* 121, 1817–1818

51 Zatorre, R.J. *et al*. (1998) Functional anatomy of musical processing in listeners with absolute and relative pitch. *Proc. Natl. Acad. Sci. U. S. A.* 95, 3172–3177

52 Gaab, N. *et al*. (2003) Functional anatomy of pitch memory: An fMRI study with sparse temporal sampling. *Neuroimage* 19, 1417–1426

53 Ackermann, H. *et al*. (2004) Temporal organization of 'internal speech' as a basis for cerebellar modulation of cognitive functions. *Behav. Cogn. Neurosci. Rev.* 3, 14–22

54 Levitin, D.J. and Menon, V. (2003) Musical structure is processed in 'language' areas of the brain: A possible role for Brodmann Area 47 in temporal coherence. *Neuroimage* 20, 2142–2152

55 Parsons, L.M. (2001) Exploring the functional neuroanatomy of music performance, perception, and comprehension. *Ann. N. Y. Acad. Sci.* 930, 211–230

56 Gougoux, F. *et al*. (2004) Pitch discrimination in the early blind. *Nature* 430, 309

57 Hamilton, R.H. *et al*. (2004) Absolute pitch in blind musicians. *Neuroreport* 15, 803–806

58 Rauschecker, J.P. (2003) Functional organization and plasticity of auditory cortex. In *The Cognitive Neuroscience of Music* (Peretz, I. and Zatorre, R.J. eds), pp. 357–365, Oxford University Press

59 Ross, D.A. *et al*. (2003) Cortical plasticity in an early blind musician: an fMRI study. *Magn. Reson. Imaging* 21, 821–828

60 Baharloo, S. *et al*. (1998) Absolute pitch: An approach for identification of genetic and nongenetic components. *Am. J. Hum. Genet.* 62, 224–231

61 Pantev, C. *et al*. (2003) Representational cortex in musicians. In *The Cognitive Neuroscience of Music* (Peretz, I. and Zatorre, R.J. eds), pp. 382–395, Oxford University Press

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

63 Braun, A. (2001) Speech mirrors norm-tones: Absolute pitch as a normal but precognitive trait. *Acoust. Res. Lett. Online, J. Acoust. Soc. Am.* 2, 85–90

64 Braun, M. (2002) Absolute pitch in emphasized speech. *Acoust. Res. Lett. Online, J. Acoust. Soc. Am.* 3, 77–82

65 Schellenberg, E.G. *et al*. (1999) Name that tune: Identifying familiar recordings from brief excerpts. *Psychon. Bull. Rev.* 6, 641–646

66 Ross, D.A. *et al*. (2004) A nonmusical paradigm for identifying absolute pitch possessors. *J. Acoust. Soc. Am.* 116, 1793–1799

67 Magnussen, S. *et al*. (2003) High-fidelity perceptual long-term memory revisited – and confirmed. *Psychol. Sci.* 14, 74–76

68 Trainor, L.J. *et al*. (2004) Long-term memory for music: Infants remember tempo and timbre. *Dev. Sci.* 7, 289–296

69 Schacter, D.L. *et al*. (2000) Memory systems of 1999. In *Handbook of Memory* (Tulving, E. and Craik, F.I.M. eds), Oxford University Press

70 O'Grady, W. and Archibald, J. (2000) *Contemporary Linguistic Analysis: An Introduction*, Pearson Education Canada Inc



## *TICS* Book Reviews

We aim to review the best of the new books in Cognitive Science in *TICS.*

Our book reviews are styled like short opinion pieces or mini-reviews of a subject area, with the aim of providing readers with more in-depth analysis. Thus, as well as critically appraising important new texts, the authors of reviews will be encouraged to use the book at a framework for wider discussion.

*Publishers:* – monographs and some edited volumes (but not undergraduate textbooks) will be considered for review in *Trends in Cognitive Sciences*. Please send us advance e-mails of forthcoming titles and copies of books you would like us to consieder for review to the Book Review Editor at the address below.

*Reviewers:* – please send any suggestions for titles that you think would be suitable for review.

*Book Review Editor*
*Trends in Cognitive Sciences*
Elsevier, 84 Theobald's Road, London WC1X 8RR, UK.
e-mail: tics@current-trends.com