UNIVERSITY OF CALIFORNIA, SAN DIEGO

# Absolute Pitch and Related Abilities

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in

Psychology

By

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The Dissertation of Kevin David Dooley is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

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# EPIGRAPH

Writing about music is like dancing about architecture.

*Martin Mull*

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## PUBLICATIONS

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## FIELDS OF STUDY

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ABSTRACT OF THE DISSERTATION

Absolute Pitch and Related Abilities

by

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Absolute pitch (AP) is a rare ability whose relevance to musical proficiency has so far been unclear. Three studies were conducted to explore this question. In the first study, 60 trained musicians – 30 who self-reported AP and 30 with equivalent age of onset and duration of musical training - were administered a test for AP and also a musical dictation test not requiring AP. Performance on both types of test were highly correlated. The findings support the hypothesis that AP is associated with proficiency in performing other musical tasks, and run counter to the claim that it confers a disadvantage in the processing of relative pitch.

In the second study, 36 trained musicians – 18 AP possessors and 18 non-possessors with equivalent age of onset and duration of musical training – were tested on interval naming tasks requiring only relative pitch. The intervals to be named were either ascending or descending, with separation ranging from 1 to 12 semitones, and equally involved all 12 pitch classes. Three different conditions were employed; these used brief sine waves, piano tones, and piano tones preceded by a V7-I chord cadence so as to establish a tonal context. AP possession was strongly correlated with enhanced performance on all these tests of relative pitch. Furthermore, no evidence was found that this absolute pitch advantage depended on key, interval size, or musical context.

In the third study, 36 trained musicians--18 AP possessors and 18 non-possessors with equivalent age of onset and duration of musical training--were asked to recall and vocalize a familiar song, and their responses were compared with the pitches of the actual recordings; this was repeated with their cell phone ringtones. Both groups were significantly more accurate than chance on the song task, but only the AP possessors performed above chance on the ringtone task. The findings confirm the existence of widespread long term pitch memory but also point to an AP advantage under some circumstances.

# CHAPTER 1: INTRODUCTION

## Overview

In this chapter, I present some background information about absolute pitch (AP), including its etiology, varieties and limitations, physiological correlates, presence in the general population, and relationship with language. I will also explore what is not yet fully understood, evaluating competing theories of its development based on previous research that range from hard genetic determinism to a universally learnable skill. I hope to clarify and reconcile the myriad findings relevant to these questions, and furthermore to offer a coherent hypothesis that would account for the existing data. Lastly, I will examine some purported drawbacks of AP and introduce the present studies comprising the chapters that follow, designed to investigate musical abilities & limitations associated with AP.

## Background

Absolute pitch (AP), commonly referred to as "perfect pitch," is a rare auditory perceptual capability, has mystified researchers for over one hundred years and fascinated musicians for centuries more (Ward, 1999). While the majority of the population possesses some form of relative pitch, with which tones can be identified in relation to other tones, AP is generally defined as the ability to either name or produce a pitch without a reference tone (Takeuchi & Hulse, 1993). Clearly, this could provide a real advantage to musicians who possess it, and so raises the question of how, and under what circumstances, it can be developed. Given the low prevalence- it is found in 1 in 10,000 people, according to some estimates- it is curious that anyone should have AP (Bachem, 1940; Profita & Bidder, 1988). However, the real issue may be: why do most people lack this ability? Aside from purely musical applications, AP is a valuable topic for psychological research in that it offers insight into developmental processes, functional and structural brain organization, and the interplay between musical and linguistic cognition.

The experience of using AP can be compared to the instantaneity with which anyone with normal vision is able to name the color of a given object. When determining that a yellow flower growing in a grassy field is really yellow, for example, an observer need not compare the flower to the grass, nor call on prior knowledge that the grass is green, to make an immediate and absolute judgment of the flower's color. Likewise, AP possessors perceive the quality of the pitch class (chroma) of musical tones in isolation, hearing the 'A-ness' of A, or the 'C#-ness' of C#. Non-possessors rely on relative pitch (RP) to perceive or produce tones, abstracting the intervallic (pitch distance) relationship between them, for example recognizing that C# is a major third above the A below it. Given a reference tone of A, then, RP could be used to produce a C# as accurately as could be done with AP. AP possessors utilize this relative pitch information as well, just as typical observers can compare shades of color, although some researchers conjecture that one comes at the expense of the other (Miyazaki, 1993).

While AP itself may prove advantageous in certain musical situations, it does not necessarily confer perceptual benefits across the board. It appears that AP possessors do not have superior pitch discrimination sensitivity or production accuracy (Burns, 1994; Levitin, 2005). It is notable, however, that a disproportionate number of famous musicians and composers, e.g. Bach, Mozart, and Beethoven among countless others, did have AP; more recently, this list has expanded to include Joshua Bell, Pierre Boulez, and Arthur Rubenstein. In Bachem's (1955) bold words, "It is well known that practically all great musicians with only a few exceptions possessed absolute pitch." Indeed, some perceptual advantages of AP possession have been documented (Hsieh & Saberi, 2007; 2008; 2009). In line with neuro-imaging and electrophysiological evidence, AP is currently conceived of as an ability to associate pitches with meaningful labels, and store (and access) those relationships in long-term memory (Zatorre, 1998). Furthermore, 'perfect pitch' is somewhat of a misnomer; AP is not actually all-or-nothing perfect, and in fact seems to be present in varying degrees among individuals. Some AP possessors, for example, can be subject to octave errors in pitch judgment; others perform better when judging tones from white keys than from black keys on a keyboard; still others are more accurate when working with certain instruments or timbres, a phenomenon sometimes referred to as 'absolute piano.' (Bachem, 1937; Lockhead & Byrd, 1981; Miyazaki, 1988; Takeuchi & Hulse, 1991). These various 'flavors' of AP themselves are clues to its origins, as some studies found them to co-vary with experience; white key tones differ from black key tones, not in any acoustically or perceptually relevant way, but only in that many methods of musical instruction expose students first to the former and then gradually progress to the latter.

The etiology of AP offers another battleground for the nature vs. nurture debate (Zatorre, 2003). Is it a genetically coded trait that a select few are born with, perhaps influenced by race or ethnicity, as some researchers suggest (Athos et al., 2007; Baharloo, 1998; Brown, 2002; Gregersen, 1999, 2001)? If it is a trainable skill, why do most AP possessors report acquiring it effortlessly at a young age while attempts to teach adults have had limited success at best (Meyer, 1899; Bachem, 1940; Cuddy, 1968, 1970)? It is no small coincidence that the typical window for successfully developing AP corresponds with the critical period for language acquisition (Newport, 1990; Kuhl, 2000; Takeuchi & Hulse, 1993; Vitouch, 2003). Indeed, recent work is implicating tone language exposure as a contributing factor; and perception of the Tritone Paradox, which correlates with both regional dialect and vocal speech range, demonstrates an implicit form of AP in the general population (Deutsch, 1990, 1991, 2004, 2006; see also Deutsch, Moore, & Dolson, 1984; 1986). Prolonged critical periods may also account for the greater proportion of AP possessors amongst the blind (Gaab, 2006; Hamilton, 2004). The finding that most individuals can recognize or produce the correct pitch of familiar songs, and that infants up to a certain age can respond to absolute pitch cues, further converge on an early learning theory of AP acquisition, such that nearly everyone is born with the potential for AP, but most do not form and retain the requisite association of pitches with meaning (Levitin, 1994; Halpern, 1989; Saffran, 2001, 2003).

## Flavors of AP: Varieties and measurements

Inseparable from defining AP is deciding how it should be quantified. There appear to be as many methodologies as there are studies in the literature, but they generally involve either pitch identification or production (Takeuchi & Hulse, 1993). With pitch identification tasks, subjects are presented with a tone and must name the pitch. Required response types for this task have included pointing to the corresponding key on a piano, assigning each pitch an arbitrary label, picking out a specific pitch amongst many alternatives, identifying both note name and octave, or simply naming the pitch class (Bachem, 1937; Cuddy, 1968; Lockhead & Byrd 1981; Miyazaki, 1988; Ward, 1999).

The last method, identifying only pitch class, seems the most informative. Whereas RP and AP subjects have been found to perform equally well in tasks based on tone height (i.e., determining the correct octave), it is the ability to recognize pitch class that sets AP possessors apart from others with musical training (Bachem, 1955; Balzano, 1984; Miyazaki, 1989). Furthermore, music theory provides universally known labels for pitch class (A, A#, etc.), but any system for octave identification will be an artificial construct, specific to the study and thus novel for the subjects. For this reason, pitch class identification has been used as the classification variable in the studies to be presented, in keeping with the AP test used by Deutsch and colleagues (e.g., Deutsch, 2006). In this test, subjects are presented with a CD recording of a series of piano tones in random order, one at a time, and asked to write down the pitch (class, e.g., C#) of each tone. Percentage of correct responses then serves as the metric of AP ability. Subjects typically either score at around chance or their scores are near-perfect; those who score above a given threshold are considered 'AP possessors.'

Production tasks typically involve adjusting an oscillator or other pitch variator to match the aurally presented tone (Takeuchi & Hulse, 1993). This is used less commonly than identification tasks; interestingly, not all subjects who can identify pitches absolutely can produce them accurately, though examples of the converse have not yet been found (Petran, 1932). In a variation of both identification and production tasks, a duration ranging from a few seconds up to a few days is inserted between stimulus presentation and response; illustrating their long-term memory for pitch labels, AP possessors show little decay whereas RP subjects deteriorate to chance levels of performance after the first minute of delay (Bachem, 1940, 1954).

As with task type, researchers have varied widely in establishing what performance standard qualifies as AP. Percentage correct, a popular metric for identification tasks, is rarely perfect, and no universal guideline exists for an objective cutoff point. Octave errors are frequently allowed for the reasons mentioned above, and semitone errors are also in many cases (Ward, 1999). The latter serves not just as a more generous criterion but as a way to include AP possessors who have a shifted tuning standard; such subjects may have been raised with instruments not tuned to A 440 Hz; anecdotally, a few AP possessors report a gradual shift of their internal tuning template with age, on the order of one or two semitones (Ward, 1963; Ward & Burns, 1982). For an illustration of the variety of measurement criteria used across different studies, see Takeuchi and Hulse (1993, p. 347).

The multitude of methodologies, though difficult to integrate, has yielded insight into different types and degrees of AP. Not an all-or-nothing trait, some possessors can be classified as having 'quasi-AP.' This category includes singers who have come to remember the lowest note in their vocal ranges, musicians who can reliably auralize the tuning pitch for their instrument (e.g., A 440 for orchestral players, or the low E to which guitarists tune), and even those afflicted with tinnitus at a fixed frequency; in short, cases of AP limited to a single reference tone. Because judgments for any other pitch requires the extrapolation from this reference point via RP, such quasi-AP possessors should be distinguishable by their increased reaction times in pitch identification tasks (Bachem, 1937, 1955; Ward, 1999). More bluntly, Bachem (1937, 1955) has written off ‘pseudo-AP’ as an erroneous application of the term AP; pseudo-AP refers to any improvement in pitch identification through training that still yields an average error of a few semitones or more.

Another flavor of AP has emerged from the variation in timbres used across studies. Referred to as ‘absolute piano,’ the name derives from the tendency of many AP possessors to perform more accurately when making judgments of stimuli whose timbre is more familiar, such as piano vs. sine wave tones (Balzano, 1984; Lockhead & Byrd, 1981; Miyazaki, 1989; Sergeant, 1969). Dovetailing with this familiarity-based advantage for piano tones is Pantev’s (1998) finding that highly skilled musicians show an increased auditory cortical representation by about 25% of piano tones but not pure tones; indeed, the degree of this effect correlates with age of onset of musical training. Although the timbre-familiarity effect has been documented for piano players, the evidence is less clear for other instruments (Marvin & Brinkman, 2000; Vanzella & Schellenberg, 2010; but c.f. Brammer, 1951).

Other factors besides familiarity may contribute to the variation in performance on AP tasks, such as the potential timbral cues available in complex tones. In comparing performance across instruments, pitch range is also a factor, and often confounded with timbre. For example, if a piccolo player with AP performs more accurately with piccolo tones than tuba tones, is it due to familiarity with the timbre or with the range of the instrument? Some performers of instruments in such extreme registers have been found to judge most accurately in the corresponding ranges, but AP possessors in general tend to do best in the central ranges where most music is written, further supporting the familiarity effect (Bachem, 1937; Miyazaki, 1989; Petran, 1932; Takeuchi & Hulse, 1993). Pitch range also sets a firm upper limit on AP performance in all possessors because of chroma fixation: frequencies above 4-5 kHz no longer produce a clear pitch percept (Semal & Demany, 1990; Ward, 1963). The effects of timbre and range on AP performance vary among subjects; some are quite susceptible to these factors, while others are virtually unaffected (Bachem, 1937, 1940). The influence of instrument familiarity raises an intriguing question for professional musicians at the boundary of AP: some non-possessors have anecdotally experienced quasi-AP ability while physically holding (though not playing) their musical instruments (Gerard Nolan, personal correspondence); perhaps the added sensory or contextual cues in such instances are sufficient in borderline cases to retrieve otherwise inaccessible long-term pitch memories.

Even greater than the effects of timbre and range on performance is that of pitch class. Specifically, AP possessors are both faster and more accurate in identifying 'white key' notes (C, D, E, etc) than 'black key' notes (C#, D#, F# etc) (Miyazaki, 1988, 1989, 1990; Takeuchi & Hulse, 1991). At least three alternative explanations have been suggested to account for this. One factor could be the additional element in black key names; they require the extra # or *b* symbol, as well as the additional step of referencing from their corresponding white key (e.g., 'is it A? No, higher…A#'). Another possibility is that white keys are simply more prevalent in music and thus more familiar to subjects. The last theory, to which I will return in the discussion of etiology, is that white keys are usually taught before black keys in early music training, thus increasing the odds that AP will be developed for those pitch classes (Miyazaki & Ogawa, 2006; Sergeant, 1969; Takeuchi & Hulse, 1991). Support for greater white key familiarity, due either to music training or general exposure, comes from pupillometry. Pupil dilation, which reflects increased information processing demands, was found to be significantly larger in black versus white key identification, and marginally so with unfamiliar versus familiar timbres, during an AP identification task (Schlemmer, Kulke, Kuchinke, & Van der Meer, 2005).

AP possessors, through a combination of pitch identification and an understanding of music theory, can identify the key in which a piece of music is played, recognizing for example when a familiar composition is transposed out of its original key. Known as ‘absolute tonality,’ this skill is present to some degree in non-possessors as well, suggesting it to be a weaker form of AP (Ward, 1999). Indeed, a number of studies have discovered better than chance performance on such tasks, even when discriminating between original and transposed recordings of well-known pieces separated by a single semitone (Sergeant, 1969; Takeuchi & Hulse, 1991; Terhardt & Ward, 1982; Terhardt & Seewann, 1983; Vitouch & Gaugusch, 2000). The presence of rudimentary or latent forms of AP in the general population has important implications for understanding its etiology; further exploration of such evidence will be discussed later.

A final question relevant to the definition of AP is its relation to categorical perception. Generally accepted as an ability to assign a verbal label to a pitch class presented in isolation (or vice versa), some researchers have suggested that pitch is perceived categorically by AP possessors (Harris & Siegel, 1975; Siegel & Siegel, 1977). However, two important characteristics reveal that this is the case for labeling but not perception; pitch discrimination is not absent within categories, nor is it enhanced at category boundaries (Burns & Campbell, 1994; Levitin, 2005). That is, AP possessors would still detect a difference between two mistuned A's, for example, to the same extent (though no better) than would RP possessors and also to the same extent as they would the difference between an equivalently separated pair of mistuned tones in adjacent pitch classes (say, a slightly raised G# and lowered A). In other words, the labeling process depends upon but does not alter pitch discrimination for AP possessors.

Given that AP consists of perceiving pitch within a defined category and assigning it a corresponding label, a related issue concerns the reliance on verbal labels for making and remembering absolute pitch judgments (Zatorre & Beckett, 1989). If such information is exclusively verbally encoded, then AP retention should be weakened by interfering verbal information; alternatively, if AP is encoded through other means, then verbal interference should have no effect, just as short term pitch memory is influenced by tonal but not verbal stimuli (Deutsch, 1970). Zatorre and Beckett (1989) explored this possibility, discovering that neither verbal nor tonal interference impaired AP retention. However, one criticism worth noting is that the verbal interference tasks involved numbers rather than pitch class names (i.e., letters A-G); it is possible that different results would be found with that adjustment, or with a more stringent test of recall, e.g. pitch production instead of identification (Takeuchi & Hulse, 1991).

Thus far, this investigation of AP has drawn largely from operational definitions and behavioral data within the domain of musical tasks and applications. To better elucidate its specific components and neural substrates, we turn now to the accruing physiological knowledge derived from recent imaging studies.

Neuroanatomy of absolute pitch

Structurally, the most widely recognized difference between AP possessors and non-possessors is a leftward asymmetry of the planum temporale (Chen, 2000; Hamilton, 2004; Levitin, 2005; Limb, 2006; Keenan, 2001; Munte, 2002; Schlaug, 1995; Zatorre, 1998, 2003). Situated in the superior temporal plane posterior to Heschl's gyrus, the PT is believed to process and analyze spectrally and temporally complex sounds as part of the auditory association cortex (Griffiths, 2002). Imaging studies have found it to respond to both words and musical tones, but particularly the latter during active listening tasks (Binder, 1996). In an MRI comparison of musicians and non-musicians, Schlaug (1995) found a greater leftward PT asymmetry in the musicians, due entirely to the subgroup of those with absolute pitch in the sample. Further investigations replicated the increased PT asymmetry amongst AP possessors, but attributed it mainly to a decreased right PT rather than enlarged left PT relative to non-possessors, indicating pruning of the right PT and/or reallocated resources to the left hemisphere (Keenan, 2001). While the dependent variable in these two studies was PT surface area, an earlier study found a larger left PT size amongst AP possessors compared to a musically unselected sample by measuring volume (Zatorre, 1998).

Functional imaging work has offered converging evidence that the left PT is particularly involved in absolute pitch identification tasks. In one MEG study, it was observed that in AP possessors, compared to non-musicians, there was a posterior shift in the left N1m equivalent current dipole (ECD) response (Hirata, 1999). More recently, an fMRI study found that left but not right PT activation correlated with both AP ability and age of onset of musical training (Ohnishi, 2001). -ERP data supports this trend, with an early ‘AP negativity’ left posterior-temporal response 150 ms after onset of pitch stimuli unique to AP possessors (Itoh, 2005). The only known case of AP continuing after lobectomy in the literature indicates that the left anterior temporal lobe, in contrast, is not necessary for this ability, at least for that one patient (Zatorre, 1989).

Indirectly, an intriguing explanation for PT involvement is proposed by Zatorre (1998) as part of a PET study of the functional anatomy of AP. Consistent with the concept of AP as a labeling ability based on stored verbal-tonal associations, AP possessors compared to non-possessors in this study showed unique activation in the left posterior dorso-lateral prefrontal cortex, an area related to learning conditional associations involving sensory stimuli, when engaged in AP tasks. Furthermore, AP and RP subjects showed similar activation during an RP interval judgment task (for which both groups can refer to stored associations between auditory interval and verbal label). Anatomically, the PT contains auditory association cortex that projects directly to the parts of the posterior DLF cortex that were most active here (Zatorre, 1998). Recent anatomical and functional imaging work further supports the notion that AP may involve unique perceptual or encoding processes for tonal information, perhaps emerging from differing patterns of cortical organization or activation (Bermudez, Lerch, Evans, & Zatorre, 2009; Loui, Li, Hohmann, & Schlaug, 2010; Oeschlin, Meyer, & Jancke, 2010; Schlemmer et al., 2005; Schulze, Gaab, & Schlaug, 2009; Wilson et al., 2009).

The neural correlates of AP can be better understood by examining what is uniquely active amongst possessors, but also what is conspicuously inactive. The other fundamental functional difference found in Zatorre’s (1998) AP versus RP comparison was that only the non-possessors showed significant activation in the right inferior frontal cortex during the RP interval judgment task. This area is believed to reflect maintenance of pitch information in auditory tonal working memory, the idea here being that AP listeners, relying on their long-term representations of individual pitches, do not need to update working memory the way other listeners would to make interval judgments.

A variety of ERP studies have reached similar conclusions regarding AP tonal working memory through converging evidence (Crummer, 1994; Hantz, 1992; Klein, 1984; Wayman, 1992; Renninger, 2003). Using variations of an oddball paradigm in which two different tones are presented at uneven frequency of occurrence, (e.g. 80% 1000 Hz tones and 20% 1100 Hz tones), a positive-going component of the event-related brain potential (P300) is typically elicited by the infrequent stimuli; again, this is held to reflect an updating of working memory (e.g. Klein, 1984). Paralleling Zatorre's (1998) PET data, the P300 elicited by such rare auditory stimuli is small or absent in AP possessors (though not in response to analogous visual oddball tasks).

However, a handful of studies have failed to replicate these results (Barnea, 1994; Hantz, 1995; Hirose, 2002), probably due in part to inconsistent choice of auditory stimuli and task difficulty across studies, such that the failures to replicate may not have chosen sufficiently difficult tasks that would require subjects to use AP ability. Renninger (2003) helped to reconcile these discrepancies by testing subjects with a range of AP and RP skills on a more demanding listening task. By correlating P300 magnitude with performance on both AP- and RP-specific tests, it was confirmed that the reduced P300 AP effect co-varied positively with AP ability and AP task demands, and negatively with RP ability. Thus, the variety of past results can be explained by these factors, while lending further support to the theory that AP possessors are less likely to rely on updating tonal working memory given their long-term internal pitch representations.

Further understanding of AP and the brain comes from AP in the blind. The typical PT asymmetry in normal AP possessors frequently reported above does not hold up in their blind counterparts; one MRI analysis revealed only a greater variability, but no specific trend, in PT asymmetry amongst the latter group (Hamilton, 2004). More directly, an fMRI study contrasted the activation patterns in blind and sighted AP possessors during a pitch memory task, finding a greater contribution of the lingual gyrus, parietal and visual association areas and reduced temporal and cerebellar activation in the former, suggesting enhanced cross-modal plasticity in response to visual sensory deprivation (Gaab, 2006). That recruitment of visually deafferented occipital cortex, particularly regions typically contributing to processing categorical sensory information, could provide an additional neural substrate for blind musicians to develop AP offers an appealing explanation for the greater proportion of AP possessors amongst the blind, as well as their apparent prolonged critical period (Gaab, 2006; Hamilton, 2004).

And, by highlighting the critical contribution of experience-dependent brain plasticity, the phenomenon also lends strong support to the importance of developmental factors in the acquisition of absolute pitch. While this perspective will be explored in greater detail below, it is important to note here that a multitude of recent studies have linked both short-term and long-term musical experience to a host of structural and functional changes at cortical and neuronal levels (e.g., Brechmann, 2004; Elbert, 1995; Fritz, 2007; Gaser, 2003; Munte, 2002; Pantev, 1998, 2003; Pascual-Leone, 2003;

Schlaug, 1995, 2001, 2003; Rauschecker, 2003). Connections between behavioral skills and their neuro-anatomical correlates raise the question of causation just as frequently as they fail to answer it, and AP is no exception. While these lines of research highlight the differences between AP possessors and non-possessors, a look at elements of AP in the general population offers more productive insight into the mystery of the origins of AP.

Long-term pitch memory in the general population

Is it the case that anyone can utilize AP to some extent? Do most people possess this ability? Considering that information concerning frequency makes its way from the lowest levels of the auditory system up to at least the tonotopic map in A1, it ought to be universally present in some form (e.g., Pantev, 1989). While learning to attach formal labels to stored pitch representations requires early musical training, a few researchers have tested for implicit forms of AP in the general population using popular music. Absolute tonality, described earlier as a potentially weaker form of AP with which a listener can identify the key of a musical composition, has been reported in a variety of samples of AP non-possessors (Sergeant, 1969; Takeuchi & Hulse, 1991; Terhardt & Ward, 1982; Terhardt & Seewann, 1983; Vitouch & Gaugusch, 2000). More recently, Schellenberg and Trehub (2003) capitalized on the ubiquitous presence of television, asking unselected college students to discriminate between six popular TV theme songs either presented in the original key or transposed up or down one or two semitones. Judgment accuracy for well-known theme songs significantly exceeded chance performance (mean 64% correct), although this was not the case for unknown themes that were included as a control to avoid acoustic artifacts from the transposition manipulation process) (see also Schellenberg & Trehub, 2008). The results are remarkably close to those achieved (mean 59%) by musically trained subjects without AP discriminating between original and transposed versions of Bach preludes in a very similar design by Vitouch and Gaugusch (2000), and notably similar to the 65% correct AP identification score achieved by Brady (1970), the only known case of an adult reliably learning AP. Though not perfect, it seems that long-term pitch memory retention is indeed widespread.

Beyond same-or-different key identification, traces of latent AP in the general population have also been found with pitch production tasks. For example, when singing the first note of a few different popular folk tunes and Christmas carols at separate sessions two days apart, unselected subjects showed less variation (mean SD 1.5 semitones) among repeated attempts of the same song compared to four different songs (mean SD 2.5 semitones) (Halpern, 1989). Considering that such songs are performed and recorded in a variety of keys, this study may have underestimated the real effect. Levitin (1994) sought to examine this using modern pop music with single objective standards of starting pitch. Subjects were twice asked to select a popular song with which they felt very familiar from a rack of CDs, imagine it was playing in their heads starting anywhere in the song, and sing, whistle, or hum along. When the produced pitches were compared to the actual recording (excluding octave errors), 67% of subjects were within two semitones on the first trial, and 60% on the second. Again, non-possessors appear to be retaining absolute pitch information, imperfectly but well above chance. One of the studies presented here directly compared the performance of AP possessors on similar tasks with that of non-possessors.

Even infants seem to recognize and respond to absolute pitch information. Saffran (2001) found that infants track tone sequences based preferentially on absolute versus relative pitch information, whereas typical adults follow the reverse pattern. Similarly, infants have been found to respond differently to familiar lullabies presented at familiar versus novel pitch levels (Volkova, 2006). Perhaps this is why mothers have been found to maintain near-identical pitch when singing the same songs to their infants in sessions more than a week apart (Bergeson & Trehub, 2003).

A more prevalent form of implicit AP is evident in judgments of illusions relating pitch class to perceived height by Deutsch and colleagues (Deutsch, 1986, 1988, 1990, 1991, 1992, 2004; Deutsch, Moore, & Dolson, 1984, 1986; Deutsch, North, & Ray, 1990). When listening to pairs of Shepard tones- complex tones consisting of octave-spaced partials designed to produce clear pitch class percepts but ambiguous pitch height- listeners generally judge which is the higher or lower tone of the pair based on proximity along the pitch class circle (Shepard, 1964). Illusions based on these tones, such as the tritone paradox, the semitone paradox and the melodic paradox, indicate that listeners reliably perceive notes as higher or lower depending on pitch class, or note name, even in the absence of pitch height information. The form of this effect that has been studied most extensively is the tritone paradox (Deutsch, 1986, 1991, 1992; Deutsch, Moore, & Dolson, 1986; Deutsch, Henthorn, & Dolson, 2004; Deutsch, North, & Ray, 1990; Dolson, 1994). For example, proximity cues are not available at the equally-spaced tritone interval (pitch classes in tritone relation are 6 semitones apart in either direction). One might expect listeners then to lack confident high-low opinions in such cases. However, Deutsch and colleagues found clear, consistent, systematic judgments based on pitch class and varying between individuals. Moreover, the arrangement of judgments along the pitch class circle in each of these illusions correlates with listeners' language and dialect, pitch range of speaking voice, and linguistic community, raising the idea that AP, at least in this implicit form, originally evolved in connection with speech (Deutsch, 1991, 1992; Deutsch, North, & Ray, 1990; Deutsch, Henthorn, & Dolson, 2004; Dolson, 1994).

Consistent with this viewpoint is the performance of tone-language speakers in both implicit and explicit AP tasks (Deutsch et al., 2004, 2006, 2009). Tone languages, such as Vietnamese, Mandarin, and Thai, differ from intonation languages such as English in that the meanings of words depend on both the pitch and pitch contour in which they are spoken. There is a clear conceptual connection with AP in that both speaking a tone language and identifying the name of a tone in isolation require the association of pitch with verbal labels. Deutsch, Henthorn and Dolson (2004) found implicit long-term pitch memory to be more stable in native Vietnamese and Mandarin speakers than English speakers. Specifically, when comparing the variation in pitch of individual words spoken across sessions on different days; both groups performed similarly within the same day sessions.

While these results might seem intuitively clear, namely that speaking a language requiring tonal precision to convey meaning ought to lead to more consistent pitch in speech production, the connection between tone language and AP is more convincing in a musical domain. Deutsch, Henthorn, Marvin and Xu (2006) sought just such evidence, testing for AP in an American (Eastman) and a Chinese (Beijing) music conservatory, with the prediction that the fluent Mandarin speakers comprising the latter group should have a much higher prevalence of AP (defined as a score of 85% or higher on the AP test). Groups were subdivided by age of onset of musical training (age 2-5 vs. 6-9), and a striking difference between groups was found within each age group. When allowing for semitone errors, 75% of Beijing students who began musical training at ages 4 and 5 met the criterion for AP versus 14% of Eastman students; for onset at ages 6 and 7, the percentage of subjects was 68% and 10%, and at 8 and 9 it was 42% and 0% respectively. It appears that early exposure to tone language (from infancy, presumably) provides a huge advantage to increase probability of acquisition of AP given musical training. Indeed, a variety of functional imaging work supports the notion that pitch information is processed differently as a result of tonal vs. intonational language background (Chandrasekaran, 2007; Gandour, 2000; Hsieh, 2001; Kaan, 2007; Krishnan, 2005; Wang, 2001; Wong, 2004; Xu, 2006). It is likely, therefore, that the developing brain's attention to absolute pitch features of words while forming linguistic pitch-meaning associations facilitates subsequent formation and retention of musical pitch-label pairings.

Building on the work of Deutsch et al. (2006) at the Eastman and Beijing Conservatories, Deutsch, Dooley, Henthorn & Head (2009) tested students at the USC Thornton School of Music in every first year aural skills class as well as in one of the school orchestras, proctoring the AP test described earlier and gathering detailed demographic information. This latter questionnaire included an extensive set of factors potentially related to AP possession, such as age of onset of musical training, instruments played, birthplace and other places lived, and languages spoken and level of fluency for both the subjects and their parents. Strong evidence was found for the correlation of tone language fluency with AP possession, supporting the tone language hypothesis over competing potential factors like ethnicity and cultural effects as contributors to AP acquisition. Specifically, taking students of East Asian ethnicity, performance on the AP test was significantly higher among those who spoke a tone language very fluently compared with those who were only fairly fluent or non-fluent; importantly, the AP performance of the latter group did not differ significantly from that of Caucasian students who spoke only nontone language. In addition, AP performance did not significantly differ between these '*tone very fluent subjects*' and the Beijing students tested in the study of Deutsch et al. (2006) mentioned above. The data also corroborated the negative correlation between AP and age of onset of musical training, although this relationship was nowhere near as strong as the effect of tone language fluency. Taken together, the findings support the notion that acquisition of AP, at least for tone language speakers, involves the same process as occurs in the acquisition of a second tone language.

Critical periods

This connection between AP and language leads to the question of critical periods. The upper age limit on AP acquisition is undeniable. It is evident in the inability of virtually any adults to learn AP (Bachem, 1940; Brady, 1970; Crozier, 1997; Cuddy, 1968, 1970; Meyer, 1899). The gradual closing of the window is observable in the diminishing rates of return with increasing age of onset of musical training in children (Crozier, 1997; Deutsch, 2006; Takeuchi & Hulse, 1993; Vitouch, 2003). This is also in line with the critical period evidence for a variety of other forms of musical development

(Trainor, 2005). As Levitin & Zatorre (2003) point out, the rare individual who develops AP on the later end of the age-of-onset spectrum is the statistical exception that proves the rule. The white-key bias amongst many AP possessors discussed earlier is best explained by the fact that these keys are typically taught first and emphasized most in formal music training, such that many young learners manage to establish stronger pitch-label representations for the white keys as their chronological opportunity wanes. This phenomenon was captured in detail cross-sectionally by Miyazaki & Ogawa (2006), who tested 4-10 year-old children in each year of a rigorous piano training program; AP for black key notes, closely following the timeline of instruction, appeared later than that for white keys and in many subjects never reached the same level of proficiency. Furthermore, the overall improvements in AP leveled off after age seven, again highlighting the upper limit for acquisition.

Recent experimental attempts to contrast the success of teaching pitch recognition to different age groups has provided direct evidence of the age-based variation in propensity to acquire AP (Crozier, 1997; Russo, 2003), with children under 6 outperforming adolescents and adults, respectively. This parallels the established timelines for first language development, i.e., acquisition at native-speaker levels of fluency, free of accent (e.g. Flege & Fletcher, 1992; Kuhl, 2000; Newport, 1990). These developmental patterns, in which a span of heightened learning sensitivity declines into a cutoff point for further improvement, are considered critical periods. However, there is general but not complete agreement as to the exact definition, and consequently whether language qualifies as such (Hakuta, 2003; Newport, 2001). The shift from absolute to relative pitch perception established by Saffran (2001, 2005, above) is fitting with the general shift in infant language acquisition by which an initial ability to learn and discriminate among any speech sounds, such as /r/ and /l/, gives way to language-specific specialties (and limitations) in speech perception (Aslin, 1998). Another music-linguistic observation relevant to the nature and origins of AP concerns an apparent emphasized speech bias towards tone frequencies most dominant in daily music exposure. Braun (2000, 2001) found speech to be coupled to precognitive memory for absolute pitch, with a tendency of Dutch speakers to gravitate toward pitches corresponding essentially to the white keys on a piano when speaking with emphasis. This too supports the idea of an innate element of AP in the general population and both a connection with and application to language. Related to this music-language connection also is the finding that musical ability correlates with second-language proficiency (Slevc, 2006).

Still more evidence draws from the increased prevalence of AP amongst the early blind, as mentioned earlier, and developmentally delayed populations including those with autistic and Williams Syndrome, to be discussed in further detail below (Brown, 2003; Chin, 2003; Foxton, 2003; Hamilton, 2004; Vitouch, 2003; Snyder, 2004). Given a generally increased window for brain maturation and plasticity, it is to be expected that these populations would be predisposed to acquire AP in greater proportions, following from the idea that a critical period is at work.

## Abnormal Populations

An investigation of five individuals with Williams syndrome supports the extended critical period hypothesis; all five demonstrated excellent AP abilities in a variety of tasks, only one of whom began musical training before age six (Lenhoff, 2001). Williams syndrome is characterized by general mild retardation but enhanced musicality and sociability. In keeping with neural correlates of AP at large, WS individuals show enlarged A1 and Heschl's gyrus and, in particular, increased leftward PT asymmetry (Hickok, 1995; Sacks, 1995; Toga, 2006). While these preliminary results are intriguing, the potential WS-AP connection awaits more research to shift from a preponderance of speculation to a more solid empirical foundation.

Similar to Williams syndrome in some ways but dissimilar in others is autistic spectrum disorder. Whereas the former is characterized by relatively increased social and linguistic skills, the latter shows just the opposite tendencies- social and linguistic impairments, with relative strengths in detail-oriented spatial skills such as the Block-Design Task (Brown, 2003; Young & Nettelbeck, 1995; Heaton, 1998). Yet, it has been conjectured that there are a disproportionate number of musical savants with AP among the ADS population, in this case due to a general cognitive processing proclivity towards local versus global features (Brown, 2003; Chin, 2003; Foxton, 2003; Heaton, 1998). This detail-oriented processing style, alternatively referred to as 'weak central coherence,' narrow or analytical attention, may allow ADS individuals to retain the meaningful perception of absolute pitch information that is generally present in infants but lost at explicit levels when relative processing takes over for most people. Snyder (1999, 2004) goes so far as to speculate that autism consists of a heightened awareness of the specific sensory details of object attributes, the inhibition of which allows the formation of more holistic and abstract concepts in normal individuals. Furthermore, Snyder (1999, 2004) continues, disinhibition (perhaps via TMS) should allow anyone to access these details and acquire skills, such as AP, second language fluency, enhanced creativity, or accelerated mental calculation(!) A fascinating possibility, to be sure, though it remains to be demonstrated. Most methodologically sound, and consequently informative, is Heaton's (1998) experimental approach to examining the influence of autism on AP development. A comparison of musically naïve autistic boys with mental-age-matched controls found an advantage for the former in a pitch memory task (identifying learned tone-animal pairs) but not a lexical memory task, lending further support to the theory that the sensory detail-focused cognitive style of autistic individuals increases their susceptibility to acquiring AP.

This emerging field of study, AP in unusual populations, may offer important insights as it develops, but the dearth of hard data due to the difficulty in obtaining a sufficient number of subjects limits the current weight of the findings. A few caveats to these aforementioned studies are worth noting. The control group in Brown's (2003) comparison of AP possessors and non-possessors on autistic-like psychological characteristics differed in potentially fundamental ways from the AP group; 62% of the latter but only 18% of the former began musical training before age 6, and the former were recruited from a single amateur performing group rather than advertisements distributed amongst music schools and university music departments. Brown's conclusion that the AP possessors evinced such socially eccentric tendencies would be better supported by contrast with an equivalently devoted group of control musicians; it is well known that serious professional artists in various domains have somewhat eccentric tendencies.

Young and Nettelbeck's (1995) case study of an autistic musical savant is fascinating in its own right but limited not just by the n of 1 but by the potential confounds in the case: the entire family clearly possesses unusual intellectual talents and orientation towards academic achievement, and moreover they are all fluent in a tone language; this provides insight into the nature of the main subject's AP abilities, but the linguistic confound in particular necessitates hesitation in drawing conclusions about the origins of AP from this example. The shifting focus to methodological shortcomings offers a fitting segue into the genetic basis of AP.

## Genetics

Of the reasoning put forward for the hereditary nature of AP, the most popular may be family incidence of the ability. Such arguments miss the seemingly obvious point that a shared family environment offers similar emphasis on and/or access to formal musical training, or simply a non-independent level of exposure to music. Other traits like native language, religion, and political affiliation tend to run in families, and AP may show similar patterns of heritability for similar, environmental reasons. Profita and Bidder (1988) rest their claim of a hereditary basis of AP on just such logic, made all the more circular that they specifically sought out AP possessors from musically educated families (even while writing off AP as an innate skill typically acquired without effort). In 8 of the ten families they analyzed with more than one AP possessor (out of 19 families total), all the possessors were siblings, so it seems likely they received comparable formal musical training.

The hunt for the genetic basis of AP continued with Baharloo (1998, 2000) along the same lines of reasoning, essentially that aggregation in families is adequate evidence for a genetic basis, and the study itself, though often cited as such evidence, concluded only that the importance of early musical training was confirmed and that genetic variations should be identifiable. An examination of three pairs of identical twins, all with AP, provides a more tangible basis for this search, although more such subjects must be found before claims can be made on these grounds (Gregersen, 1998).

Drayna (2001) estimates heritability for pitch perception to be about 70-80% based on monozygotic and dizygotic twin performances on the Distorted Tunes Test, which admittedly tests relative rather than absolute pitch; he (1998) also praises Baharloo's admittedly unfinished search for the AP gene (as does Gregersen [1998]), and laments 'an ugly problem here- the quagmire of plasticity' as an unpleasant hindrance to this genetic treasure hunt.

Sparking recent debate, Gregersen (1999, 2001) noted the larger proportion of AP amongst Asians in a large survey of music students, suggesting ethnic genetic differences among other explanations for this finding. As Henthorn and Deutsch (2007) pointed out, however, a reanalysis of this data reveals the ethnic differences to depend almost entirely on whether early childhood was spent in America or East Asia, essentially disarming the ethnic genetic argument and strengthening support for the tone language effect in its place; however, cultural differences also remained as a potential factor in differential AP acquisition rates. Most recently, Athos et al.'s (2007) internet survey was intended to capture AP possessors but unfortunately was susceptible to self-selection and biased responding given the method of data collection. Again, no actual AP gene was discovered, but the collected data was portrayed as evidence for such an explanation, without any explicit proof. What was found, to the extent that it can be relied upon, is the large effect of early musical training; an inflated sense of bimodal distribution of AP (missing the continuous elements of the ability in the population by classifying respondents as have- or have-nots and allowing those with intent to obtain perfect scores by whatever means necessary); and a potentially erroneous estimate of which pitch classes were identified most accurately. There are reasons to expect that genetics play a role in AP acquisition, chief among them the fact that so many people fail to develop or retain AP even under optimal conditions, such as early musical training and tone language fluency. Experimental genetic manipulation in mice, for example, has been shown to enhance learning and memory (Tang, 1999). However, clear evidence of an AP gene has yet to be found.

Imperfect pitch

Another domain of AP research involves the search for shortcomings and disabilities of AP possessors. Various attempts to document musical disadvantages of AP have generally relied on convoluted relative pitch tests. The studies most frequently cited to support such claims used a movable-do arbitrary pitch labeling system, in combination with mistuned tones in some cases, to confuse AP listeners into making more errors than non-possessors on an interval judgment task (Miyazaki, 1992; 1993; 1995). More recently, Miyazaki & Rakowski (2002) have shown that AP possessors, though significantly better at comparing written and sounded melodies under normal circumstances, performed marginally worse than non-possessors when the transcription is transposed into a wrong key. For a subject with AP, such rigged procedures are akin to an auditory Stroop task, as Miyazaki himself acknowledged (2000); the immediate perceptual knowledge of a written or heard tone as having a specific identity clashes with the added cognitive burden of re-labeling the tone based on the arbitrary rules of a given procedure. Such artificial conditions designed to find flaws in AP performance, though interesting as exploratory studies, bear little resemblance to authentic musical tasks and contexts.

These claims continue to be repeated in the literature, despite such shaky foundations. For example, Miyazaki (2004) describes AP as “irrelevant to and dispensable to music,” (p. 427) even a “handicap for musicianship” (p. 428). Levitin and Rogers (2005) echo this sentiment: “Sometimes regarded as a mark of musicianship, AP is in fact largely irrelevant to most musical tasks” (p. 26). Levitin (2008) later writes, “Most absolute pitch possessors actually have difficulty with relative pitch tasks” (p. 126). These allegations stand in stark contrast to the positive reputation of AP, widespread outside of the music perception literature and evident in the existence of commercial products designed to engender AP in their eager users (e.g., Burge, 2011). So, although absolute pitch is generally regarded as a desirable musical ability, the majority of studies testing its merits have concluded otherwise.

Studies

With the relevance of AP to musical ability so far a subject of controversy in the academic literature, the following experiments were designed to explore the potential benefits (or drawbacks) of AP in musical contexts. For all studies, musicians were recruited and tested for AP with the same test used and described in Deutsch et al. (2006). One challenge of isolating the contributions of AP to proficiency in musical tasks is that AP is associated with early onset of music training (and, subsequently, duration of musical training). Detailed questionnaires were therefore used to assess all subjects' musical training, linguistic background, and other potentially relevant characteristics. This made possible the evenly matched distribution of such variables in the AP possessor and non-possessor groups tested in these studies.

The aim of the first study (Dooley & Deutsch, 2010) was to test for advantages of AP possession in musical tasks beyond the mere identification of isolated tones. The most obvious yet undocumented advantage of AP ought to emerge in musical dictation tasks, which involve notating an aurally presented melody but do not require AP when a reference tone is given. 60 musicians were recruited for this study: 30 who self-reported AP possession, and 30 who did not but had equivalent age of onset and duration of musical training. Each subject was given the test for AP (Deutsch, 2006) and a musical dictation test modeled after the standard entrance examination given to all entering music majors at a prestigious music conservatory; this dictation test consisted of 3 brief musical excerpts: 2 tonal melodies and 1 four-part harmony, all composed in keeping with Western musical convention and each with the first note given in advance on the response sheet. Although this task required only relative pitch, it was hypothesized that AP possessors would still outperform non-possessors, even controlling for age of onset and duration of musical training, and the hypothesis was strongly confirmed.

Having established this strong positive correlation between performance on the AP test and the musical dictation test (Dooley & Deutsch, 2010), the second study was designed to further explore the contributions of AP possession (while controlling for age of onset and duration of musical training) to proficiency in other musical tasks (Dooley & Deutsch, under review). Since the AP advantage in musical dictation could be interpreted as resulting from simple identification of individual tones rather than from integrated comprehension of meaningful musical relationships, a stronger case for the relevance of AP to music could be made using interval identification, a relative pitch task depending only on accurate perception of the relationship between the two pitches comprising each interval.

For this study, 36 musicians (18 AP possessors and 18 non-possessors with equivalent age of onset and duration of musical training) were each asked to identify a series of musical intervals (e.g. minor second, major third, etc.). Three sets of 144 intervals were presented, all of which included all twelve interval sizes from a minor second up to an octave and created in all twelve keys; half of the intervals (randomly selected) were ascending, half descending, and a different ordering was used for each set. In one set, the tones forming these intervals were brief (30ms) sine waves lasting just long enough to evoke a clear sense of pitch; in the second set, the intervals were longer (500ms) piano tones; and the third set was identical to the second except that each interval was preceded by a V7-I chord cadence to provide a clear musical context. Although previous work (e.g., Levitin, 2008; Miyazaki, 2004) has deemed AP irrelevant or even harmful to music, particularly in tasks involving relative pitch, it was again hypothesized that AP possession would be associated with more accurate performance on the interval identification tasks, even controlling for age and onset of musical training.

The aim of the third study was to investigate the extent of long-term pitch memory for familiar tonal stimuli in both AP possessors and non-possessors matched for onset and duration of musical training (Dooley, under review). A number of studies have found evidence that long-term memory for absolute pitch information is widespread in the general population, at least to some degree (e.g. Deutsch, 2006; Levitin, 1994; Schellenberg & Trehub, 2003; Smith & Schmuckler, 2008), and this has led some researchers to consider AP to be a simple labeling ability that combines widespread pitch memory with unusually strong retention of verbal-pitch associations (e.g. Levitin, 2008; Wilson et al., 2009). However, recent anatomical and functional imaging studies support the notion that AP may involve unique perceptual or encoding processes for tonal information, possibly emerging from differing patterns of cortical organization or activation (Bermudez et al., 2009; Loui et al., 2010; Oeschlin, Meyer, & Jancke, 2010; Schulze, Gaab, & Schlaug, 2009). The question then arises whether AP possession is simply a labeling ability, as Levitin's (1994) two-factor model suggests, or actually confers advantages in long-term pitch memory even when formal labels are not required.

To answer this question, AP possessors and non-possessors were assessed on a long-term pitch memory production task in which they were asked to recall and vocalize any familiar song of their choice in the same key in which they were hearing it internally; this was repeated for their cell phone ringtones. Subject vocalizations were recorded and compared to the corresponding target pitches of the actual songs and ringtones chosen. If long-term pitch memory were truly widespread and AP conferred no additional advantages when learned pitch labels are not required, then both AP possessors and non-possessors would be expected to perform equally well; conversely, if AP is more than a verbal-pitch labeling ability, then one would expect AP possessors to demonstrate greater accuracy than non-possessors on these production tasks.

# CHAPTER 2: ABSOLUTE PITCH CORRELATES WITH HIGH PERFORMANCE ON MUSICAL DICTATION

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Abstract

Absolute pitch (AP) – the ability to name a musical note in the absence of a reference note - is a rare ability whose relevance to musical proficiency has so far been unclear. Sixty trained musicians – thirty who self-reported AP and thirty with equivalent age of onset and duration of musical training - were administered a test for AP and also a musical dictation test not requiring AP. Performance on both types of test were highly correlated ($r = .81$, $p < .001$). When subjects were divided into three groups based on their performance on the AP test, highly significant differences between the groups emerged. Those who clearly possessed AP showed remarkably high performance on the musical dictation test, the scores of those without AP varied widely, and the performance of the intermediate group of borderline AP possessors fell between that of clear AP possessors and clear non-possessors. The findings support the hypothesis that AP is associated with proficiency in performing other musical tasks, and run counter to the claim that it confers a disadvantage in the processing of relative pitch.

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Introduction

Absolute pitch (AP) is defined as the ability to name a musical note in the absence of a reference note, and its prevalence in Western cultures is estimated at less than one in 10,000 (Bachem, 1955). While the subject of much informal speculation, the relationship between AP and musical proficiency has so far been little investigated. On one hand, many distinguished musicians have, at least anecdotally, been credited with possessing AP (e.g. Bachem, 1955), and many other musicians seek to develop this skill. In addition, certain advantages of AP possession have been shown in psychoacoustic tasks involving identification of pitches (Hsieh & Saberi, 2007, 2008a, 2009). However, AP possessors have been found to be subject to a Stroop-like interference effect (Hsieh & Saberi, 2008b; Miyazaki & Rakowski, 2002), and generalizing from this, some researchers have claimed that AP is musically disadvantageous or irrelevant to other aspects of musical processing (e.g. Levitin and Rogers, 2005). Furthermore, the potential correlation of AP with the ability to perform various musical tasks is complicated by its association with age of onset of musical training. For example, Miyazaki and Rakowski (2002) have pointed out that to the extent that AP possessors enjoy an advantage in performing musical tasks, this may be due to earlier onset of musical training, longer duration of musical training, or both of these factors.

The present study was designed to test the hypothesis that AP is advantageous in musical contexts beyond the identification of isolated tones, controlling for age of onset and years of musical training. To this end, 60 musically trained subjects were recruited: 30 who self-reported having AP, and 30 who were equivalent in terms of age of onset and duration of musical training. All subjects were given a test of AP, together with a musical dictation test modeled after the placement examination given to all entering music majors at a prestigious music conservatory (the USC Thornton School of Music). The relative contributions to performance level on the musical dictation test of AP possession, age of onset, and duration of musical training were assessed.

## Method

### *Subjects*

There were 60 subjects in this study. These were 30 males and 30 females; average age 22.7 years (range 18-30). 30 subjects were recruited who self-reported AP; 30 matched controls were then recruited with equivalent onsets and durations of musical training. Of those who scored more than 80% correct on the AP test (n= 30, 13 male, 17 female), average age was 22.1 years (range 18-30), average age of onset of musical training was 4.6 years (range 3-8) and average number of years of formal musical training was 15.8 (range 11-25); of those who scored less than 20% correct on the AP test (n= 22, 13 male, 9 female), average age was 23.3 years (range 18-30), average age of onset of musical training was 4.9 years (range 1-8) and average number of years of training was 15.8 (range 10-28); of those who scored between 20% and 80% correct on the AP test (n= 8, 4 male, 4 female), average age was 23.0 years (range 19-30), average age of onset of musical training was 4.4 years (range 3-6), and average number of years of training was 14.4 (range 3-27). All subjects self-reported normal hearing.

### *Procedure*

All subjects were individually tested. They were first given the test for AP that had been employed in the studies by Deutsch *et al*. (2006, 2009). This test consisted of successive presentations of the 36 tones spanning three octaves from $C_3$ (131 Hz) to $B_5$ (988 Hz), and subjects were asked to write down the name of each tone (C, F#, E; and so on) after they heard it. All tones were separated from temporally adjacent tones by an interval larger than an octave, in order to minimize the use of relative pitch in making judgments. The tones were piano tones of 500 ms duration, with 4.25-s inter-onset intervals; these were presented in three 12-tone blocks, with 39-s pauses between blocks. A practice block of four successive tones preceded the three test blocks. No feedback was provided at any time during the test.

For the second test, the subjects were presented with three short musical passages (Fig. 1), and in each case were asked to notate what they heard. They were informed that they would be presented aurally with each passage four times in succession, and were provided with blank staff paper on which was given the starting note (or notes, in the case of the third passage) for each passage. They began notating each passage at their own discretion, and continued notating during all four presentations[1]. The experimenter played each new passage, and each presentation of the passage, when the subjects indicated their readiness to hear it.

The first two passages each consisted of a single 32-note melodic line. The tempo of the first passage was 64 bpm (i.e., 937 ms per dotted quarter note). The tempo of the second passage was 88 bpm (i.e., 682 ms per quarter note). The third passage consisted of four-part harmony; for this passage, the first note was given for the soprano (top) and bass (bottom) lines, consisting of 18 and 16 notes respectively, and subjects were instructed to notate only these two lines. The tempo of this passage was 48 bpm (i.e., 1250 ms per quarter note). The passages were composed in accordance with the conventions of Western tonal music, and the entire test, including the approximate level of difficulty and administration procedure, was closely modeled after the musical placement exam given to entering music majors at the USC Thornton School of Music.

Following the tests, the subjects filled out a questionnaire regarding the onset and duration of their music education, and demographic information.

*Instrumentation*

For both types of test, the stimuli were piano tones, generated on a Kurzweil K2000 synthesizer tuned to $A_4$ = 440 Hz. They were recorded onto a Zoom H2 digital audio recorder and were presented to subjects from this recorder via Sony MDR-7506 dynamic stereo headphones, at a level of approximately 72 dB SPL.

Results

Fig. 2 shows, for each subject, and across all three passages, the percentage of tones that were correctly notated in their correct serial positions, as a function of percentage correct on the test for AP. As can be seen, there was a strong positive relationship between performance on the AP test on the one hand and the musical dictation test on the other ($r = .81$, $p < .001$).[2] This correlation remained equally strong when controlling for age of onset and years of musical training ($r = .81$, $p < .001$). Neither age of onset ($r = -.23$, $p > .05$) nor duration ($r = .19$, $p > .05$) of musical training correlated significantly with the dictation scores.

These trends persisted when each passage was analyzed separately. Indeed, performance was highly consistent across passages, with high correlations between dictation scores on *passages 1* and *2* ($r = .84$, $p < .001$), *2* and *3* ($r = .81$, $p < .001$), and *1* and *3* ($r = .82$, $p < .001$). Performance on the AP and musical dictation tests were strongly and significantly correlated taking each passage separately (*passage 1* ($r = .76$, $p < .001$), *passage 2* ($r = .82$, $p < .001$), and *passage 3* ($r = .78$, $p < .001$); again, these correlations remained just as high when controlling for onset and duration of music training ($r = .75$, $p < .001$; $r = .83$, $p < .001$; $r = .78$, $p < .001$, for *passage 1*, *2*, and *3* respectively). As with the overall dictation score, neither age of onset ($r = -.19$, $p > .05$; $r = -.06$, $p > .05$; $r = -.23$, $p > .05$, respectively) nor duration of musical training ($r = .21$, $p > .05$; $r = .17$, $p > .05$; $r = .23$, $p > .05$, respectively) were significantly correlated with performance on any of the individual passages.

To quantify the extent to which each of these factors predicted overall performance on the dictation test, a multiple regression was performed with percentage correct on the AP test, age of onset of musical training, and years of musical training as predictor variables. AP score alone accounted for nearly two-thirds of all the variance in scores on the musical dictation test ($\beta = .81$, $R^2_{adj} = .66$, $F(1, 58) = 113.08$, $p < .001$). In fact, including age of onset of training ($\beta = -.04$) and years of training ($\beta = .07$) in the overall regression model accounted for only an additional 1% of the variance in musical dictation scores ($R^2_{adj}$ change = .01, $F(2, 56) < 1$).

It can also be seen (Fig. 2) that the subjects were divisible into three groups: those who were clear AP possessors *(> 80%* correct on the AP test), all of whom displayed remarkably high performance on the dictation test; those who were clear AP non-possessors *(< 20%* correct), whose dictation scores varied widely; and those who were borderline AP possessors (scoring between *20%-80%* correct), whose dictation scores correspondingly fell between those of the other two groups. (For reference, chance performance on the AP test – based on a 1/12 chance across 36 trials – averages 8.33% correct, and the probability of guessing over 20% correctly is less than .01.) This trichotomous categorization of AP ability is consistent with findings from other studies (e.g., Temperley and Marvin, 2008; Miyazaki & Ogawa, 2006).

To analyze these between-group differences in the musical dictation scores while controlling for duration and age of onset of musical training, an ANCOVA was performed, with AP category (*< 20%, 20-80%, > 80% correct on the AP test*) as the grouping variable, and age of onset and years of training as covariates. Age of onset was nonsignificant ($F < 1$), as was years of training ($F < 1$), and even while controlling for these, the main effect of AP score was highly significant and accounted for most of the variance in performance on the musical dictation test ($F(2,55) = 66.04$, $p < .001$, $\eta^2 = .71$), consistent with the overall regression analysis described above.

On post hoc comparisons, the performance level was significantly higher for *AP possessors* compared with *non-possessors* ($p < .001$); for *AP possessors* compared with *borderline possessors* ($p < .001$); and for *borderline possessors* compared with *non-possessors* ($p < .005$). Given that there were no significant differences between the groups in terms of age of onset of training ($F < 1$) or years of training ($F < 1$), these findings indicate strongly that the differences in performance levels between the groups were associated primarily with their differing degrees of AP possession.

## Discussion

By considering the relevance of AP to performance on a musical dictation test not requiring AP, the present study adds to a broader, ongoing exploration of the correlates of AP. While it is outside the scope of this article to discuss the genesis of AP in detail, we note that it has been proposed to be genetic in origin (Theusch *et al.*, 2009). It has also been shown that AP possessors have an exaggerated leftwise asymmetry of the planum temporale compared with non-possessor musicians (Keenan *et al.*, 2001; Schlaug *et al.*, 1995). In addition, it has been found that tone language speakers have a far higher prevalence of AP than do speakers of nontone languages, indicating a speech-related critical period in its genesis (Deutsch *et al.*, 2006, 2009). Related to this, tone language speakers show enhanced abilities to perceive and produce musical pitch (Pfordresher & Brown, 2009). Indeed, the potential for developing AP is evident very early in life (Saffran & Griepentrog, 2001). Incremental effects of early music education on the development of AP have also been documented (Miyazaki & Ogawa, 2006).

As Miyazaki & Rakowski (2002) have pointed out, it is important to distinguish the contributions of AP to musical ability from those of early musical training. In the experiment reported here, the strength of the relationship between AP and a test of musical ability holds, even controlling for age of onset and duration of musical training. Regardless of whether subjects were grouped into discrete categories of AP possession vs. partial possession vs. non-possession, or analyzed as a whole, the single factor of AP score alone accounted for the majority of all variance in performance on the musical dictation tests. Taken together, these results run contrary to the claim that AP is musically irrelevant or disadvantageous (e.g. Levitin & Rogers, 2005) and instead strongly support the hypothesis that AP contributes to musical proficiency beyond the simple identification of isolated pitches. The AP possessors in this study uniformly showed very high performance on the musical dictation test, and so showed no evidence of impaired relative pitch processing, thus adding to the growing body of research documenting advantages of AP possession in musical and psychoacoustic tasks (Hsieh & Saberi, 2007, 2008a, 2009).

Our present findings are also related to those reported by Miyazaki and Rakowski (2002). These authors tested AP possessors and non-possessors using a task that consisted of comparing auditory & visual presentations of melodies to make ‘same’ or ‘different’ judgments, for both tonal and atonal patterns, and for transposed as well as untransposed passages. Consistent with the present findings, the authors identified a significant AP advantage for accuracy in judgment of both tonal and atonal melodies when these were played to subjects in the correct key as written; however, they obtained a moderate negative correlation between AP score and judgment accuracy for the transposed melodies, although this correlation was significant only for the atonal melodies. A likely explanation for this apparent discrepancy is that AP possessors are subject to Stroop-like interference effects in artificial situations (Hsieh & Saberi, 2008b; Miyazaki & Rakowski, 2002; Takeuchi and Hulse, 1993).

Converging on a unanimous definition or operationalization of “musical ability” is, of course, a near-impossible task, certainly one outside the scope of the present paper. However, the extent to which the present findings can be considered to reflect overall musical ability depends in part on the external validity of the dictation test used. While the placement exam in the USC Thornton School of Music, upon which this musical dictation task was modeled, can no more capture musicality than any other single test, this task has at least stood the test of time as a practical measure for use by this music conservatory, whose faculty include many highly distinguished musicians. In the present experiment, its relevance to the common demands of music education and performance was further confirmed by a number of subjects who commented (unprompted) that the dictation task presented in the study was very similar to that required of them in various music courses.

While the overwhelmingly large role played by AP in predicting performance on the present dictation test was surprising relative to the comparatively small effects of onset and duration of musical training, we should note that conclusions drawn from this data are limited to the range of the characteristics of the subjects included in the study. Specifically, age of onset of musical training for all subjects ranged from age 1 to age 8, and duration of training ranged from 3 to 28 years; thus, these factors may play a larger role in predicting proficiency at musical dictation or other musical tasks for subject populations that include wider ranges of musical experience.

Although AP is often considered a dichotomous trait (e.g. Theusch *et al.*, 2009), some research has found the distinction between AP and non-AP to be more blurred than commonly thought (Takeuchi & Hulse, 1993; Vitouch, 2003). It is worth noting that in the present study also, a substantial minority of subjects did not fall neatly into either the category of AP possessor or that of non-possessor; rather, their AP scores far exceeded chance performance while still falling well short of the level of consistency achieved by clear AP possessors. Furthermore, the musical dictation scores of subjects in this intermediate category fell between those of the AP possessors and non-possessors. The 'borderline' nature of their AP possession was also reflected in their self-awareness regarding AP: While 27 of the 30 clear AP possessors believed they had AP (the other three, when asked, responded 'don't know' to the question of whether or not they possessed AP) and 17 of the 22 non-possessors believed they did not possess AP (five of the non-possessors responded 'don't know'), the eight subjects in the borderline group were split between 3 'yes', 3 'no', and 2 'don't know'. It is also an open question what factors lead individuals to develop borderline AP; one which will likely have implications for the broader question of the genesis of AP in general.

It is also important to note that while all subjects whose AP scores exceeded chance levels performed well on the musical dictation test (an overall mean of 91.7% correct and no scores below 56%) and all clear AP possessors performed very well on the test (a mean of 95.4%, with no scores below 78%), some non-possessors also performed well (a mean of 47.5%, but one even scored above 80% correct). AP is therefore not required for successful performance on musical dictation tasks – and indeed many world-class musicians do not possess AP – however from our present findings this ability appears to confer a musical advantage rather than a disadvantage.

Footnotes

1. As an exception, one AP possessor finished notating all three passages after only three listenings, declining the option to hear each one a fourth time, and scored 100%, 100%, and 97.1% correct on the three passages.

2. Because normality assumptions were not met for the raw data based on the Shapiro-Wilk test for AP scores ($p < .001$), musical dictation scores ($p < .001$), years of musical training ($p < .005$), and age of onset of musical training ($p < .005$), all variables were rank-transformed, and all reported statistics are based on the rank-transformed data. Nonetheless, all patterns of significance for the raw data were nearly identical to those reported.

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Figures

Figure 2.1. The three musical passages presented for the musical dictation test. The first tone for each passage was given for the melodic dictation passages, and the highest and lowest notes for the four-part harmony passage.

Figure 2.2. Overall percentage correct on the musical dictation test, as a function of percentage correct on the test for absolute pitch. A least-squares linear regression trendline has been fitted to the data. (color online)

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Figure 2.1

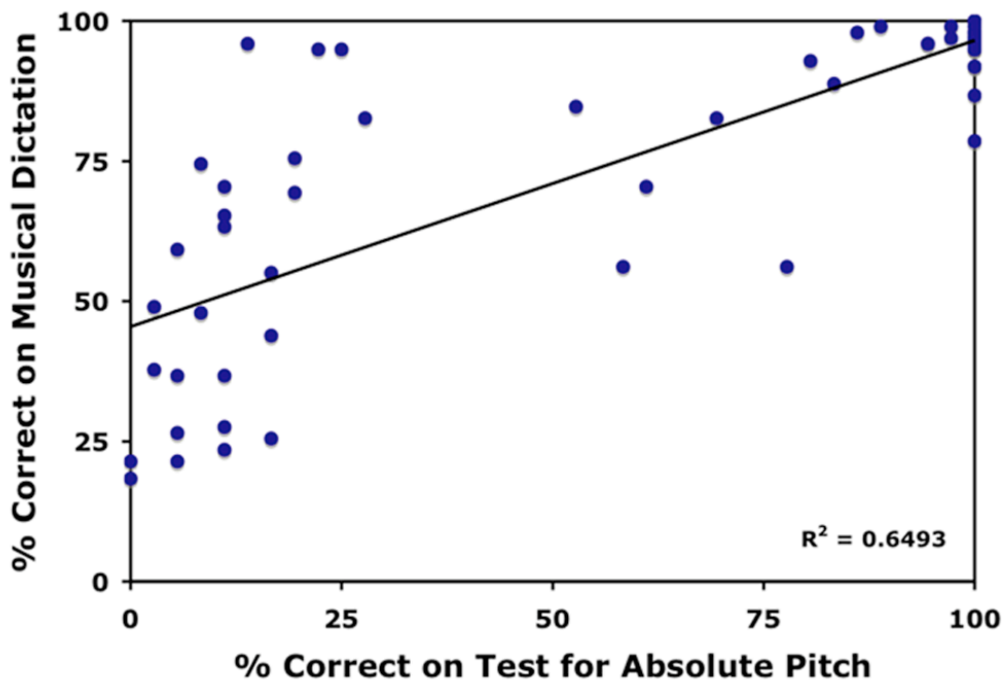
100
75
50
25
0
% Correct on Musical Dictation
R² = 0.6493
0
25
50
75
100
% Correct on Test for Absolute Pitch

Figure 2.2

# CHAPTER 3: ABSOLUTE PITCH CORRELATES WITH HIGH PERFORMANCE ON INTERVAL NAMING TASKS

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Abstract

Absolute pitch, the rare ability to identify or produce a musical tone without a reference tone, has been shown to be advantageous in some musical tasks; however, its relevance in musical contexts primarily involving relative pitch has been questioned. To explore this issue, 36 trained musicians – 18 absolute pitch possessors and 18 non-possessors with equivalent age of onset and duration of musical training – were tested on interval naming tasks requiring only relative pitch. The intervals to be named were either ascending or descending, with separation ranging from 1 to 12 semitones, and equally involved all 12 pitch classes. Three different conditions were employed; these used brief sine waves, piano tones, and piano tones preceded by a V7-I chord cadence so as to establish a tonal context. The possession of absolute pitch was strongly correlated with enhanced performance on all these tests of relative pitch. Furthermore, no evidence was found that this absolute pitch advantage depended on key, interval size, or musical context.

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Introduction

Absolute pitch (AP), the rare ability to name a musical tone in the absence of a reference tone, has attracted the attention of researchers for over a century, and generated speculation about its utility in musical processing (Bachem, 1955; Ward, 1999). However, studies exploring the relationship between AP and musical proficiency have yielded mixed results, and this relationship remains unclear. Historically, AP has been revered as a musical gift, possessed by world-class performers and composers (Bachem, 1955), and many musicians seek to develop this skill. Recently, advantages of AP possession have been demonstrated in psychoacoustic tasks involving pitch perception, e.g. in identifying extremely short (5 ms) pure tones, or complex tones with missing fundamentals (Hsieh & Saberi, 2007, 2008a, 2009). In addition, a strong positive correlation has been found between performance on an AP test and a melodic dictation task that was derived from music conservatory placement examinations (Dooley & Deutsch, 2010).

In contrast, some researchers have claimed that AP is musically irrelevant or even detrimental to other aspects of musical processing, particularly in tasks requiring only relative pitch (Levitin, 2008; Levitin & Rogers, 2005; Miyazaki, 1993, 1995). The only evidence, to our knowledge, on which this claim is based was provided by Miyazaki (1993, 1995; Miyazaki & Rakowski, 2002) who found Stroop-like interference effects for AP possessors under specific conditions (see below for a detailed discussion of this work). As pointed out by Dooley and Deutsch (2010), such effects could erroneously be interpreted as due to a general disadvantage of AP possession.

An additional challenge to understanding the potential musical benefits of AP arises from its association with early age of onset of musical training. As Miyazaki and Rakowski (2002) have pointed out, any musical advantage that may be enjoyed by AP possessors could be due to early onset of musical training or long duration of musical training (see also Deutsch et al., 2006; 2009). Any study examining differences between possessors and non-possessors of AP should therefore control for these factors.

The advantage to AP possessors in musical dictation tasks found by Dooley and Deutsch (2010) could in principle be interpreted as deriving from the identification of a series of individual tones, rather than from the integrated comprehension of musical relationships. A stronger test of the relevance of AP to performance on musical tasks that could be unrelated to AP possession would be interval identification, in which accurate performance depends only on perceiving the relationship between the two pitches comprising the interval. To investigate the relationship between AP and performance on interval naming tasks beyond the identification of each tone separately, 36 trained musicians – 18 AP possessors and 18 non-possessors with equivalent age of onset and duration of musical training – were tested with a series of such tasks requiring only relative pitch (RP). Three sets of intervals were used: In the first condition, the intervals were formed by brief sine waves just long enough to give a clear sense of pitch (Hsieh and Saberi, 2007), the second condition consisted of piano tones, and the third condition was identical to the second except that each interval to be named was preceded by a V7-I chord cadence (Miyazaki, 1993) such that the first tone forming each interval would be interpreted as the tonic. The relative contributions of AP possession, age of onset, and duration of musical training to performance on these interval naming tasks were assessed.

Method

*Subjects*

There were 36 subjects in the study. These were 17 males and 19 females; average age 24.0 years (range 19-31). Eighteen subjects (9 males, 9 females) were recruited who scored more than 80% correct on a test of AP (see below); of these, average age was 24.1 years (range 20-31), average age of onset of musical training was 5.1 years (range 3-8) and average number of years of formal musical training was 17.1 (range 10-26). Eighteen matched control subjects (8 males, 10 females) were then recruited, with equivalent onsets and durations of musical training, but who scored less than 20% correct on the AP test; these were of average age 23.8 years (range 19-31), average age of onset of musical training 5.1 years (range 3-7) and average number of years of training 17.5 (range 11-25). T-tests confirmed that the two groups of subjects did not differ significantly in age of onset, $t(34) = -0.14$, $p > .05$, or duration, $t(34) = 0.28$, $p > .05$, of musical training. All subjects self-reported normal hearing.

*Procedure*

All subjects were individually tested. They were first given the test for AP that had been employed in the studies by Deutsch et al. (2006, 2009) and Dooley & Deutsch (2010). This test consisted of successive presentations of the 36 tones spanning three octaves from $C_3$ (131 Hz) to $B_5$ (988 Hz), and subjects were asked to write down the name of each note (C, F#, E; and so on) after they heard it. All tones were separated from temporally adjacent tones by an interval larger than an octave, in order to minimize the use of relative pitch in making judgments. The tones were piano tones of 500 ms duration, with 4.25-s inter-onset intervals; they were presented in three 12-tone blocks, with 39-s pauses between blocks. A practice block of four successive tones preceded the three test blocks. No feedback was provided at any time during the test.

The remainder of the experiment consisted of interval naming tasks. These were presented in three different conditions. In all conditions, the subjects were presented with sequential intervals and were asked to write down the name of each interval after they heard it. In each condition, all 144 intervals ranging from a minor second (1 semitone separation) up to an octave (12 semitone separation) were presented. These were based on each of the 12 pitch classes from F# below middle C to the F above, such that each interval size (from 1 to 12 semitone separation) based on each pitch class was included for each of the three versions, and each pitch class occurred equally often. Half of the intervals, with randomly selected orderings, were transposed up one octave, and half, also with randomly selected orderings (independent of the previous selection) were descending rather than ascending. Different random orderings of the intervals were created for each condition, and in all three conditions the intervals were presented in 12 blocks of 12 intervals, with 4-sec silence between each trial and 30-sec silence between each block. The order of presentation of the three conditions was counterbalanced so that each possible ordering of the three conditions was presented to an equal number of subjects in each group.

The tones in Condition 1 (*sine wave*) consisted of 30 ms sine waves, including 5 ms rise and fall times, with no gap between tones within a pair. Conditions 2 (*piano*) and 3 (*piano with cadence*) each consisted of synthesized piano tones of 500 ms duration, with a 1-sec inter-onset interval between tones within a pair. Condition 3 differed from Condition 2 in that a V7-I chord cadence preceded each tone pair, so as to define the first tone of the pair as the 'tonic' (see Fig. 1, *piano with cadence*, as an example). Each chord in the cadence was of 1-sec duration, with no gap between the chords, and there was a 1-sec silent interval between the end of each cadence and the first tone of the pair. Following the tests, the subjects filled out a questionnaire regarding the onset and duration of their music education, and demographic information.

*Instrumentation*

For the AP test, the stimuli were piano tones, generated on a Kurzweil K2000 synthesizer tuned to $A_4$ = 440 Hz and recorded onto a Zoom H2 digital audio recorder. For Condition 1, the stimuli were sine waves generated using Audacity (Version 1.3.6). For Conditions 2 and 3, the stimuli were piano tones, generated with MIDI using GarageBand (Version 3.0.4). All stimuli were stored on a Macbook Pro as WAV files and presented to subjects via Sony MDR-7506 dynamic stereo headphones, at a level of approximately 72 dB SPL.

<u>Results</u>

Fig. 2 shows, for each subject, the total percentage of intervals that were correctly labeled across all three conditions as a function of AP possession. As can be seen, AP possession was strongly and positively correlated with performance on the interval naming task, $r = .72$, $p < .001$.[1] This relationship was even stronger when controlling for age of onset and duration of musical training, $r = .77$, $p < .001$. Neither age of onset, $r = -.28$, $p > .05$, nor duration of training, $r = .31$, $p > .05$, correlated significantly with the interval scores combined.

These trends persisted when performance in each condition was analyzed separately (Fig. 3). Indeed, performance was highly consistent across conditions, with high correlations between interval scores in the *sine wave* and *piano* conditions, $r = .75$, $p < .001$; *piano* and *piano with cadence* conditions, $r = .93$, $p < .001$; and *sine wave* and *piano with cadence* conditions, $r = .73$, $p < .001$. Performance on the AP and interval tests were strongly and significantly correlated taking each condition separately (Fig. 2): *sine wave*, $r = .50$, $p < .01$; *piano*, $r = .77$, $p < .001$; and *piano with cadence*, $r = .72$, $p < .001$. Again, these correlations were even stronger when controlling for onset and duration of music training: $r = .52$, $p < .01$; $r = .82$, $p < .001$; and $r = .78$, $p < .001$, for the *sine wave, piano,* and *piano with cadence* conditions respectively. As with the overall interval score, neither age of onset, $r = -.22$, $p > .05$; $r = -.26$, $p > .05$; $r = -.25$, $p > .05$, respectively, nor duration of musical training, $r = .22$, $p > .05$; $r = .32$, $p > .05$; $r = .36$, $p < .05$, respectively, were significantly correlated with performance in any of the individual conditions, with the exception of duration of training with scores on the *piano with cadence* condition. This last result suggests that musical experience made a small but significant contribution to performance accuracy (accounting for 13% of the variance) when musical context was provided.

To quantify the extent to which each of these factors predicted overall performance on the interval naming tasks, a multiple regression was performed, with AP possession, age of onset of musical training, and years of musical training as predictor variables. AP possession alone accounted for over 50% of all variance in the total scores on the interval naming tasks, β= .72, $R^2_{adj}$ = .51, $F(1, 34) = 37.03$, $p < .001$. Including age of onset of training, β= -.18, and years of training, β= .21, in the overall regression model accounted for an additional 12% of the variance in scores, $R^2_{adj}$ change = .12, $F(2, 32) = 5.09$, $p < .05$. These findings strongly indicate that the differences in performance levels between the two groups of subjects were associated primarily with their differing degrees of AP possession.

This pattern of results held when each interval condition was considered individually. Repeating this analysis for scores on the *sine wave* condition alone, the factor of AP possession accounted for roughly 25% of all variance, β= .50, $R^2_{adj}$ = .23, $F(1, 34) = 11.35$, $p < .01$. Including age of onset of training, β= -.16, and years of training, β= .13, in the overall regression model accounted for only an additional 3% of the variance in interval scores, $R^2_{adj}$ change = .03, $F(2, 32) = 1.58$, $p > .05$. In the *piano* condition, AP possession accounted for over 50% of all variance, β= .77, $R^2_{adj}$ = .58, $F(1, 34) = 49.07$, $p < .001$; including age of onset of training, β= -.13, and years of training, β= .25, in the overall regression model, $R^2_{adj}$ change = .10, $F(2, 32) = 6.46$, $p < .01$. In the *piano with cadence* condition, AP possession again accounted for the majority of all variance, β= .72, $R^2_{adj}$ = .50, $F(1, 34) = 36.12$, $p < .001$; including age of onset of training, β= -.08, and years of training, β= .32, in the overall regression model, $R^2_{adj}$ change = .12, $F(2, 32) = 6.38$, $p < .01$.

Parsing the data further, the influence of pitch class on accuracy in interval naming was considered in relation to that of AP (Fig. 4). A two-way ANOVA was carried out on percentage correct for each of the three conditions, with AP possession as a between-subjects factor and the pitch class of the first tone forming each interval (henceforth termed 'key') as a within-subjects factor. For the *sine wave* condition, the main effect of AP was significant, $F(1, 34) = 12.76$, $p = .001$, $\eta^2 = .27$; the main effect of key was significant, $F(11, 374) = 6.88$, $p < .001$, $\eta^2 = .17$; and the AP x key interaction was not significant, $F(11, 374) = 1.63$, $p > .05$. For the *piano* condition, the main effect of AP was significant, $F(1, 34) = 30.59$, $p < .001$, $\eta^2 = .47$; the main effect of key was significant, $F(11, 374) = 3.51$, $p < .001$, $\eta^2 = .09$; and the AP x key interaction was not significant, $F(11, 374) = 1.04$, $p > .05$. For the *piano with cadence* condition, the main effect of AP was significant, $F(1, 34) = 28.96$, $p < .001$, $\eta^2 = .46$; the main effect of key was not significant, $F(11, 374) = 1.39$, $p > .05$; and the AP x key interaction was not significant, $F(11, 374) = 1.62$, $p > .05$. In addition, post-hoc *t*-tests comparing the overall accuracy of possessors and non-possessors for each pitch class separately were significant at $p < .001$ for all 12 keys. In sum, the significant advantage of AP possession across all three conditions was not related to the pitch classes of the tones of which the intervals were comprised.

This analysis was repeated, testing the within-subjects variable of interval size rather than key (Fig. 5). As can be seen, the performance of AP possessors exceeded that of non-possessors for all interval sizes; however, the degree of this difference varied by interval. For the *sine wave* condition, the main effect of AP was significant, $F(1, 34) =$

12.66, $p = .001$, $\eta^2 = .27$; the main effect of interval size was significant, $F(11, 374) = 17.83$, $p = .001$, $\eta^2 = .34$; and the AP x interval size interaction was marginally significant, $F(11, 374) = 1.83$, $p = .05$, $\eta^2 = .05$. For the *piano* condition, the main effect of AP was significant, $F(1, 34) = 31.04$, $p < .001$, $\eta^2 = .48$; the main effect of interval size was significant, $F(11, 374) = 10.21$, $p < .001$, $\eta^2 = .23$; and the AP x interval size interaction was significant, $F(11, 374) = 2.05$, $p < .05$, $\eta^2 = .06$. For the *piano with cadence* condition, the main effect of AP was significant, $F(1, 34) = 28.86$, $p < .001$, $\eta^2 = .46$; the main effect of interval size was significant, $F(11, 374) = 9.00$, $p < .001$, $\eta^2 = .21$; and the AP x interval size interaction was significant, $F(11, 374) = 2.64$, $p < .01$, $\eta^2 = .07$.

Although not of primary interest in the present investigation, the main effects of interval size are worth considering. As can be seen (Fig. 5), there is a negative relationship between interval size and interval naming accuracy, and in fact this correlation is significant taking overall scores across groups and condition, $r = -.77$, $p < .01$. This may be due in part to the greater frequency of occurrence of smaller intervals in Western music (Vos & Troost, 1989). Furthermore, it can be seen that consonance was also a contributing factor to interval naming accuracy, such that subjects were on average more likely to correctly identify intervals separated by 7 semitones (perfect fifth) and 12 semitones (octave) than smaller but less consonant intervals. Specifically, post-hoc paired samples t-tests revealed overall accuracy to be significantly greater for 12 semitones than for 11 semitones (major 7$^{th}$), $t = 3.51$, $p = .001$, 10 semitones (minor 7$^{th}$), $t = 4.29$, $p < .001$, and 8 semitones (minor 6$^{th}$), $t = 3.17$, $p < .01$; similarly, overall accuracy was significantly greater for 7 semitones than for 6 semitones (tritone), $t = 2.68$, $p < .05$. This pattern is consistent with results from previous studies examining accuracy for different interval sizes (Killam, Lorton, & Schubert, 1975; Rakowski, 1990), and Rakowski (1990) has noted the influence of both interval size and consonance in predicting accuracy of interval recognition and reproduction.

The comparatively small but significant interaction between AP possession and interval size most likely reflects the variation in accuracy for all subjects across interval sizes, coupled with floor and ceiling effects, such that between-group differences were compressed on intervals with the highest and lowest accuracy rates (Fig. 5). Post-hoc *t*-tests were performed to compare the overall accuracy of AP possessors and non-possessors for each interval size, and the expected AP advantage was confirmed for all interval sizes: $p < .01$ for intervals separated by 1 semitone, $p = .001$ for separations of 2 and 6 semitones, and $p < .001$ for all other interval sizes. Thus, the accuracy of AP possessors was significantly greater than that of non-possessors for every interval size tested.

## Discussion

The results of this study strongly support the hypothesis that AP possession is associated with enhanced performance on musical tasks requiring only RP: The factor of AP possession alone accounted for the majority of all variance in performance on our interval tasks. Since AP possession is associated with early musical training (Miyazaki & Rakowski, 2002) it is important to point out that the strength of the relationship between

AP and interval naming found here held even controlling for age of onset and duration of musical training. Our finding of uniformly high performance among AP possessors therefore adds to the growing body of research documenting advantages of AP possession in musical and psychoacoustic tasks (Dooley & Deutsch, 2010; Hsieh & Saberi, 2007, 2008a, 2009).

Our findings run contrary to the claim that AP is musically irrelevant or disadvantageous, particularly in matters of RP (Levitin, 2008; Levitin & Rogers, 2005; Miyazaki, 1993, 1995). This discrepancy can be reconciled by considering the results of Miyazaki and Rakowski (2002). Consistent with the present findings, these authors identified a significant AP advantage for accuracy in judgment of both tonal and atonal melodies when these were played to subjects in the correct key as written; however, they obtained a moderate negative correlation between AP score and judgment accuracy for transposed melodies, which were presented at different pitch levels than as written (although this correlation was significant only for atonal melodies). A likely explanation for the apparent inconsistency between our findings and those of Miyazaki and Rakowski is that AP possessors are subject to Stroop-like interference effects in artificial situations (Hsieh & Saberi, 2008b; Miyazaki & Rakowski, 2002; Roberts & Hall, 2008; Stroop, 1935; Takeuchi and Hulse, 1993).

Similarly, the apparent disadvantage of AP possession in naming out-of-tune intervals in the studies of Miyazaki (1993, 1995) can be interpreted as resulting from this Stroop-like interference. Two methodological factors in particular are likely to have contributed to such interference in those studies. One was the use of detuned intervals, in which the relative distance between the tones conflicted with the interval formed by the pitch classes of the individual tones. For example, the correct response for a C 40 cents sharp and an E 40 cents flat would be a minor third, but an AP possessor using the identities of the tones to determine the interval size could be led astray, rounding off to a C and an E and then concluding that the interval formed a major third. The other factor to be considered in these earlier studies was the requirement to name intervals using movable-do labels whose relative meanings conflicted with their absolute fixed-do meanings for all reference pitches other than C. For example, the response key labeled 'mi' would actually refer to E only in the C reference condition, and not in the F# reference condition. It should be pointed out that in these studies the performance of AP possessors dropped below that of non-possessors only on the non-C reference conditions, in which such Stroop-like interference would be in effect (see also Renninger et. al, 2003; Itoh et. al, 2005).

Indeed, the findings of the present study indicate that AP is advantageous in interval naming across all keys and interval sizes when the stimuli are limited to the standard tunings typically encountered in Western tonal music. Furthermore, the consistency of the AP advantage that we found across all three conditions employed in the study, and in particular the high correlation between individual scores on the *piano* and *piano with cadence* conditions ($r = .93$, $p < .001$), confirm that these results did not depend on the presence or absence of musical context (Fig. 3). More specifically, inserting a V7-I chord cadence before the interval to be named, (a procedure also used by Miyazaki (1993) to provide musical context) did not erase the sizable AP advantage in interval naming across all 12 keys (Fig. 4) and all 12 interval sizes tested (Fig. 5).

Also of interest in the present study was the possible effect of tone duration on contributions of AP possession to interval naming accuracy. The tones used in the *sine wave* condition were designed to last just long enough to give a clear sense of pitch (Hsieh & Saberi, 2007). Although the raw scores were lower for all subjects in this condition (Fig. 3), the AP advantage proved no greater as a proportion (mean percentage correct was 64% greater for AP possessors than non-possessors) than in the *piano* (72%) or *piano with cadence* conditions (64%). Therefore the consistent difference between AP possessors and non-possessors across all three conditions indicates that the superior performance of AP possessors was not dependent on timbre or tone duration.

While the large role played by AP in predicting performance on the interval naming tasks was surprising relative to the comparatively small effects of onset and duration of musical training, we should note that conclusions drawn from the present data are limited to the range of the characteristics of the subjects included in the study. Specifically, in order that the AP and non-AP groups could be compared appropriately, the age of onset of musical training for all subjects ranged from age 3 to age 8, and the duration of training ranged from 10 to 26 years. These other factors may play a larger role in predicting proficiency at interval naming or other musical tasks for subject populations that include wider ranges of musical experience.

Clearly related to the effects of AP possession on perception and cognition are the means by which AP is acquired. Although outside the scope of this article, a number of potential factors have been identified, including tone language fluency (Deutsch et al., 2006, 2009), physiological differences (Keenan et al., 2001; Schlaug et al., 1995), genetics (Theusch et al., 2009), and early music education (Miyazaki & Ogawa, 2006);

indeed, it appears that the potential for developing AP is present in infancy (Saffran & Griepentrog, 2001).

It is also important to note that while all AP possessors performed well on the interval tasks in this study (an overall mean of 74% correct and no scores below 50%), some non-possessors also performed well (a mean of 44%, and one even scored above 70% correct). AP is therefore not necessary for successful performance on interval naming, as has also been shown for musical dictation by Dooley and Deutsch (2010), even though it appears to be associated with a substantial advantage in these tasks. Anatomical and functional imaging findings have revealed underlying differences in the way AP possessors and non-possessors perceive and encode pitch, and these AP advantages may derive from fundamentally different perceptual or cognitive processes (Loui et al., 2010; Oeschlin et al., 2010; Schulze et al., 2009; Zatorre et al., 1998). More research is needed to explore exactly how AP possession confers such a strong advantage in RP tasks, and also in which other domains of musical proficiency it might prove beneficial.

Footnotes

1. Because normality assumptions were not met for the raw data based on the Shapiro-Wilk test for interval test scores ($p < .001$), years of musical training ($p < .05$), and age of onset of musical training ($p < .01$), all variables were rank-transformed, and all reported correlation and regression statistics are based on the rank-transformed data. Nonetheless, all patterns of significance for the raw data were nearly identical to those reported.

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Figures

Figure 3.1. An example interval from each condition, in musical notation. See text for details.

Figure 3.2. For each subject, overall percent correct on the interval naming tasks as a function of percent correct on the test for absolute pitch. (Color online.)

Figure 3.3. Mean percent correct in each condition, grouped by AP possession.

Figure 3.4. Mean percent correct in each condition, grouped by AP possession and pitch class of the first tone of each interval.

Figure 3.5. Mean percent correct in each condition, grouped by AP possession and interval size.

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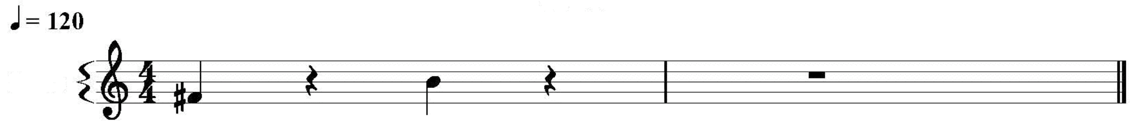
**Sine Wave**


**Piano**




**Piano with Cadence**


Figure 3.1

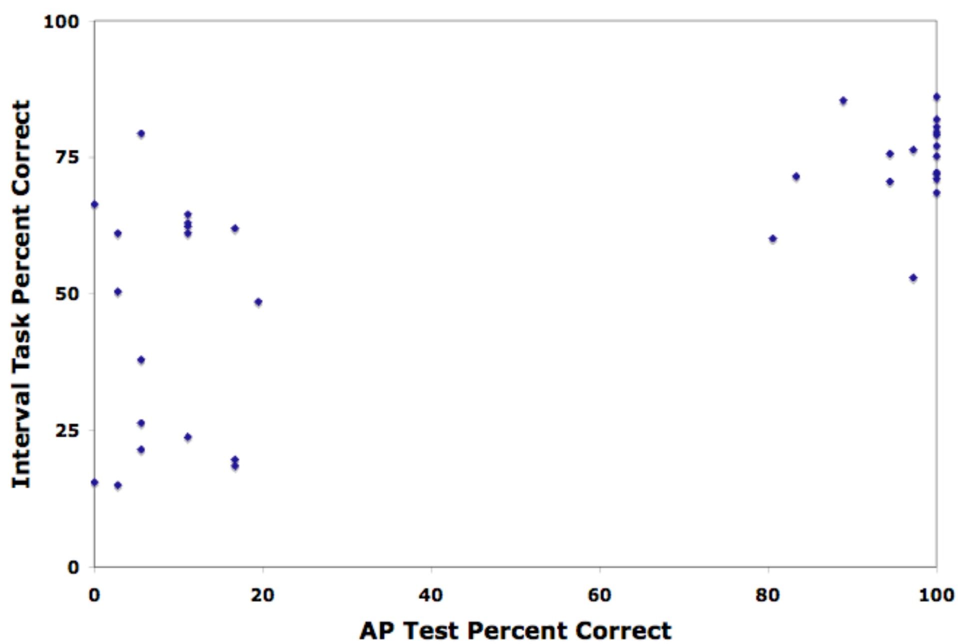

100
75
50
25
0
Interval Task Percent Correct
0
20
40
60
80
100
AP Test Percent Correct

Figure 3.2

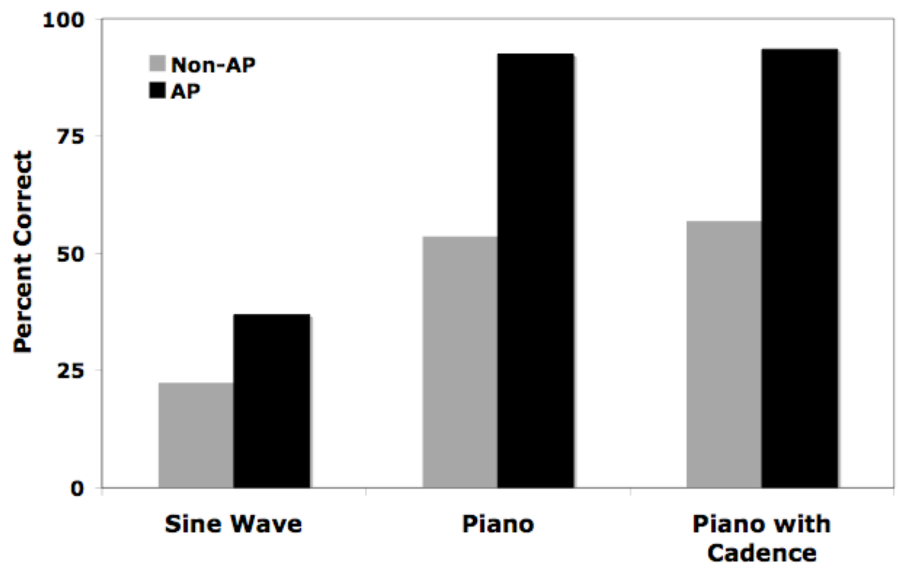

100
75
50
25
0
Percent Correct
Non-AP
AP
Sine Wave
Piano
Piano with Cadence

Figure 3.3

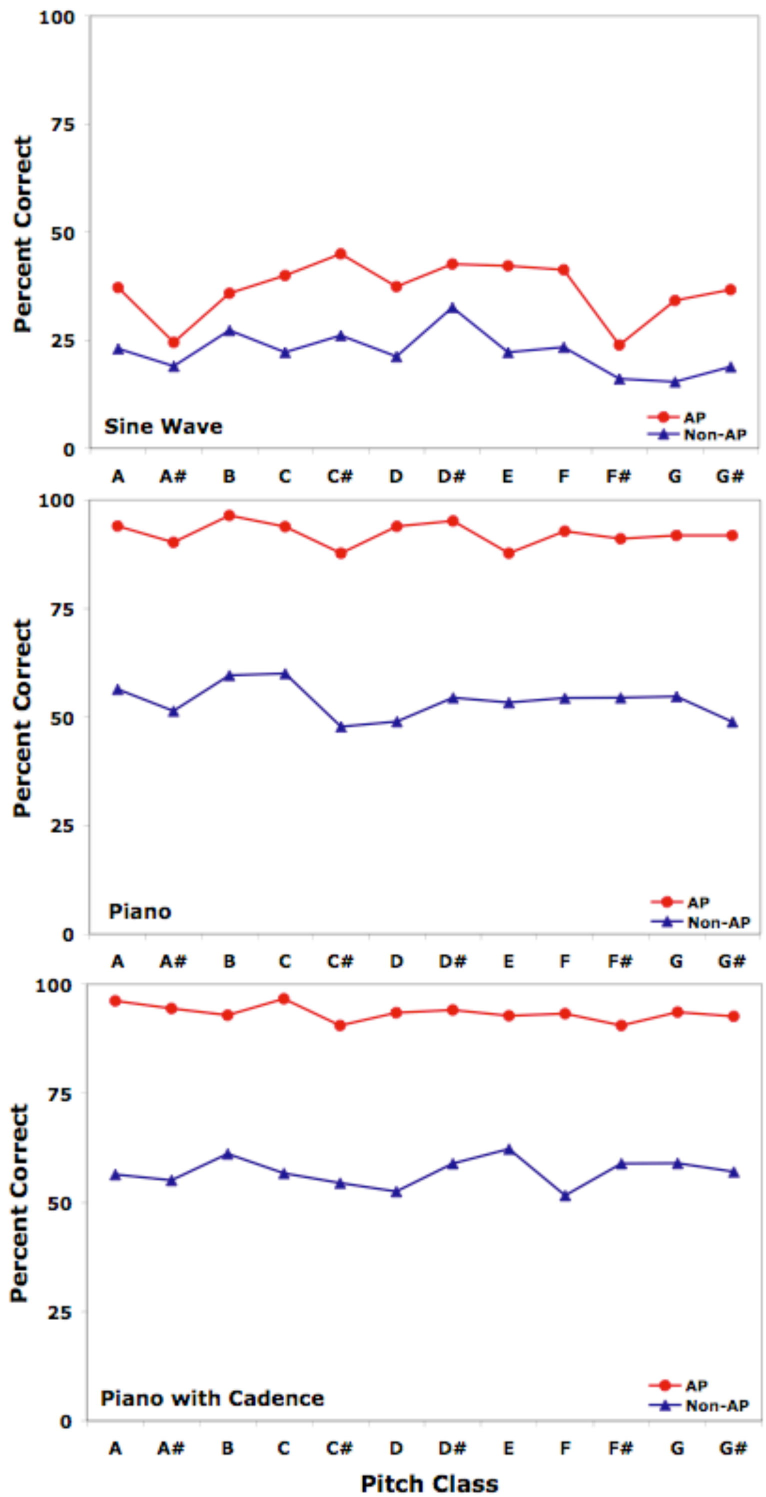
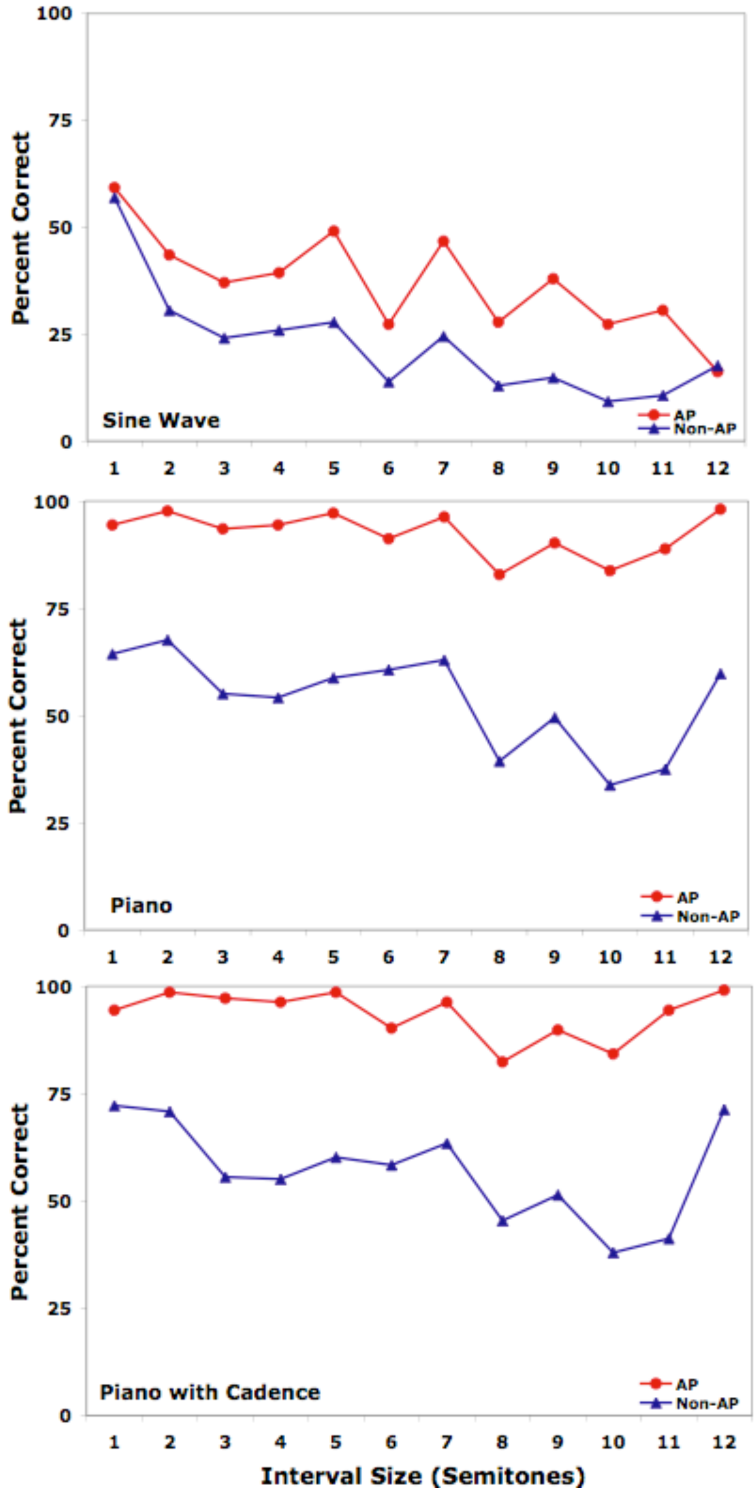

100
75
50
25
0
Percent Correct
Sine Wave
AP
Non-AP
A A# B C C# D D# E F F# G G#
Piano
Piano with Cadence
Pitch Class

Figure 3.4



Sine Wave
Piano
Piano with Cadence
AP
Non-AP
Percent Correct
Interval Size (Semitones)
0
25
50
75
100
1
2
3
4
5
6
7
8
9
10
11
12


Figure 3.5

# CHAPTER 4: SONGS, CELL PHONES, & ABSOLUTE PITCH: LONG-TERM PITCH MEMORY FOR FAMILIAR TONAL STIMULI

Running head: Songs, cell phones, & absolute pitch

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Abstract

Absolute pitch (AP) is a rare phenomenon as formally defined, but long-term pitch memory appears much more common when tests involve familiar musical material and do not require the use of formally learned pitch labels (Halpern, 1989). It is unclear whether AP possession confers additional advantages to long-term pitch memory in such tasks, or merely combines a rare ability to form pitch-label associations with a more general capacity for pitch memory. To test this, 36 trained musicians--18 AP possessors and 18 non-possessors with equivalent age of onset and duration of musical training--were asked to recall and vocalize a familiar song, and their responses were compared with the pitches of the actual recordings; this was repeated with their cell phone ringtones. Both groups were significantly more accurate than chance on the song task, but only the AP possessors performed above chance on the ringtone task. The findings confirm the existence of widespread long term pitch memory but also point to an AP advantage under some circumstances.

Introduction

Absolute pitch (AP), the ability to name or produce a tone without any external reference, has intrigued researchers for over a century, and the reasons for its low prevalence in Western society remain unclear (Vitouch, 2003; Ward, 1999). Despite the rarity of AP as formally defined, widespread use of AP information has been shown in adults (Deutsch, 2006) and infants (Saffran & Griepentrog, 2001). Researchers have also found converging evidence of long-term pitch memory amongst the general population using either production (Halpern, 1989; Levitin, 1994) or perception tasks (Gußmack, Vitouch, & Gula, 2006; Marvin & Brinkman, 2000; Schellenberg & Trehub, 2003, 2008; Smith & Schmuckler, 2008; Terhardt & Seewann, 1983) in which subjects can demonstrate retention of absolute pitch information about familiar auditory stimuli without requiring knowledge of pitch names. Although AP has traditionally been regarded as a reflection of unusually good long-term memory for musically relevant pitches (Bachem, 1955), the above findings have more recently led to the conception of AP as simply a labeling ability that combines widespread pitch memory with unusually strong retention of verbal-pitch associations (Schellenberg & Trehub, 2003; Wilson, Lusher, Wan, Dudgeon, & Reutens, 2009).

However, there is strong evidence that short-term memory for pitch is not dependent on verbal labels (Deutsch, 1970), and this has also been shown specifically in AP possessors, suggesting the use of multiple coding strategies in short term memory for pitch (Zatorre & Beckett, 1989). Recent anatomical and functional imaging work further supports the notion that AP may involve unique perceptual or encoding processes for tonal information, perhaps emerging from differing patterns of cortical organization or activation (Bermudez, Lerch, Evans, & Zatorre, 2009; Loui, Li, Hohmann, & Schlaug, 2010; Oeschlin, Meyer, & Jancke, 2010; Schlemmer, Kulke, Kuchinke, & Van der Meer, 2005; Schulze, Gaab, & Schlaug, 2009; Wilson et al., 2009; Zatorre et al., 1998). The question then arises whether AP possession confers advantages in long-term pitch memory beyond the labeling of isolated tones.

To investigate this, two groups of musicians, one composed of AP possessors and the other (AP non-possessors) matched in onset and duration of musical training, were asked to recall any familiar song of their choice and vocalize it in the same key they were hearing internally, in a task similar to that used by Levitin (1994). Subjects then repeated the procedure by imagining and vocalizing their cell phone ringtone. Responses were recorded and compared to the corresponding pitches of the original song recording and cell phone ringtone. The design provided an opportunity to directly compare AP possessors' and non-possessors' long-term pitch memory for ecologically valid stimuli, i.e., sounds that are familiar and relevant to the subject, without necessitating knowledge of pitch labels. If long term pitch memory were truly widespread and AP possessors were unusual only in their ability to attach labels to pitches, then both groups should perform equally well; conversely, superior performance by AP possessors would suggest advantages for pitch memory beyond the ability to label isolated tones.

## Method

### *Subjects*

Thirty-six subjects participated in this study: 17 males and 19 females, average age 24.0 (range 19-31). Eighteen subjects (9 male, 9 female) were recruited who scored more than 80% correct on the AP test; of these, average age was 24.1 (range 20-31), average age of onset of musical training was 5.1 (range 3-8) and average number of years of formal musical training was 17.1 (range 10-26). Eighteen matched controls (8 male, 10 female) with equivalent onsets and durations of musical training to the AP group but who scored less than 20% correct on the AP test were then recruited; average age was 23.8 (range 19-31), average age of onset of musical training was 5.1 (range 3-7) and average number of years of training was 17.5 (range 11-25). *T*-tests confirmed that the two groups did not significantly differ in age of onset, $t(34) = -0.14$, $p > .05$, or duration, $t(34) = 0.28$, $p > .05$, of musical training. All subjects self-reported normal hearing.

*Procedure*

Each subject was tested individually. First, the test for AP that had been employed in the studies by Deutsch, Henthorn, Marvin, & Xu (2006), Deutsch, Dooley, Henthorn, & Head (2009), and Dooley & Deutsch (2010) was given. This consisted of successive presentations of the 36 tones spanning three octaves from $C_3$ (131 Hz) to $B_5$ (988 Hz); subjects were asked to write down the name of each tone (C, F#, etc.). All tones were separated from temporally adjacent tones by an interval larger than an octave to minimize the use of relative pitch in making judgments. The tones were piano tones of 500 ms duration, with 4.25-s inter-onset intervals; these were presented in three 12-tone blocks, with 39-s pauses between blocks. A practice block of four successive tones preceded the three test blocks. No feedback was provided during the test.

For the second test, subjects were asked to recall a song of their choosing that they could easily imagine, and then to sing, hum, or whistle a few seconds of the song in the same key in which it was “heard” and to specify which part of the song had been reproduced (e.g., chorus, guitar solo). Next, subjects repeated this procedure (i.e., recall and vocalize in the same key what was “heard”) using whichever cell phone ringtone they could most easily imagine. Finally, a recording of the actual chosen ringtone was obtained for comparison.

Subjects were free to choose any song they wished given the condition that it must exist as a specific recording whose title and artist they could identify (as opposed to a song like “Happy Birthday” which may have been listened to in multiple keys). Furthermore, subjects were not allowed to choose a song or ringtone if they already knew what key it was in based on pre-existing knowledge (such as by recalling the sheet music or having previously checked their ringtones against a piano). Subjects were not told in advance that they would be asked to recall or make judgments about songs or ringtones. Following the tests, subjects filled out a questionnaire regarding the onset and duration of their music education.

*Instrumentation*

Subject vocalizations and their ringtones were recorded onto a Zoom H2 digital audio recorder as *.wav* files and copied onto a MacBook Pro. The songs subjects chose were downloaded from iTunes (v. 9.2.1) and then converted to *.wav* files using Audacity software (v. 1.3.6). Audacity was used to select the first note of each subject's vocalizations and the corresponding note from the original song and ringtone recordings, based on subjects' specifications of which part of the song they had chosen.

All of these notes were analyzed for pitch to the nearest semitone using Melodyne Editor software (v. 1.1.8). Upon import, the Melodyne pitch algorithm determined and displayed the pitch of each note to the nearest cent, using the default standard setting of A = 440 Hz. Based on this output, each note was quantized to the nearest semitone, and this pitch class was used for all statistical analyses.

## Results

Vocalized pitches are displayed in Figure 1 for all subjects in relation to the corresponding target pitches of the actual recordings. Figure 2 shows the distributions of differences, in semitones, between the pitch class of each subject's responses compared to that of the actual recordings. Note that chance performance would show a roughly uniform distribution across all pitch classes for any given target tone. Given a song or ringtone starting on C, for example, random guessing should yield a correct response of C 8.33% of the time (i.e., 1/12) or, more broadly, a tone that is no more than one semitone higher or lower than the correct tone (in this case, a vocalization of B, C, or C#) 25% of the time (i.e., 3/12). In contrast, above-chance performance would appear as a larger-than-expected proportion of responses falling on or near the target tone.

As can be seen (Figure 2a & 2b), both AP possessors and non-possessors performed significantly above chance on the song vocalization task, as confirmed by an exact chi-square goodness-of-fit test comparing the pitch class distance in semitones between the actual and attempted pitches (ranging from 0 to 6) for subjects in each group with the distribution expected by chance. For AP possessors, $\chi^2(6) = 29.33$, $p < .0001$, and for non-possessors, $\chi^2(6) = 17.33$, $p = .009$.

Specifically, 6 out of 18 AP possessors (33.34%) vocalized the correct song pitch; the binomial probability of a result this unlikely arising by chance is $p < .01$. Fourteen of 18 AP possessors (77.78%) were within one semitone of the correct song pitch, $p < .0001$. Similarly, 6 of the 18 non-possessors (33.33%) vocalized the correct song pitch, $p < .01$; and 10 of 18 (55.56%) non-possessors were within one semitone of the correct song pitch, $p < .01$.

On the ringtone vocalization task (Figure 2c), AP possessors again performed well above chance. Taking the pitch class distance in semitones between each subject's vocalization and the actual ringtone pitch (ranging from 0 to 6), an exact chi-square goodness of fit test determined the AP possessors' performance to be significantly different from the distribution expected by chance, $\chi^2(6) = 47.67$, $p < .0001$. More specifically, 9 of 18 AP subjects (50%) vocalized the correct ringtone pitch, binomial probability $p < .0001$, and 14 of 18 (77.78%) were within one semitone, $p < .0001$.

In contrast, the accuracy of the AP non-possessors on the ringtone vocalization task did not exceed chance levels (Figure 2d). An exact chi-square goodness-of-fit test, based on pitch class distance in semitones between actual and vocalized pitches (ranging from 0 to 6), did not significantly differ from chance distribution, $\chi^2(6) = 3.00$, $p = .84$. Indeed, none of the 18 non-possessors (0%) produced the correct ringtone pitch, and only 4 of them (22.22%) produced errors of only one semitone. Given an 8.33% chance of guessing the pitch correctly and 25% chance of an error no greater than one semitone, the binomial probability of these results arising by chance is very likely, $p \approx 1$, $p = .69$, respectively.

Comparing the two groups directly, the performances of AP possessors and non-possessors were significantly different on the ringtone task: AP possessors were 12.25 times more likely than non-possessors to come within one semitone, Fisher's exact test $p = .002$, Cramer's $V = .56$. AP possessors were 2.8 times more likely than non-possessors to come within one semitone on the song task, although this difference was not significant, Fisher's exact test $p = .29$ (Figure 3). Indeed, the average difference in semitones between actual and vocalized pitch was significantly different between AP possessors and non-possessors for the ringtone task, $t(34) = 3.70$, $p < .001$, $r = .54$, but not the song task, $t(34) = 1.23$, $p > .05$ (Figure 4).

Combining performance across tasks, the probability of guessing the correct pitch both times by chance is 0.69%, and the probability of coming within one semitone both times by chance is 6.25%. None of the AP non-possessors vocalized the correct pitch in both tasks, $p \approx 1$; 3 of them (16.67%) came within one semitone both times, $p = .10$. In contrast, 5 AP possessors (27.78%) vocalized the correct pitch both times, $p < .0001$, and 12 of them (66.67%) came within one semitone both times, $p < .0001$.

Neither age of onset of musical training nor years of experience correlated significantly with performance in either task, whether based on difference in semitones between the subject's vocalization and the pitch of the actual recording, all *p*s > .05, or based on whether subjects were within 1 semitone of the correct pitch, all *p*s > .05.

## Discussion

Based on previous research, one might expect to find evidence of widespread pitch memory in AP possessors and non-possessors alike (Gußmack, Vitouch, & Gula, 2006; Halpern, 1989; Levitin, 1994; Schellenberg & Trehub, 2003, 2008; Smith & Schmuckler, 2008); alternatively, there is reason to predict superior performance of AP possessors on pitch memory tasks even when verbal pitch labels are not required (Hsieh & Saberi, 2008; Loui et al., 2010; Marvin & Brinkman, 2000; Oeschlin et al., 2010; Schulze et al., 2009; Zatorre et al., 1998). In fact, the present study provides support for both these predictions.

AP possessors and non-possessors both performed significantly more accurately than chance on the song vocalization task; in particular, the percentages of non-possessors who produced the correct pitch (33%) or were within 1 semitone of the correct pitch (56%) were very close to the percentages of accurate subjects (averaged across trials) engaged in a similar task in Levitin's (1994) study (25% and 54% respectively). It is worth noting that while all subjects in the present study were formally trained (all starting by age 8 and playing for at least 10 years), Levitin's subjects represented a wider range of musical experience; this corroborates our findings that neither onset nor duration of musical training correlated significantly with performance on either task. As a trend, AP possessors were slightly more accurate than non-possessors on the song task in the present study, with 33% producing the correct pitch and 78% within one semitone. Thus, AP does not appear to provide a large advantage in pitch memory for familiar songs.

However, the two groups' performances in the ringtone task were substantially different. While AP possessors were once again significantly more accurate than chance, with 50% producing the correct pitch and 78% within 1 semitone, the performance of non-possessors was no better than chance, with none (0%) producing the correct pitch and only 22% differing by one semitone (in the latter case, random guessing would yield a 25% accuracy rate on average). Clearly, AP possession is a powerful predictor of success in this task, indicating that it does in fact enhance pitch memory to some degree. How exactly this advantage is achieved, and in which situations it is most apparent, is unclear, though some possible perceptual, cognitive, and anatomical factors have been proposed (Hsieh & Saberi, 2008; Loui et al., 2010; Oeschlin et al., 2010; Schulze et al., 2009; Zatorre et al., 1998; Zatorre & Beckett, 1989).

Considering this question of when AP would be most advantageous in pitch memory tasks, the present findings offer some insight. AP possession may enhance long-term memory for tonal information in general; recent functional imaging research indicates an AP advantage for acoustic signal processing, due to greater neural efficiency (Oechslin et al., 2010). The comparable accuracy of non-possessors when recalling pitches of familiar songs, documented here and elsewhere (Halpern, 1989; Levitin, 1994), is the exception to the rule. Non-possessors may be exhibiting AP-like skill in such tasks in part by relying on motor memory from singing songs repeatedly (Hsieh & Saberi, 2008; cf. Kaernbach & Schlemmer, 2008). Hsieh and Saberi (2008) suggest that non-possessors can perform accurately in some situations by accessing an internal pitch template through a procedural vocal-motor form of memory retrieval; this is compatible with observations of supplementary motor area activation during auditory imagery tasks (Halpern & Zatorre, 1999).

Furthermore, non-possessors may attain this level of accuracy from a combination of frequent exposure (Schlemmer et al., 2005) and careful attention to such aesthetically meaningful, engaging stimuli (Brown & Martinez, 2007). This is consistent with observed differences in cortical activation patterns between ‘passive’ vs. ‘active’ listening to music, notably the recruitment of vocal pre-motor areas in the latter case, reflecting an underlying connection between musical discrimination, mental imagery, and vocal-motor production (Brown & Martinez, 2007). In the present study, subjects’ song task accuracy benefited from a greater degree of active listening: while subjects may have sung along with their favorite tunes on occasion, they would not, in all likelihood, have practiced singing along with their phones (Smith & Schmuckler, 2008). Following this logic, the AP advantage for ringtones found in the present study should also show up in other tasks involving familiar and tonal but less musically engaging or sing-able sounds (i.e., other stimuli or contexts that elicit passive rather than active listening), such as producing the pitch or detecting pitch shifts of alarm clocks, car horns, and other regularly used but seldom-appreciated sonic appliances.

Schulze et al. (2009) found evidence of functional differences in the way AP possessors perceive and encode tonal stimuli, compared with non-possessors; AP possessors may process and categorize absolute pitch information even without consciously focusing on or labeling the sounds that they hear. Non-possessors are capable of retaining absolute pitch information as well, but may do so to a similar degree only in musical contexts that promote attending to or rehearsing these details, i.e., active listening (Brown & Martinez, 2007). The pitches of even a melodic ringtone, for example, would not elicit the same attention or conscious musical analysis from most listeners as an equivalently tonal pop single, due to its context and function; repeated exposure alone would be enough to encode the ringtone's pitches only for AP possessors. It is worth noting that about half of the subjects' ringtones in each group in the present study were in fact segments of popular songs; the key difference, then, is the context, not the content. More direct support for this explanation could be obtained by training AP non-possessors to actively attend to their ringtones and reliably produce the starting pitch.

Overall, these findings indicate that AP is more than just a rare verbal pitch-labeling ability combined with a general long-term pitch memory capacity (Schellenberg & Trehub, 2003); in some circumstances, AP possession enhances pitch memory without conscious use of pitch labels. The performance of non-possessors on the song task also raises an exciting possibility. If a sizeable proportion of musicians are capable of producing the pitch of a particular song accurately, as these data suggest, it should be feasible to parlay this ability into a rudimentary form of AP. Reliably recalling a particular tune (having previously determined the starting pitch) could function as an internal reference and give many more people conscious access to absolute pitch information.

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Figure Captions

Figure 4.1. Vocalized pitches and corresponding target pitches for all subjects. Filled circles = AP non-possessors, song task; Open circles = AP possessors, song task; Filled squares = AP non-possessors, ringtone task; Open squares = AP possessors, ringtone task. Shaded cells indicate correct responses.

Figure 4.2. The distribution of differences, in semitones, between the pitch class of each subject's response compared to the corresponding pitch class of the actual recording, by group and vocalization task. Differences of 6 semitones are distributed equally between +6 and -6. (a) AP possessors, song task ($n = 18$). (b) AP non-possessors, song task ($n = 18$). (c) AP possessors, ringtone task ($n = 18$). (d) AP non-possessors, ringtone task ($n = 18$).

Figure 4.3. Percentage of subject vocalizations coming within one semitone of the corresponding target pitch for each task, grouped by AP possession (chance performance $\approx 25\%$).

Figure 4.4. Mean absolute difference in semitones between vocalized pitch and target pitch for each task, grouped by AP possession (chance performance $\approx 3$ semitones). Error bars represent 1 standard error.

Chapter 4, in part, has been submitted for publication of the material as it may appear in Attention, Perception, & Psychophysics, 2011, Dooley, Kevin, Springer, 2011. The dissertation author was the primary investigator and author of this paper.

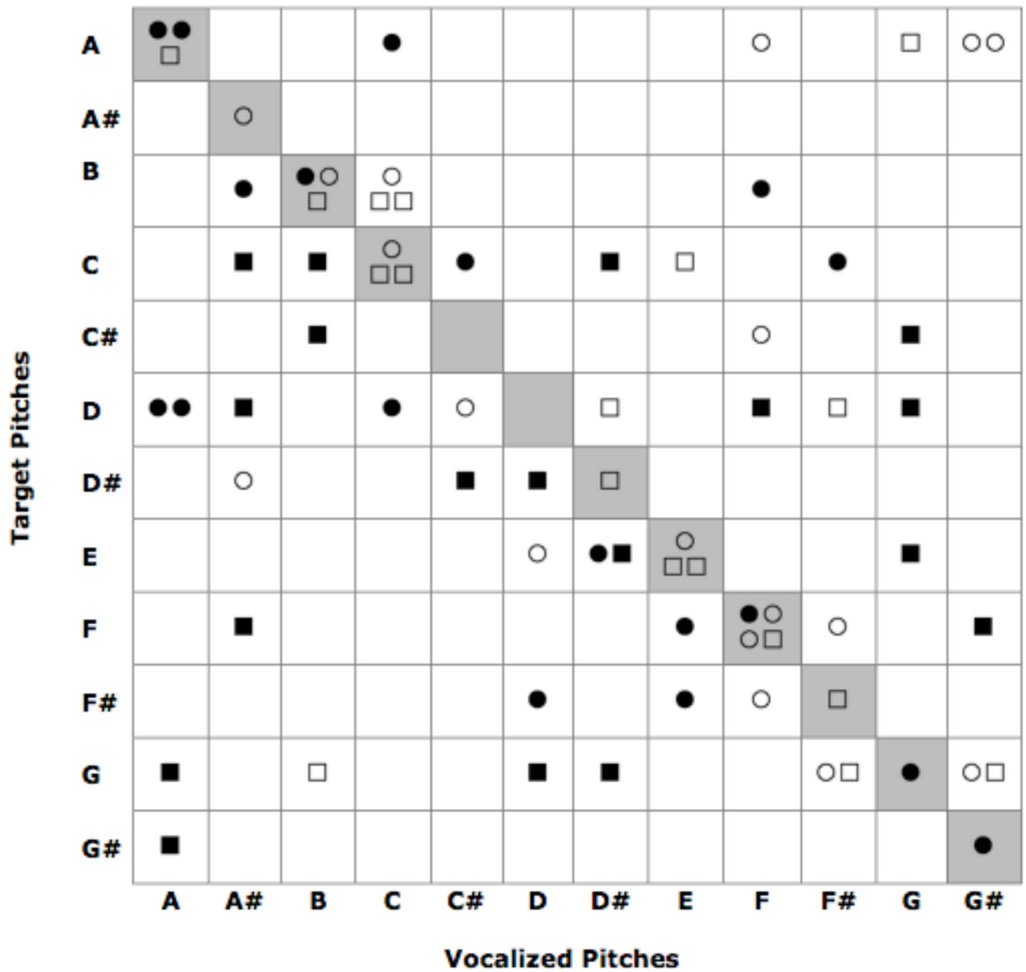
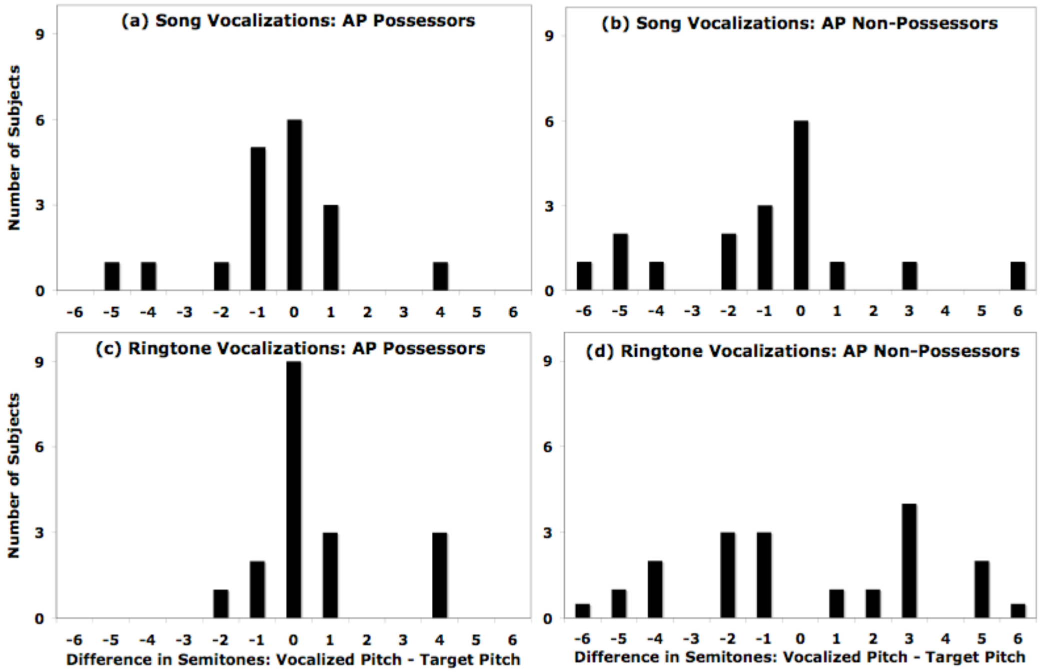



Figure 4.1



(a) Song Vocalizations: AP Possessors
(b) Song Vocalizations: AP Non-Possessors
(c) Ringtone Vocalizations: AP Possessors
(d) Ringtone Vocalizations: AP Non-Possessors
Number of Subjects
0
3
6
9
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
Difference in Semitones: Vocalized Pitch - Target Pitch


Figure 4.2

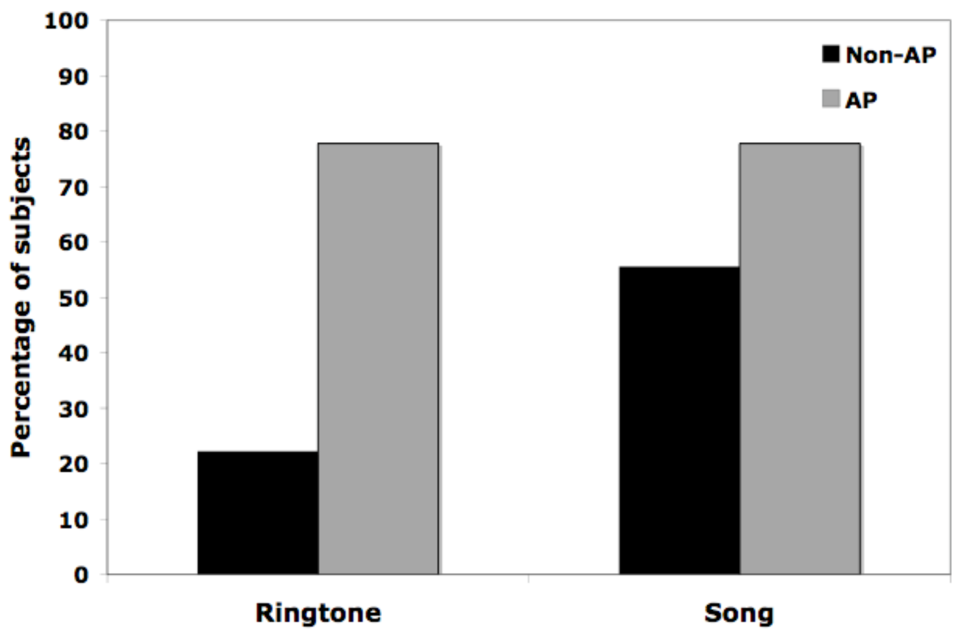

100
90
80
70
60
50
40
30
20
10
0
Percentage of subjects
Non-AP
AP
Ringtone
Song

Figure 4.3

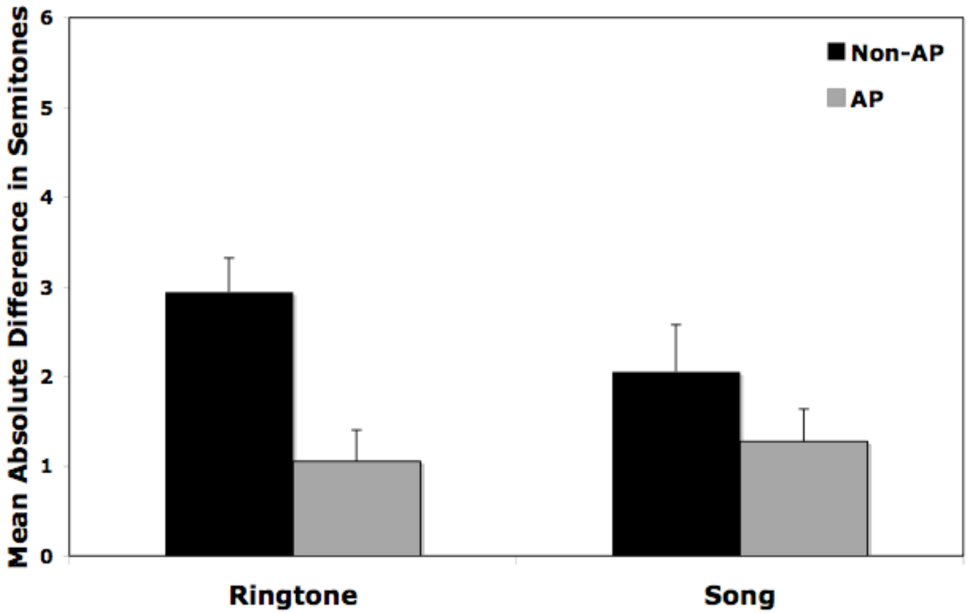

Mean Absolute Difference in Semitones
6
5
4
3
2
1
0
Non-AP
AP
Ringtone
Song

Figure 4.4

# CHAPTER 5: DISCUSSION

## Overview

In this chapter, I will recapitulate the main findings of each study, considering implications, limitations, and follow-up questions. Next, I will discuss general conclusions, integrating the results as a whole with others reported in the literature. Finally, I will suggest future directions for research to address related questions about AP.

## Chapter 2: AP and musical dictation

The purpose of this study (Dooley & Deutsch, 2010) was to compare the proficiency of AP possessors on an applied musical task with that of non-possessors matched for equivalent age of onset and duration of musical training. Sixty subjects (30 self-reported possessors and 30 non-possessors) were tested for AP, and also given a musical dictation test modeled after a standard entrance examination from a prestigious music conservatory. The dictation test involved notating 3 aurally presented, tonal musical excerpts, for which the first note of each was provided on the response sheet; thus, the task required only relative pitch. However, it was hypothesized that AP possessors would outperform non-possessors, even controlling for age of onset and duration of musical training, and indeed this was the case.

AP score alone, whether considered as a discrete or continuous variable, accounted for the majority of all variance in performance on the musical dictation test, overshadowing the relatively minor contributions of age of onset and duration of musical training. Contrary to widespread allegations that AP is irrelevant or even detrimental to music, (e.g., Levitin, 2008; Levitin & Rogers, 2005; Miyazaki, 2004), these findings strongly support a clear advantage to AP possession in musical tasks requiring only relative pitch. AP possessors demonstrated uniformly very high performance on the dictation test, thus showing no evidence of impaired relative pitch processing. Specifically, the mean score on the dictation test for clear AP possessors (those who scored over 80% correct on the AP test) was 95.4% correct, with no scores below 78%; by contrast, the mean dictation score for non-possessors (those who scored below 20% correct on the AP test) was 47.5%, and only one subject scored above 80%. This is consistent with other recent work documenting AP advantages in psychoacoustic tasks (Hsieh & Saberi, 2007; 2008a; 2009).

The present findings also address a more general question in the literature, namely the distribution of AP ability in the population. While AP is frequently considered a dichotomous trait, often for sake of convenience in supporting arguments for genetic origins (e.g. Athos et al., 2007; Theusch et al., 2009), the distinction between AP and non-AP may be more blurred (Dooley & Deutsch, 2010; Takeuchi & Hulse, 1993; Vitouch, 2003). A substantial number of subjects in this study did not fit neatly into either the clear AP possessor or non-possessor categories; their scores on the AP test exceeded chance performance (greater than 20% correct) but fell short of those of clear possessors (less than 80% correct). Correspondingly, the dictation scores of this intermediate "borderline AP" group fell between those of the clear AP possessors and non-possessors as well (a mean of 77.8% correct, ranging from 56%-95%; note that all scores fell between the mean scores of the other two groups). Although any cutoff threshold used to define discrete categories of AP ability is ultimately arbitrary, this trichotomous categorization is consistent with findings in other recent work (e.g., Marvin, 2008; Miyazaki & Ogawa, 2006).

The existence of this borderline AP group raises questions for future study: how does one partially acquire AP? Is there something qualitatively different about these subjects, or their early musical training or linguistic exposure? Or do they simply represent the overlapping outliers of the surrounding categories of AP (non-)possession, achieving similar scores via dissimilar strategies or capacities? The answers to these questions will be informative but elusive, as borderline AP appears to be even rarer than clear AP based on our samples.

Another question raised by our findings is the degree to which AP possession facilitates musical dictation accuracy for more diverse levels of musical training. For all subjects in our study, age of onset of musical training ranged from age 1 to age 8, and duration of training ranged from 3 to 28 years. Our conclusions are necessarily limited to these ranges of experience, and results may vary for subjects with different musical backgrounds. A related challenge is determining how to operationalize musical ability. While outside the scope of this study, our choice of task was grounded in its use as a placement exam for incoming music majors at a music conservatory; further corroborating its validity were multiple (unsolicited) comments from subjects noting that it was very similar to tasks required of them in music classes at this university.

On the other hand, musical ability cannot be boiled down into any single task, and there are doubtless many important aspects not captured by this dictation test. Although a reference note was provided for each musical excerpt, allowing the task to be completed using only relative pitch, it could be argued that AP possessors might do so by merely identifying each note separately rather than comprehending meaningful relationships between the notes (Miyazaki & Rakowski, 2002). While such a strategy would still be useful and applicable in a variety of musical settings, this line of reasoning invites further tests of musical ability, depending more explicitly on relative pitch processing. This was the motivation for the study presented in Chapter 3.

Chapter 3: AP and interval naming

Interval identification, which requires only recognizing the relationship between two pitches, is a relative pitch task almost by definition. Following up on our previous work (Dooley & Deutsch, 2010), our purpose in this study was to compare AP possessors and non-possessors (again matched in age of onset and duration of musical training) on their ability to accurately identify a variety of intervals, as a stronger test of relative pitch proficiency. Once again, we hypothesized that AP possession would be an advantage rather than a disadvantage, despite numerous claims to the contrary in the literature; once again, we were right.

After identifying 18 AP possessors and 18 matched non-possessors using the same AP test as in the previous study, we asked subjects to identify a series of 144 musical intervals comprised of every interval size (minor second through octave) built on every key in standard Western tuning. These intervals were presented in three different conditions: a sine wave condition consisting of brief (30ms) pure tones; a piano condition consisting of longer (500ms) piano tones; and a cadence condition consisting of the same tones as the piano condition but with each interval preceded by a V7-I chord cadence to provide musical context. These variations allowed us to test for possible moderating factors such as timbre, key, interval size, tone duration, and musical context.

Consistent with our previous study (Dooley & Deutsch, 2010), AP possession accounted for the majority of variance in performance on the musical tasks, even controlling for age of onset and duration of musical training. This strongly supports the hypothesis that AP possession is associated with enhanced performance on musical tasks requiring only relative pitch, and contradicts widespread claims to the contrary (Levitin, 1999; 2008; Levitin & Rogers, 2005; Miyazaki, 1993, 1995, 2004; Miyazaki & Rakowski, 2002). Specifically, the mean overall score on the interval task was 74% correct for AP possessors (with no scores below 50% correct), compared with a mean of 44% correct for non-possessors (with only one score above 70% correct). Furthermore, this AP advantage held across all three conditions and across all keys and intervals sizes tested, confirming that the effect did not depend upon timbre, key, interval size, tone duration, or musical context.

As in the previous study, these conclusions are limited to the range of musical experience of the subjects tested; specifically, the extent of the advantage conferred by AP possession in such interval naming tasks may vary for individuals with later onsets or fewer years of musical training. In addition, the stimuli used were all based on standard Western tuning (A = 440 Hz). It is not clear whether these results would differ using different tuning standards (e.g., all notes shifted by half a semitone), and in fact this would be an interesting follow-up. Miyazaki's results (1993, 1995) suggest that the AP advantage may not hold for detuned intervals (in which the relationships between the notes forming a given interval size are not consistent); however, this apparent disadvantage observed for AP possessors may actually be due to Stroop-like interference effects from the stimuli and/or the response apparatus used (see Dooley & Deutsch, 2010; Miyazaki, 2000; Stroop, 1935; Takeuchi & Hulse, 1993).

Thus far, we have investigated the impact of AP possession on proficiency in musical tasks requiring only relative pitch. In contrast to widespread misconceptions in the literature that AP is irrelevant or disadvantageous to music, our results confirmed a considerably strong AP advantage in such tasks. To gain further insight into the nature of AP, we turn now to consider the extent to which non-possessors can demonstrate AP-like abilities using musical tasks requiring long-term pitch memory.

## Chapter 4: AP and pitch memory for familiar tonal stimuli

At first glance, it might seem redundant to examine the accuracy of long-term pitch memory in subjects after previously confirming that they do not perform beyond chance levels in standard tests of AP. However, previous research has documented the presence of just such a capacity in non-possessors, using a variety of stimuli and methods (Gußmack, Vitouch, & Gula, 2006; Halpern, 1989; Levitin, 1994; Schellenberg & Trehub, 2003, 2008; Smith & Schmuckler, 2008). Taken together, it appears that many non-possessors are capable of reproducing the pitches of a familiar song in or near its original key (or judging whether it is played in the correct key) with statistically significant accuracy.

This has led some researchers to speculate that AP is simply the combination of a commonplace pitch memory capacity with a rare retention of verbal-pitch labels (e.g., Levitin, 2008; Schellenberg & Trehub, 2003). If this were the case, then one would expect AP possessors and non-possessors to demonstrate similar levels of accuracy in such song reproduction or recognition tasks, as these tasks require only the recall of familiar pitches without necessitating the use of learned pitch labels. Conversely, an AP advantage in such tasks would suggest that verbal-pitch label retention is not the only distinguishing feature of AP possession. To test this, 18 AP possessors and 18 non-possessors (matched for age of onset and duration of musical training) were asked to recall and vocalize part of any familiar song of their choice in the same key in which they remembered it, in a procedure similar to that of Levitin (1994); subjects were then asked to repeat this procedure using their cell phone ringtone. Subject vocalizations were compared with the pitch class of the corresponding notes of the original song recordings and cell phone ringtones.

In summary, both AP possessors and non-possessors performed significantly more accurately than chance on the song task, and in fact the performance of non-possessors on this task closely approximated the results obtained by Levitin (1994); the accuracy of AP possessors and non-possessors did not significantly differ on this task, although a trend favoring AP possessors was present and might reach significance with a substantially larger subject pool. In contrast, only AP possessors exceeded chance levels of accuracy on the ringtone task, and their performance did differ significantly from that of non-possessors on this task. Thus, AP possession may enhance long-term memory for tonal information, at least under some circumstances, without the conscious use of verbal labels. Taken together, these intriguingly divergent results implicate specific factors in the retention of long-term pitch memory, and they raise a variety of testable questions.

One potential factor is motor memory; non-possessors may be exhibiting AP-like skill in song (but not ringtone) production tasks by virtue of previous practice, having repeatedly sung the songs they chose to vocalize (Halpern & Zatorre, 1999; Hsieh & Saberi, 2008; c.f. Kaernbach & Schlemmer, 2008). In addition, familiar songs (but not ringtones) are more likely to have elicited 'active' rather than 'passive' listening, which Brown & Martinez (2007) found to be associated with cortical activation patterns involved in musical discrimination, mental imagery, and vocal-motor production. Conversely, AP possessors may perceive or encode pitch information automatically, facilitating a greater capacity for long-term pitch memory retention even in the absence of active listening. This line of reasoning could be tested using other familiar but musically un-engaging tonal stimuli (e.g., noisy everyday gadgets which one regularly encounters but rarely sings along with), such as alarm clocks or car horns.

It is also worth noting that roughly half of the ringtones for both groups actually were excerpts from popular songs; thus, it appears to be the context rather than the content that matters most, lending further support to the importance of actively attending to or rehearsing the stimuli. If non-possessors could be trained to actively attend to their ringtones and, over time, learn to accurately and reliably produce the pitch, it would provide stronger evidence for this explanation. The results also point to a more exciting possibility along these lines. The finding that a substantial proportion of non-possessors were able to accurately recall and vocalize a particular pitch suggests that this ability could be refined into a rudimentary form of AP. Anyone who can reliably recall a particular note from a particular song, once the identity of that pitch has been determined, should be able to use this memory as an internal reference and, in theory, function as if in partial possession of AP.

## General Conclusions

Altogether, the studies presented here have addressed a number of questions regarding the nature of AP and related abilities. The general impression of AP, both historically and among musicians today, is that of a rare but desirable gift, such that commercial products are available for customers hoping to acquire it, and the nature of its origins continue to dominate much of the research on this topic (Bachem, 1955; Burge, 2011; Zatorre, 2003). However, the apparent consensus in the music perception literature over the last two decades is that AP is irrelevant to music in general and a handicap for relative pitch processing in particular (Levitin, 2008; Levitin & Rogers, 2005; Miyazaki, 1993, 1995, 2004; Miyazaki & Rakowski, 2002). Converging evidence from our studies presented in Chapters 2 and 3 confirm that, on the contrary, AP possession actually confers a significant advantage in a variety of musical tasks requiring only relative pitch.

These findings can be reconciled with the previous literature by considering, as argued in Chapters 2 and 3, that the few studies cited as proof of AP's detriments (Miyazaki, 1992, 1993, 1995, 2004; Miyazaki & Rakowski, 2002) are in fact simply documenting Stroop-like interference effects for AP possessors in contrived situations, rather than broadly negative impacts of AP possession on musically relevant tasks (Dooley & Deutsch, 2010; Hsieh & Saberi, 2008b; Miyazaki, 2000; Stroop, 1935; Takeuchi & Hulse, 1993). Such effects were obtained and misinterpreted through a combination of artificial stimuli (e.g., detuned intervals), incongruent comparisons (e.g., materials provided for comparison judgments transposed into incorrect keys), and the use of ambiguously and incongruently labeled response apparatuses (e.g., individual response keys named to refer to multiple pitches depending upon absolute or relative interpretations of their names). It would be no more surprising, nor informative, to find that subjects are slower and less accurate at color identification if the response keys used were labeled with color words printed in incongruent colors; nor would such a finding prove these subjects color-blind. Indeed, included but widely ignored in these prior studies are indications that AP possessors show no such "disadvantages" when the stimuli and response apparatuses are in fact congruent (Miyazaki, 1993; 1995). The erroneous claim that AP somehow inhibits or limits relative pitch processing, for which these studies are typically cited as evidence, is at odds with physiological data suggesting that many AP possessors can in fact engage in both absolute and relative modes of processing (Renninger et al., 2003; Itoh et al., 2005). It remains to be seen exactly under which circumstances AP possession is most advantageous for various musically relevant tasks; based on the findings presented in Chapters 2 and 3, it is likely that AP will prove beneficial under all but the most convoluted conditions.

As discussed in Chapter 4, the interaction between AP possession and stimulus source (i.e., song vs. cell phone) in accuracy for long-term pitch memory informs the inquiry into the general nature of AP. The superior accuracy of AP possessors for recall of ringtone pitch calls into question the proposition that pitch memory is widespread and normally distributed throughout the population, and that AP possessors differ only in their unusual capacity for retaining verbal-pitch labels (Levitin, 1994; Schellenberg & Trehub, 2003). In fact, AP possessors have been shown to use multiple coding strategies (Zatorre, 1989), and differ from non-possessors on a number of anatomical and functional grounds (Keenan et al., 2001; Klein et al., 1984; Loui et al., 2010; Oeschlin et al., 2009; Schlaug, 1995; Schulze et al., 2009; Wilson et al., 2009; Zatorre et al., 1998) that may facilitate qualitatively different pitch memory capacity (Hsieh & Saberi, 2008a).

Few characteristics of AP have been more extensively agreed upon than the recognition that acquisition for adults is near impossible. The finding that many non-possessors demonstrated accurate memory for the pitch of familiar songs, consistent with previous research (e.g., Halpern, 1989; Levitin, 1994; Schellenberg & Trehub, 2003) suggests that, at least under certain circumstances, access to long-term pitch memory may be widely consciously accessible. Though not equivalent to true AP, such a common capacity, if properly harnessed and honed, may prove more promising an avenue towards some degree of late-onset AP acquisition than the fruitless strategies previously attempted (e.g., Brady, 1970; Crozier, 1997; Cuddy, 1967, 1970). Together, the findings presented in Chapter 4 suggest that while the ubiquity of long-term pitch memory has been overstated (and the differences between possessor and non-possessors have been understated), there is nevertheless reason to believe that some AP-like abilities may be within reach for many adult non-possessors.

Future Directions

These findings raise a number of testable questions regarding the nature and benefits of AP. Perhaps the most exciting prospect, if uncertain- considered to be the “holy grail” of AP research (Diana Deutsch, personal correspondence)- is the possibility of applying the results of Chapter 4 to developing AP-like abilities in adult non-possessors. It is plausible that the ability to reliably recall or produce a particular pitch from a familiar song can be parlayed into general access to an internal template for AP; such a skill may never match the speed or accuracy of true AP, but could still prove useful for musicians in many contexts.

The findings in Chapters 2 and 3, in support of a strong advantage of AP possession across various musical tasks, call for further inquiry into the benefits conferred by AP possession in other musical settings. As discussed above, one logical consideration would be an extension of the conditions included in these studies into other timbres, tone durations, and tunings. Identification of triads, $7^{th}$ chords, and other more complex stimuli would further test relative pitch processing of AP possessors and non-possessors with musically relevant material.

More broadly, it is worth considering the impact of AP possession outside of purely musical contexts. Given the substantially superior performance of AP possessors in each of these experiments, a natural follow-up question concerns the potential benefits of AP possession more generally. For example, does AP aid in non-musical memory tasks such as digit span, whether through access to additional encoding cues (i.e., the pitch of spoken words) or some more central cognitive characteristic? We are in fact in the process of gathering data on this very question, and preliminary results are promising.

Another extra-musical question concerns possible differences in personality traits, or cognitive styles, between AP possessors and non-possessors. For example, Chin (2003) and Brown et al. (2003), have suggested that there may be a link between AP possession and autism-like tendencies. However, the logic behind this line of reasoning is akin to looking at the relatively high proportion of AP possession among the early blind and concluding that AP possessors in general tend to have vision problems. Here too, we have gathered preliminary data, and there appears to be no difference in autism-like traits between AP possessors and non-possessors with equivalent musical training.

Another area of interest concerns the dramatically elevated prevalence of AP that we have previously documented amongst fluent speakers of tone languages (e.g., Deutsch et al., 2009). Given that many musicians develop (or retain) AP in the complete absence of tone language exposure, is there something different about the training, biology, cognitive processing, or other factors of these AP possessors compared to those who are tone language fluent? Lastly, where do the borderline AP possessors fit in to all of these questions? As discussed in Chapter 2 (or see Dooley & Deutsch, 2010), AP possession is not an all-or-nothing ability but rather exists on a continuum, and it is unclear what leads some musicians to "sort of" develop or maintain AP. Of course, it is possible that this group actually represents a heterogeneous hodgepodge of various predispositions and background experiences, but any shared characteristics would be worth uncovering. The rarity of such subjects, even compared to AP possessors in general, will render systematic investigation of this phenomenon particularly difficult, but an exploration of the contributing factors to borderline AP, and its subsequent benefits in music and other domains, may prove uniquely informative to understanding the origins and related abilities of AP in general.

# GLOSSARY

**Absolute Pitch (AP):** the ability to recognize or produce a pitch without a reference

**Cadence:** a sequential progression of chords, often creating a sense of resolution

**Cent:** $1/100^{th}$ of a semitone

**Chord:** a combination of pitches (typically 3 or more) sounded simultaneously

**Interval:** a combination of two notes, or the ratio between their frequencies

**Key:** the pitch class that serves as the tonal or harmonic center of a piece

**Octave:** the interval formed by two notes with a 2:1 frequency ratio

**Pitch class:** the set of all notes in octave relationship, e.g. all C's or all C#'s

**Perfect Pitch:** informal term for absolute pitch (AP)

**Relative Pitch (RP):** the ability to recognize or produce a pitch given a reference

**Semitone:** the interval formed by two adjacent notes in a 12-note scale (i.e. the octave is divided into 12 equal parts); the frequency ratio is $2^{1/12}:1$

**Timbre:** the quality of a sound distinct from pitch or loudness

**Tonal:** music consisting of hierarchical pitch relationships based on a key or tonic

**Tonic:** the first note of a scale; the tonal center of a piece

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