Absolute Pitch

Annie H. Takeuchi and Stewart H. Hulse

Absolute pitch (AP) is the ability to identify a tone’s pitch or to produce a tone at a particular pitch without the use of an external reference pitch. AP exists in varying degrees among people generally described as AP possessors. AP possessors vary not only in the accuracy with which they can identify pitches but also in their ability to produce pitches absolutely and in their ability to identify tones of various timbres and in various pitch registers. AP possessors’ memory for pitches is mediated by verbal pitch names; they do not have superior memory for pitches per se. Although the etiology of AP is not yet completely understood, evidence points toward the early-learning theory. This theory states that AP can be learned by anyone during a limited period early in development, up to about age 6, after which a general developmental shift from perceiving individual features to perceiving relations among features makes AP difficult or impossible to acquire.

Absolute pitch (AP) is the ability to identify the pitch of a musical tone or to produce a musical tone at a given pitch without the use of an external reference pitch. Most humans process musical pitch relatively rather than absolutely. They process the melodic and harmonic relations among pitches instead of the absolute pitches themselves. In contrast, people who have AP can encode and remember absolute pitches.

AP is a rare ability; its incidence is generally estimated at less than .01% of the general population (Bachem, 1955; Profita & Bidder, 1988). Those who have AP claim that identifying pitches absolutely is effortless and immediate (Bachem, 1940; Corliss, 1973; Profita & Bidder, 1988; Revesz, 1953) and that they made no special effort to develop AP (Baird, 1917; Boggs, 1907; Weinert, 1929, cited in Petran, 1932). In contrast, efforts by adults to develop AP have never achieved unqualified success, although efforts to teach children AP have been more successful.

These characteristics of AP would not excite so much interest were it not for the fact that AP is generally considered a desirable ability. AP is useful to musicians, especially when studying atonal music (Crutchfield, 1990). In atonal music, there is no tonic pitch that can serve as a reference point. Therefore it is more difficult to detect minor pitch errors by determining pitch relations in atonal music than in tonal music. AP enables a performer or listener to detect pitch errors on an absolute basis, without having to determine pitch relations. In addition, Abraham (1901, cited in Petran, 1932) suggested that AP could be an advantage to composers because it would enable them to work with units of a single tone, whereas composers without AP must work with pitch relations that require a minimum unit of two tones.

Psychologists have puzzled over several questions about AP for over 100 years. Why does AP occur so rarely? Does AP involve superior memory or superior discrimination of pitches? Do AP possessors perceive music in the same way that nonpossessors do? Is AP learned, and if so, how? Why is it learned by some people and not by others? We address these questions in the latter parts of this article. However, we begin by addressing a more basic question: What exactly can an AP possessor do?

Abilities of AP Possessors

Methods of Measuring AP

Three kinds of tasks have been used to measure AP: identification tasks, production tasks, and memory decay tasks. We discuss each of these tasks in the following sections.

Pitch Identification Task

The most common method of assessing AP is with a pitch identification task. Subjects are asked to identify absolutely the pitches of various tones. In Western music, the octave, which is the interval formed by two pitches whose fundamental frequencies stand in a 2:1 ratio, is divided into 12 parts. The division is into logarithmically equal parts in the equal-tempered tuning system, the tuning system most commonly used in psychological studies. Theoretically, the frequency at each point of division corresponds to a musical pitch, although in musical practice, a small range of frequencies surrounding the division is accepted as corresponding to a particular musical pitch. Thus, there is a many-to-one mapping of frequency to pitch in music.

Pitch names are composed of two parts. The first part is the pitch class, for example, C, C-sharp, or D. The frequency at each of the 12 divisions of an octave corresponds to a different pitch class. The distance from one pitch class to an adjacent pitch class is called a semitone. In an equal-tempered tuning system,
tones a semitone apart have fundamental frequencies forming a $2^{1/12}$ ratio. The second part of a pitch name is the octave designation. All pairs of tones an octave apart have the same pitch class; they are distinguished by their octave designation. Although there is no universal means of designating octaves in music, in the most commonly used system, the octave runs from C up to B, and middle C (261.6 Hz) is designated C4. The B next to middle C (246.9 Hz) is B4. The C an octave above middle C (523.2 Hz) is C5, the C an octave below middle C (130.8 Hz) is C1, and so on. The pitch A4, used to tune orchestras, corresponds to 440.0 Hz by modern convention.

**Accuracy of absolute pitch identifications.** Percentage of correct identification is the most common measure of performance in pitch identification tasks, and under normal circumstances, the measure works well. However, single percentage correct can be a misleading index under certain conditions. Some subjects may consistently identify pitches a semitone low or a semitone high (Bartholomew, 1925, cited in Petran, 1932; Weinert, 1929, cited in Ward, 1963a). This can occur because a subject is accustomed to a different tuning standard for A than 440.0 Hz. There are also anecdotal reports that as a result of aging, an AP possessor's pitch perception may shift by one or two semitones, so that all pitch identifications are one or two semitones too high (Triepel, 1934, cited in Ward & Burns, 1982; Vernon, 1977). To the extent that pitch perception depends on the place of maximum stimulation on the basilar membrane, this shift in absolute pitch perception may be due to loss of elasticity of the basilar membrane as the subject ages, which results in a gradual shift in the place where a particular frequency maximally excites the basilar membrane (Vernon, 1977; Ward & Burns, 1982).

Ward (1963a, Ward & Burns, 1982) proposed four solutions to the problem of measuring AP in subjects who consistently err by a semitone. The first solution was to adjust the stimuli to each individual subject's musical scale, which would involve a calibration process before actually testing absolute pitch identifications. This tedious process has only been used in one study (Weinert, 1929, cited in Ward, 1963a). The second solution was to count any identifications within a semitone of the actual pitch as correct. This procedure has been adopted in several studies (Baggaley, 1974; Miyazaki, 1988a). However, this solution does not distinguish subjects who consistently err by a semitone in the same direction from subjects who randomly err by a semitone. The third method, which is commonly used, was to measure the average error, the number of semitones by which misidentifications err (Carpenter, 1951; Carroll, 1975). This measure also does not take into account the consistency of the direction of error.

The method recommended by Ward (1963a) was to analyze the results in terms of information theory, measuring not the overall accuracy of pitch identifications, but rather the consistency of identifications in terms of the amount of information transmitted. In information theory, the amount of information transmitted, which is measured in bits, is an estimate of the number of response categories that would have produced errorless identification. The number of bits is the base 2 logarithm of the number of equally likely alternatives a subject can accurately choose among. For example, 1 bit of information transmitted implies that given only 2 response categories, identification would be perfect. Two bits of information implies 4 response categories would produce perfectly accurate identification; 3 bits implies 8 response categories, and so on (Miller, 1956). Measuring performance in terms of information transmitted eliminates the need to establish criteria for a correct or incorrect pitch identification because it measures consistency rather than accuracy of identification. AP possessors can retain about 6 bits of information about pitch, which corresponds to about 64 response categories (Attneave, 1959; Carroll, 1975; Ward, 1953, 1963b), whereas nonpossessors retain on average about 2.5 bits or 5.7 categories (Fulgosi, Knezovic, & Zarevski, 1984; Hartman, 1954; Pollack, 1952, 1953).

Given the foregoing, how accurate are absolute pitch identifications as measured by percentage of correct identification? In Table 1, we present the results of several absolute pitch identification experiments conducted since 1970. The table shows the range and the mean of the percentage of correct pitch identifications by AP possessors in each experiment, where correctness is determined by the criteria given in the rightmost column. Octave errors, which are discussed below, occur when the pitch class of a tone is correctly identified but the octave identification is incorrect.

It is apparent from the table that accuracy of absolute pitch identification has varied widely across experiments. There are a number of possible reasons for this fact. One is that experimenters have used different methods to determine whether a particular subject would qualify as an AP possessor. For example, Zatorre and Beckett (1989) relied on self-reports. In contrast, Miyazaki (1988a) simply tested a number of music students and determined from analysis of the data which subjects were AP possessors. Other factors affecting accuracy of identification, which are discussed in more detail later, are the timbre and pitch register of the tones tested. Also, it has been widely reported that tones above 4000–5000 Hz lose their musical quality and have no distinct pitch class (Semal & Demany, 1990; Stevens & Volkmann, 1940; Ward, 1954). This may be of relevance for interpreting the Lockhead and Byrd (1981) study, which used sine tones with frequencies above 5000 Hz. Also, in experiments by Carroll (1975) and by Lockhead and Byrd (1981), subjects indicated the pitch by playing back the corresponding note on a piano. As we discuss below, the sound of the piano tone could have provided feedback that allowed a subject to use relative pitch cues in succeeding trials to identify pitches. Although these variations no doubt contributed to the differences in measured AP across experiments, they cannot account for the variations within a single experiment. The variations within experiments reflect the wide range of AP among AP possessors.

Although we cannot determine the lower limit of AP because this limit is confounded with the question of what defines an AP possessor, we can study the upper limit of AP. The most common approach to determining the limit in acuity of AP identifications has been to have subjects identify to the nearest musical pitch tones spaced less than a semitone apart. Often, subjects also indicate whether the pitch is mistuned and, if so, the direction of the mistuning. In such a task, tones of several different frequencies can correspond to the same musical pitch. At issue is how consistently AP possessors identify frequencies that are spaced less than a semitone apart. van Krevelen (1951)
Table 1
Pitch Identifications by Absolute Pitch (AP) Possessors in Studies Since 1970

<table>
<thead>
<tr>
<th>Study</th>
<th>No. AP possessors tested</th>
<th>% correct</th>
<th>Pitch register and range</th>
<th>No. tones tested</th>
<th>Spacing between test tones (semitones)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balzano (1984)</td>
<td>3</td>
<td>84.3–91.2</td>
<td>Sine</td>
<td>A2–G#5</td>
<td>1</td>
<td>Excluding octave errors</td>
</tr>
<tr>
<td>Benguerel and Westdal (1991)</td>
<td>10</td>
<td>62–100</td>
<td>Sine</td>
<td>C3–C5</td>
<td>1</td>
<td>Within 0.5 semitone</td>
</tr>
<tr>
<td>Carroll (1975)</td>
<td>5</td>
<td>79.7–95.3</td>
<td>Piano</td>
<td>A3–C5</td>
<td>1</td>
<td>Excluding octave errors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>48.0–92.8</td>
<td>Piano</td>
<td>A1–C7</td>
<td>1</td>
<td>Excluding octave errors</td>
</tr>
<tr>
<td>Lockhead and Byrd (1981)</td>
<td>4</td>
<td>99.0</td>
<td>Piano</td>
<td>C1–A7</td>
<td>1</td>
<td>Excluding octave errors</td>
</tr>
<tr>
<td>Miyazaki (1988a)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experiment 1</td>
<td>7</td>
<td>90.2–99.4</td>
<td>Sawtooth</td>
<td>C3–C6</td>
<td>0.2b</td>
<td>Identified nearest pitch class within 1 semitone</td>
</tr>
<tr>
<td>Experiment 2</td>
<td>22</td>
<td>45.0–99.7</td>
<td>Sine</td>
<td>C3–C6</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Miyazaki (1989)</td>
<td>7</td>
<td>91.6</td>
<td>Piano</td>
<td>C1–B7</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>74.4</td>
<td>Sine</td>
<td>C2–B7</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>64.8–97.9</td>
<td>Synthesized piano</td>
<td>C1–B7</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Miyazaki (1990)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experiment 2</td>
<td>10</td>
<td>53.3–99.6</td>
<td>Synthesized piano</td>
<td>C2–B6</td>
<td>1</td>
<td>Identified pitch class only</td>
</tr>
<tr>
<td>Takeuchi and Hulse (1991)</td>
<td>19</td>
<td>58.4–100</td>
<td>Synthesized piano</td>
<td>E3–D#5</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Zatorre and Beckett (1989)</td>
<td>21</td>
<td>27.1–100</td>
<td>Piano</td>
<td>C2–G6</td>
<td>5</td>
<td>Excluding octave errors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>37.3–100</td>
<td>Piano</td>
<td>C4–C#3</td>
<td>1</td>
<td>Excluding octave errors</td>
</tr>
</tbody>
</table>

* C4 is middle C (261.6 Hz). The range of the piano is A0–C8.  
  b The octave C4–C5 was divided into 60 parts (0.2 semitone apart). One third of these tones were lowered by one octave, and one third were raised by one octave.

ABSOLUTE PITCH

Tested 17 AP possessors on frequencies ranging from 404 Hz to 478 Hz in increments of 2 to 3 Hz. Standard deviations, an index of the consistency of pitch identifications, averaged approximately 0.34 semitone across all subjects, with a minimum of 0.19 semitone. Ward’s (1963b) analysis of these data and of Abraham’s AP tests on himself (1901, cited in Ward, 1963b) suggested that for both Abraham and van Krevelen’s best subject, adjacent stimuli needed to be separated by about 0.5 semitone to achieve 95% correct identification.

In more recent investigations, AP possessors identified to the nearest musical pitch tones separated by 0.2 semitone, ranging from 130.8 Hz to 1046.5 Hz (Miyazaki, 1988a) and from 220.0 Hz to 440.0 Hz in a study performed in our laboratory. Although these experiments differed in the range of frequencies tested, in both studies, a few subjects demonstrated perfectly consistent mappings of frequency to pitch: All presentations of a particular frequency were identified as the same pitch, whereas all presentations of a frequency 0.2 semitone removed from that frequency were identified as the adjacent pitch. For such subjects, the limit of their acuity in making absolute pitch identifications may have been their limit of perceiving frequency differences.

In a series of tests of absolute pitch identification on a single subject, Ward (1963b; Ward & Burns, 1982) first presented tones one at a time, along with numerical identifications of each tone. The subject was given index cards and instructed to write anything that would help her identify the tones as Number 1, Number 2, and so on. Unlike the methods discussed earlier, this method required a one-to-one mapping of frequency to response and circumvented the difficulty that there is no common musical pitch name for tones that fall between semitones. After testing the subject with sets of tones in various pitch ranges and registers and with spacings of 1, 0.5, and 0.25 semitones, Ward (1963b) concluded that perfectly correct absolute pitch identification in this subject was limited to pitches separated by 1 semitone.

This limit of one semitone on a task involving a one-to-one mapping of frequency to response is reasonable given that several studies have shown that in musical contexts, pitches are perceived in discrete categories one semitone apart. Pitches that fall between semitones are assimilated to the nearest semitone (Harris & Siegel, 1975; Siegel & Siegel, 1977). Therefore, treating tones separated by less than a semitone as distinct pitches runs counter to musical practice and training.

Speed of absolute pitch identifications. Many authors distinguish between absolute pitch identifications made directly and
identifications made indirectly through a single reference pitch (Bachem, 1937, 1940, 1955; Baggageley, 1974; Baird, 1917; Balzano, 1984; Revesz, 1953; Seashore, 1940). For example, many orchestral musicians claim that they can reliably produce the pitch A₄ (440 Hz), to which they tune their instruments (Bachem, 1937, 1955; Revesz, 1953). Such musicians could identify the pitch of a tone indirectly by identifying the pitch relation between that tone and A₄ and then determining what pitch bears that relation to A₄. Most musicians develop the ability to identify relations among pitches, called relative pitch, as part of their musical training.

If some pitch identifications are made directly and others indirectly, these two types of identification should be distinguishable by their speed (Bachem, 1937, 1955; Baggageley, 1974; Baird, 1917; Balzano, 1984; Costall, 1985; Revesz, 1953; Seashore, 1940; Teplov, 1961/1966, cited in Spender, 1980). Identifications made directly should be faster than identifications made through a reference pitch. In addition, one might expect the speed of pitch identifications to increase monotonically as a function of distance from the reference pitch. To test this hypothesis, Takeuchi (1989) asked AP possessors to indicate whether the pitch of an auditory tone matched the name of a pitch class presented visually on a computer monitor and measured the response time. There was no evidence in the response time data to support the hypothesis that some AP possessors based their identifications on a single pitch referent. Rather, as discussed later, responses were slower to both auditory and visual pitch classes corresponding to the black keys of a piano keyboard than to pitch classes corresponding to the white keys. In general, the most accurate identifications were made most quickly, both within subjects and across subjects, as has been reported in several other experiments (Baird, 1917; Carroll, 1975; Miyazaki, 1988a, 1989, 1990; Whipple, 1903).

Pitch Production Task

Another method for evaluating AP performance is with a production task, in which subjects produce a tone at a given pitch, usually by adjusting an oscillator or other pitch variator or, more rarely, by singing. Singing is rarely used because of the difficulty of objectively determining the pitch of the sung tone.

Not all people who can identify the pitch of a tone absolutely can also produce a tone at a given pitch absolutely (Petran, 1932; Revesz, 1953). Weinert (1929, cited in Petran, 1932) found that only 14 of 21 AP possessors he tested could produce pitches absolutely.

In production tasks, performance is usually measured in terms of either accuracy, as indicated by the average deviation from a fixed standard frequency, or consistency, as indicated by the standard deviation of productions of the same pitch. Consistency is the better measure of AP, because accuracy is based on an equal-tempered tuning system with an A₄ of 440.0 Hz. However, subjects may be accustomed to a different tuning standard or to a different tuning system.

One difficulty reported by some researchers who have used a production task is that AP possessors will accept a range of frequencies as a given pitch. Therefore, some subjects, when asked to tune an oscillator to a particular pitch, argue that the pitch is not a single frequency but is anywhere within a particular range of frequencies (Petran, 1939). This many-to-one mapping of frequency to pitch is especially evident in Petran's (1932) experiment in which subjects adjusted a tone variator to produce A₄ (440.0 Hz) but were allowed to adjust the tone variator dial in only one direction on any given trial; they were not allowed to adjust the dial back and forth. In this study, when the tone variator was initially set at a frequency below 440.0 Hz, the final setting, averaged over eight AP possessors and five repetitions, was 410.5 Hz, substantially lower than the average final setting of 453.8 Hz produced by the same subjects when the device was initially set above 440.0 Hz. This result suggests that for these AP possessors, the pitch A₄ corresponded to frequencies ranging from about 410 Hz to 454 Hz, a range of about 1.8 semitones. However, this interpretation is tempered by the unidirectional adjustment task, which may have caused subjects to set a more liberal criterion for A₄ than they might have used had they been allowed to adjust the tone variator dial back and forth.

Absolute pitch productions are usually tested in a single session. However, absolute pitch productions varied over the course of a day by about 0.05 semitone in Wynn's (1972) study and by about 0.4 semitone in Abraham's study of himself (1901, cited in Ward, 1963b). Productions also varied by about 0.33 semitone across days (Abraham, 1901, cited in Ward, 1963b; Wynn, 1972). Interestingly, Wynn (1972, 1973) reported that variations in the frequency his wife produced as A₄ were correlated with her menstrual cycle. He reported similar variations with menstrual cycle in another female subject. Both of these subjects were tested by singing an A₄ each morning. Wynn measured the frequency of the second harmonic of this sung tone from a frequency meter. Spot checks were occasionally made by having the subjects adjust an oscillator to produce A₄, and the two methods produced consistent results. Wynn (1972) also reported variations with a period of 20 days in a male subject who produced A₄ by adjusting an oscillator. Wynn conjectured that these variations may have been related to the subject's level of urinary 17-ketosteroids, precursors to testosterone, which varies systematically in human males over a 20-day cycle. However, no hormonal measurements were made on the male subject.

These variations within and across days suggest that when comparing the consistency of absolute pitch productions by subjects in different experiments, it is important to take into account whether the productions were made on a single day or on several days and whether the sessions took place at the same time each day or varied in time of day.

What is the upper limit of performance on an absolute pitch production task? Bachem (1937, 1940) reported that the best AP possessors were consistent to 0.1 semitone in their AP productions. Other studies have shown that the standard deviations of absolute pitch productions by the best AP possessors are about 0.2 semitone (Rakowski, 1978; van Krevelen, 1951).


**Decay-Rate Tasks**

A third way to assess AP is to measure the rate of memory decay for a pitch. AP possessors should be able to remember a pitch over a longer period of time than nonpossessors. Two types of tasks have been used to measure the rate of memory decay. One is a same/different comparison of pitches in which subjects decide whether two tones separated by a variable duration are the same or different pitch (Bachem, 1954). The duration between the two tones varies from about 5 s up to 1 day or even 1 week in these experiments. In the other type of task, subjects reproduce a pitch after delays ranging from 1 s to 1 day, either by adjusting an oscillator themselves (Rakowski, 1972; Rakowski & Morawska-Bungeler, 1987) or by directing the experimenter to do so (Bachem, 1940).

The two types of tasks produce similar results. For retention intervals of up to 1 min, there is minimal decay in memory by both AP possessors and nonpossessors and little, if any, difference between AP possessors and nonpossessors (Bachem, 1954; Rakowski, 1972; Rakowski & Morawska-Bungeler, 1987). At longer intervals, AP possessors show no further decay of memory, whereas nonpossessors deteriorate to chance levels of performance (Bachem, 1940, 1954; Rakowski & Morawska-Bungeler, 1987). Presumably, these results occur because at short retention intervals, both AP possessors and nonpossessors use echoic memory of the pitch to perform the task. At longer retention intervals, echoic memory has decayed, and AP possessors instead remember the verbal pitch name, whereas nonpossessors have no alternative strategy for remembering the pitch and therefore perform at chance.

In a variation on these tasks, Siegel (1974) asked subjects to indicate which of two tones was higher in pitch. Time intervals between the two tones ranged from 1 to 15 s, and interfering tones were presented during this interval. When the tones were separated by 0.75 semitone or more, and retention intervals were more than 1 s, AP possessors performed this task more accurately than did nonpossessors.

When pitch names cannot be used to perform the task, there is no longer any difference between AP possessors and nonpossessors, even after long retention intervals, which supports the idea that AP possessors remember only the verbal label for the pitch over long intervals. Pitch names cannot be used when frequencies tested are extremely high and lack a definite pitch class. Several studies have shown that the upper frequency limit of tones judged to be musical is 4000–5000 Hz (Semal & De-many, 1990; Stevens & Volkmann, 1940; Ward, 1954). At higher frequencies, AP possessors show what Bachem (1948) called *chroma fixation*, although subjects could perceive that the tones were increasing in pitch height, the pitch class of the tones no longer changed. Some subjects identified all tones above 5000 Hz as pitch class C-sharp, for example. In Bachem’s (1954) memory decay experiment, there was no difference between AP possessors and nonpossessors for frequencies of 5000 Hz or more.

The difference between AP possessors and nonpossessors is also attenuated when the frequencies of the tones to be remembered fall between musical pitches, for example, 1000 Hz falls between B, and C, (Rakowski, 1972), and when the frequencies of the tones to be remembered are separated by intervals of less than 0.5 semitones, so that the standard and comparison tones correspond to the same pitch name (Siegel, 1974). In these cases, AP possessors do not precisely remember the pitch because it is encoded only roughly, with respect to the nearest musical pitch.

**Issues in Absolute Pitch Tasks**

**Octave Errors**

An octave error occurs when a subject correctly identifies or produces the pitch class of a note but incorrectly identifies or produces the octave. Octave errors are considered a special case in absolute pitch identification tasks because many researchers claim that AP possessors directly and quickly identify the pitch class of notes but identify the octave by estimating the pitch height, that is, the overall highness or lowness of the note, just as AP nonpossessors do. AP possessors therefore differ from nonpossessors only in their ability to identify pitch class and not in their ability to identify octave (Bachem, 1948, 1955; Baird, 1917; Carpenter, 1951; Carroll, 1975; Lockhead & Byrd, 1981; Rakowski & Morawska-Bungeler, 1987; Revesz, 1953).

There is a good deal of empirical support for the claim that pitch class identification and octave identification are distinct processes. Miyazaki (1989) reported no qualitative difference between the octave identifications of AP possessors and nonpossessors (the design of the experiment did not allow a direct quantitative comparison), whereas AP possessors were more consistent than nonpossessors in their pitch class identifications. Carroll (1975) analyzed the results of a pitch identification task in terms of the amounts of information transmitted about octave and about pitch class. There was no difference between AP possessors and nonpossessors in the amount of octave information transmitted, whereas significantly more pitch class information was transmitted to AP possessors than nonpossessors. In addition, a majority of errors by AP possessors in pitch identification tasks are octave errors (Bachem, 1937; Baird, 1917; Carroll, 1975; Costall, 1985; Lockhead & Byrd, 1981; Miyazaki, 1989; Revesz, 1953; Stumpf, 1883, cited in Carroll, 1975).

Ward (1963a, 1963b; Ward & Burns, 1982) suggested that octave errors occur because subjects confuse the overtones of a complex tone with the fundamental. If this were the case, as Ward himself stated, there should be fewer octave errors with pure tones than with complex tones. However, AP possessors make fewer octave errors with piano tones than with pure tones (Lockhead & Byrd, 1981; Riker, 1946).

Alternatively, octave errors may occur because subjects are not familiar with the musical instruments producing the tones to be identified. As we discuss later, differences in timbre over different pitch registers in musical instruments can provide cues to pitch height. However, a subject unfamiliar with an instrument would be unable to make use of these subtle timbral cues and therefore may make more octave errors. Oakes's (1955) report that the majority of subjects making octave errors with piano tones were not pianists supported this explanation.

In addition, subjects may also have difficulty with the terminology for denoting octaves. Whereas there are two common systems for denoting pitch class (C, D, E, etc. in the United
States; do, re, mi, etc., elsewhere), there is no comparably common terminology for denoting octaves. Therefore, the method of identifying octaves used in any particular experiment is likely to be novel for the subjects and prone to error.

Because of the special status of octave errors, some experimenters have chosen not to count octave errors as errors in pitch identification tasks (Bachem, 1954; Zatorre & Beckett, 1989). Others have avoided the matter altogether by requesting that subjects identify pitch class only (Baggaley, 1974; Miyazaki, 1988a, 1989; Stumpf, 1883, cited in Petran, 1932; Weinert, 1929, cited in Carroll, 1975). Because studies have shown that there is no significant difference between the abilities of AP possessors and nonpossessors to identify octaves, and because of the difficulty in denoting octaves, we agree that the inclusion of octave designations in absolute pitch identifications is unnecessary.

Relative Pitch Cues

An important consideration in the design of pitch identification tasks is the possibility that subjects may use relative pitch cues from trial to trial to help them identify tones. For example, if the subject knows the pitch of a tone on Trial 1, then on Trial 2, the subject can compare the pitch relation of the new tone with the tone from Trial 1. The subject can then identify the pitch of the new tone by determining the pitch relation between the tones of Trials 1 and 2 (a trivial problem for a musician). Thus, when the subject is told the correct pitch name after each trial in a pitch identification task, there is a possibility that pitch identifications are being made on a relative and not an absolute basis. Although most experiments do not provide such feedback for this reason, in some studies, subjects indicated the pitches of tones by playing them back on a piano (Carroll, 1975; Lockhead & Byrd, 1981). Because the piano sounded a pitch, subjects could determine the correctness of their responses by listening for a discrepancy in pitch between the stimulus and the piano tone. Even if the response was incorrect, the discrepancy between the stimulus and the piano tone could be used to correctly identify the pitch of the stimulus. Subsequent responses could then be made on the basis of relative pitch.

Most experimenters have used interfering material between trials to try to erase pitch memory and therefore prevent the use of relative pitch cues from trial to trial (see Ward & Burns, 1982, for a survey of commonly used procedures). Another common procedure is to space pitches on consecutive trials more than an octave apart (Carroll, 1975; Miyazaki, 1988a, 1989). This wide spacing is thought to discourage the use of trial-to-trial relative pitch cues. However, the concern about the use of relative pitch cues may not be necessary. Petran (1932) reported no difference in accuracy of absolute pitch identifications when testing was done in a single session without interference between trials compared with when a single pitch was tested on separate days, so that no trial-to-trial cues were available.

Effects of Timbre, Pitch Register, and Pitch Class

Several studies have shown that the accuracy of absolute pitch identifications can vary as a function of the timbre, pitch register, and pitch class of the tones that are to be identified. We discuss these effects below.

Effects of Timbre

Many studies have reported that some subjects are more or less accurate in their pitch identifications depending on the timbre of the tones that are to be identified. Roughly speaking, timbre refers to the perceived acoustic quality of a sound. Thus, the unique sounds of different musical instruments are defined by their timbre. Timbre is multidimensionally determined; the spectrum (waveform) and the attack and decay characteristics of a tone are especially important in determining timbre (Grey, 1977; Handel, 1989; Plomp, 1976).

Because of the inherent limitations of pitch range on conventional musical instruments, many studies have confounded pitch range with timbre. That is, a wider range of pitches was tested on some instruments than on others. In addition, we report below that extremely high and low pitches tend to be identified less accurately than more central pitches. The difficulty in identifying pitches played on certain instruments may therefore be due, at least in part, to the pitch register of some instruments. For example, the tuba generally plays notes of low pitch. If absolute pitch identifications for tuba notes were unusually difficult, the difficulty could be due to either the lowness of the pitch or the tuba timbre. However, among musical instruments, the piano is the easiest timbre in which to identify pitch (Bachem, 1937; Baird, 1917; Boggs, 1907; Petran, 1932; von Kries, 1892, cited in Neu, 1947). The superior accuracy of absolute pitch identifications for notes played on the piano cannot be accounted for by pitch range or register because the pitch range of the piano is the largest of all conventional musical instruments and encompasses the registers of all other standard orchestral instruments (Kennan & Grantham, 1983).

The pitches of piano tones are also easier to identify than pitches of pure tones or other electronically produced timbres (Baggaley, 1974; Balzano, 1984; Lockhead & Byrd, 1981; Miyazaki, 1989; Peterson, Porter, & Stevens, 1988; Rakowski, 1978; Rakowski & Morawska-Bungeler, 1987; Riker, 1946; Wedell, 1941). Although some of these studies also suffered from confounds of pitch range or pitch register with timbre, the consistent superiority of the piano timbre over other timbres suggested that the timbre effect was not due to pitch range or pitch register.

There are two explanations for the effects of timbre on absolute pitch identifications. First, individual subjects may find some timbres more familiar than others, and greater familiarity with a timbre may make pitch identification easier. For example, violinists who were AP possessors judged the pitch of violin tones more accurately than clarinet tones (Brammer, 1951). In addition, both AP possessors and nonpossessors made the most accurate absolute pitch identifications on the first instrument that they learned to play (Sergeant, 1969). Whipple (1903) described a subject who made significantly more accurate pitch identifications of tones played on her own piano than on unfamiliar pianos. Finally, when the initial transients of an instrumental tone were deleted so that the timbre was less familiar, pitch identifications of these tones were less accurate than of the original tones (Sergeant, 1969). These observations all sug-
suggest that familiarity with the timbre of an instrument can be a
determinant of the accuracy with which an AP possessor can
identify the pitch of tones.

Second, it has been suggested that variations in timbre over
changes in pitch may provide cues to pitch (Lockhead, 1982;
Ward, 1963b; Ward & Burns, 1982). Although many acoustic
instruments, notably the piano, vary noticeably in timbre over
different pitch registers, the variations in timbre among closely
spaced pitches are subtle and unlikely to be sufficient to pro-
duce accurate absolute pitch identifications. Moreover, the
timbre of a single pitch can vary substantially as a function of
the loudness and articulation of the tone. Therefore, timbral
variations are not solely a function of differences in pitch.

Although effects of timbre suggest that some AP possessors
do not identify pitch solely on the basis of pitch cues, there is no
direct evidence that AP possessors use timbral cues to identify
pitch. One way to examine the use of timbral cues by AP pos-
sessors would be to compose two sets of tones made up of novel
timbres. In one set, the tones would vary only in pitch. In the
other set, tones would vary in both timbre and pitch. Each set of
tones would be presented to subjects until the tones were fami-
lar. Subjects would then be tested on their absolute pitch identi-
fications of these tones. If AP possessors use timbral cues to
identify pitch, then identifications should be more accurate for
the set of tones that vary in timbre than for the set of tones that
do not vary in timbre.

Effects of Pitch Register

Many researchers have reported that AP possessors generally
make more accurate pitch identifications in central pitch regist-
ers, as opposed to extremely high or low registers (Bachem,
1937; Baird, 1917; Miyazaki, 1989; Petran, 1932; Rakowski,
1978; Rakowski & Morawksa-Bungeler, 1987; Riker, 1946;
Ward, 1963b; Weinert, 1929, cited in Petran, 1932; Whipple,
1903). Absolute pitch identifications are also faster in central
than in extreme pitch registers (Baird, 1917). However, Stumpf
(1883, cited in Petran, 1932) reported two exceptions to this
finding: a double bass player who was most accurate with low
pitches and a violinist who was most accurate with high

pitches.

Most music is written in central pitch registers. However,
music for the double bass is likely to have a predominance of
low pitches, and music for the violin is likely to have a predomi-
nance of high pitches. Both the general trend favoring central
pitch registers and the exceptions to this trend suggest that the
most accurate pitch identifications are made in the most famili-

ar pitch register, just as timbral effects seem to be due to famil-

arity.

Another factor that contributes to the difficulty of identify-
ing extremely high pitches is that, as discussed earlier, tones
with fundamental frequencies above 4000–5000 Hz are no
longer perceived as musical and have an indeterminate pitch
class (Semal & Demany, 1990; Stevens & Volkmann, 1940;
Ward, 1954). Several studies have reported a decline and eventu-
ally a total loss in accuracy of absolute pitch identifications for
tones above about 4000 Hz (Abraham, 1901, cited in Ward,
1963b; Bachem, 1948, 1954; Baird, 1917; Carpenter, 1951;
Ward, 1963b). This effect is not specific to AP possessors. Tasks
requiring relative pitch also cannot be performed with tones of
frequencies above about 5000 Hz (Attneave & Olson, 1971; von

In spite of these findings, a few experiments have tested abso-
lute pitch identifications using frequencies above 5000 Hz and
included performance on these frequencies in the general mea-
ure of performance, thus underestimating the AP ability of the

Note that not all AP possessors are affected by timbre and
pitch register. Bachem (1937, 1940, 1954) distinguished be-
tween AP possessors who were unaffected by timbre or by pitch
register up to about 5000 Hz and AP possessors who were lim-
ited with respect to timbre, pitch register, or both. Several other
researchers also described AP possessors who showed no effect
of timbre and pitch register (Boggs, 1907; Revesz, 1916/1925,
cited in Petran, 1932).

Effects of Pitch Class

Pitch classes vary in both the accuracy and the speed with
which they are identified. Specifically, black-key pitches are
identified less accurately than white-key pitches (Baird, 1917;
Black-key pitches include a sharp or flat in the pitch class name
and correspond to the black keys of a piano. White-key pitches
do not require a sharp or flat in the pitch class name and corre-
spond to the white keys of a piano.

Also, absolute pitch judgments are slower for black- as com-
pared with white-key pitches (Miyazaki, 1988a, 1989, 1990; Ta-
keuchi & Hulse, 1991). Response times in a cross-modal match-
ing task, in which the pitch of an auditory tone was compared
with a visually presented pitch name, were slower for both
black-key pitches and black-key pitch names than for white-key
pitches and white-key pitch names (Takeuchi & Hulse, 1991).
In this experiment, pianolike tones were produced on a synthe-
sizer, so that all tones were spectrally identical. There were no
physical cues in the auditory tones to distinguish a black-key
pitch from a white-key pitch.

Effects of pitch class on absolute pitch judgments are more
common than effects of timbre or pitch register. Analysis of
individual subjects in Takeuchi and Hulse's (1991) experiment
showed that 18 of 19 AP possessors were significantly slower
and less accurate in identifying black- compared with white-key
pitches. Miyazaki (1990) did not analyze results from individ-
ual subjects but did report that the least accurate group of AP
possessors showed the largest differences between black- and
white-key pitches whereas the most accurate group showed the
smallest differences.

Elsewhere (Takeuchi & Hulse, 1991), we developed two alter-
native theories to account for the differences between black-
and white-key pitches. We mention them briefly here. One ex-
planation, which invokes the early-learning theory of AP deve-
lopment described later, holds that AP may not develop for all
pitch classes. In music lessons, particularly piano lessons,
white-key pitches are generally taught before black-key pitches.
The piano keyboard is arranged so that the white-key pitches
form the scale of C major. The key of C major is therefore a
convenient starting point for teaching piano students. More
important, black-key pitches are defined in terms of their neigh-
boring white-key pitches. For example, F-sharp is the black key one step to the right of the white key F; and B-flat is the black key one step to the left of the white key B. Therefore, before a music student can identify black-key pitches on a piano keyboard, the student must know the white-key pitches.

Because white-key pitches are generally learned before black-key pitches, it follows that AP may develop for white-key pitches before it develops for black-key pitches. According to the early-learning theory of AP development discussed later, children lose the ability to develop AP. This loss may occur before all of the pitch classes are learned. The consequence may very well be partial AP; that is, AP for white-key pitches only. In fact, Teplov (1961/1966, cited in Spender, 1980) reported a significant correlation between the accuracy with which a child identified particular pitch classes and the incidence of these pitch classes in the child's current repertory. This correlation supports our notion that AP does not develop equally or simultaneously for all pitches.

If an AP possessor has AP for only white-key pitches, then identification of black-key pitches would depend on referring them to neighboring white-key pitches. This process should require further processing time and to be open to error, resulting in the observed longer response times and higher error rates in identifications of black-compared with white-key pitches.

An alternative theory proposes that just as there are frequency-of-use distributions for English words as well as for musical intervals (e.g., Vos & Troost, 1989), there are frequency-of-use distributions for pitches and pitch names. Although actual counts have yet to be made, there is good reason to believe that in the musical literature, black-key pitches and pitch names are less common than white-key pitches and pitch names. Responses in a variety of tasks, such as lexical decision and word naming, are faster and more accurate for frequently—compared with infrequently—occurring words (Besner & McCann, 1987). We suggest that the same may be true for pitches and pitch names. Responses are slower and less accurate to black-than to white-key pitches and pitch names because black-key pitches occur less frequently than white-key pitches and are therefore less familiar.

**Absolute Tonality**

Some people report that they can identify the musical key of a piece of music absolutely, an ability called absolute tonality; although they cannot identify individual pitches absolutely (Anderson, 1991; Sergeant, 1969; Teplov, 1961/1966, cited in Spender, 1980). The key of a piece of music determines which pitch classes will occur predominantly and also the relative stability of the pitch classes. The tonic pitch in a particular key is the most stable pitch and acts as a point of arrival, or focal point, for other pitches. Pitch classes that are included in the scale of a key are more stable and occur more often than pitch classes not included in the scale of a key (Krumhansl, 1990). Terhardt (Terhardt & Seewann, 1983; Terhardt & Ward, 1982) found that AP nonpossessors were able to determine at greater-than-chance levels whether a musical excerpt was played in the key in which it was notated or was transposed to a different key. In transposition, pitch relations are preserved, whereas the absolute pitches change by some constant. Subjects were able to detect transpositions even when the change in absolute pitches was only one semitone. These findings suggest that absolute tonality may be a weak form of AP. Indeed, Vernon (1977) claimed that he had absolute tonality before he had AP.

However, if absolute tonality is a weak form of AP, then AP possessors should also have absolute tonality. This is not quite the case. Although there is no question that AP possessors are able to identify keys absolutely, they report doing so indirectly, by identifying individual pitches. In contrast, people with absolute tonality identify keys on the basis of the overall impression of a set of pitches (Corliss, 1973; Terhardt & Seewann, 1983; Terhardt & Ward, 1982). It seems that it is easier for AP possessors to identify pitches absolutely than to identify keys absolutely, which is not consistent with the idea that absolute tonality is a weak form of AP.

**Comparisons of AP Possessors and Nonpossessors**

Absolute pitch production tasks show clear differences between AP possessors and nonpossessors; AP possessors are more consistent in their absolute pitch productions than nonpossessors (Petran, 1932; Rakowski & Morawska-Bungeler, 1987; Siegel, 1972). Memory decay tasks, as discussed earlier, also show clear differences between AP possessors and nonpossessors after long retention intervals; AP possessors show little memory decay after retention intervals of a minute or more, but nonpossessors deteriorate to chance levels of performance (Bachem, 1940, 1954; Rakowski, 1972; Rakowski & Morawska-Bungeler, 1987).

On the other hand, as Table 1 suggests and as several other researchers have reported (Brammer, 1951; Meyer, 1899; Oakes, 1955; Petran, 1932; Rakowski, 1978; Rakowski & Morawska-Bungeler, 1987; Rasch, 1987; Riker, 1946; Seashore, 1940; Terhardt & Ward, 1982; Wedell, 1941), there is often no clear distinction between self-reported AP possessors and nonpossessors in accuracy of absolute pitch identifications. Perhaps this is because there is a finite set of possible responses in a pitch identification task but not in a pitch production or reproduction task. Thus, there is a greater chance of randomly producing a correct response in the identification task than in the other tasks, which may artificially inflate the performance of AP nonpossessors in the identification task. Then too, as noted above, some AP possessors can identify pitches absolutely without being able to produce pitches. If it is the case that absolute pitch production is found among subjects who are most accurate at pitch identification, then it is likely that there will be a greater difference between AP possessors and nonpossessors in production tasks than in the less selective pitch identification studies.

Although pitch identification experiments show no real discontinuity between AP possessors and nonpossessors, several studies have reported that the distribution of performance scores is bimodal (Carroll, 1975; Miyazaki, 1988a; Riker, 1946). Oakes (1955) claimed that distributions of performance scores on the basis of average semitone error, number of correct identifications, and number of correct identifications in which errors of an octave or a semitone were counted as correct were all normal and not bimodal. However, Carroll (1975) pointed out that if Oakes's data were converted to frequency histograms,
Conclusions About the Abilities of AP Possessors

We conclude that there are two populations: AP possessors and nonpossessors. However, measures of AP performance by these two populations may overlap, particularly in pitch identification tasks. Moreover, there are substantial differences in AP even among AP possessors. The extent of sensitivity to timbre, pitch register, and pitch class—as well as the degree of accuracy or consistency in absolute pitch identification and production—varies widely.

For these reasons, we propose that a continuous and multidimensional measure of AP should be constructed on the basis of standardized tests of pitch identification and production. The measure should be multidimensional in that it should reflect performance on both identification and production tasks, as well as sensitivity to timbre, pitch register, and pitch class. The measure should be continuous to accurately reflect both the degree of consistency in absolute pitch identification and production tasks and the degree of effects of timbre, pitch register, and pitch class. We feel consistency better reflects AP than does accuracy in both identification and production tasks because AP possessors may be accustomed to different tuning standards or different tuning systems than they are tested with. This measure of AP would allow researchers to establish consistent and objective criteria for distinguishing AP possessors from nonpossessors. Moreover, it would provide detailed information about subjects' degrees of AP and would do so in a standardized form so that different experiments could be compared.

Because AP possessors are so rare, the number of AP possessors studied in any single experiment is usually quite small; several published reports are single-case studies (Brady, 1970; Carpenter, 1951; Stanaway, Morley, & Anstis, 1970; Vernon, 1977; Ward & Burns, 1982). If a standard measure of AP were available, meta-analysis of the results of several studies could provide a more accurate picture of the nature of AP. For instance, Miyazaki's (1990) data suggest that the least accurate pitch identifiers are the most sensitive to pitch class. Also, Weinert (1929, cited in Petran, 1932) reported that the AP possessors whom he found were able to produce tones absolutely also the ones least affected by variations in timbre. The extent to which an AP possessor is sensitive to timbre, pitch register, and pitch class may be negatively correlated with the AP possessor's degree of AP. In addition, although some AP possessors can identify pitches but cannot produce pitches absolutely, there are no documented cases of AP possessors who can produce pitches absolutely but are unable to identify pitches. These findings suggest there may be a regular hierarchy of AP in which effects of timbre, pitch register, and pitch class are apparent only at low levels and absolute pitch production ability is characteristic of high levels of AP. Determining such a hierarchy of AP could provide insights into both the process by which AP judgments are made and the etiology of AP.
AP possessors do not remember the sound of the tone. Rather, they identify the tone and remember the pitch name. In a pitch reproduction task, the subject then recalls the pitch name and produces a tone corresponding to that pitch. This explanation accounts for the finding that AP possessors and nonpossessors show the same rate of memory decay for tones too high in frequency to have identifiable pitch classes, which AP possessors therefore cannot use pitch names to encode (Bachem, 1954; Rakowski, 1972). It also explains AP possessors’ less accurate memory for tones whose frequencies fall between musical pitches compared with tones whose frequencies correspond precisely to musical pitches (Eaton & Siegel, 1976; Rakowski, 1972). If the only available coding is in terms of musical pitch, a pitch encoded as a little lower than C will not be reproduced as accurately as a pitch encoded C.

Zatorre and Beckett (1989) questioned whether AP possessors' memory for pitches was exclusively verbal. Their approach was to examine the extent to which tonal and verbal interference disrupted memory for pitches. If AP possessors’ memory for pitches was exclusively verbal, their pitch memory would be adversely affected by verbal interference but not by tonal interference. Although this reasoning was sound, their experiment lacked several critical controls. First, Zatorre and Beckett did not test any AP nonpossessors. According to their hypothesis, AP nonpossessors would show the reversed pattern of results: adverse effects of tonal interference but not of verbal interference because AP nonpossessors could only remember a pitch in terms of the sound quality and not in terms of a verbal pitch name. Also, Zatorre and Beckett did not necessarily test absolute encoding of pitch. Subjects were presented a set of three pitches to remember, and after the interference procedure, they indicated which of two comparison sets of pitches was identical to the original set. In the changed set, the second pitch was altered by one scale step, so that the relations among the pitches in the set were altered. Subjects could therefore have performed the task by detecting a change in the pitch relations rather than on the basis of absolute pitch. Finally, these investigators did not rule out the possibility that numbers, the verbal interference used in the experiments, might be stored in memory independent of pitch names and thus would have no detrimental effect on memory for the pitches, even though the pitches were represented in memory verbally.

A direct test of the verbal-mediation hypothesis would compare absolute productions of pitches with reproductions of these pitches after a long retention interval. Some of the tones to be reproduced would be mistuned from the equal-tempered scale, though not enough for the subject to notice the mistunings. If AP possessors' memory for absolute pitch was verbally mediated, then production and reproduction would produce identical results, regardless of the slight mistunings of the original tones in the reproduction task. That would be true because the pitch of the tones would have been encoded only in terms of their pitch names in the reproduction task. If, however, information other than the verbal pitch name was remembered, then the slight mistunings in the original tones would be reproduced. This experiment has not been performed to our knowledge.

Perception of Pitch Relations by AP Possessors

Do AP possessors perceive pitch relations in the same way that nonpossessors do? Corliss (1973) has reported that in her own experience as an AP possessor, pitch relations such as intervals and chords are identified indirectly, by first identifying the absolute pitches of the component tones and then determining the pitch relations.

Ward and Burns (1982) suggested that if AP possessors identified intervals indirectly, then they would make errors when identifying pitch intervals composed of mistuned notes. For example, if presented a mistuned interval composed of a pitch 0.4 semitone below C4 and a pitch 0.4 semitone above D4, AP possessors might identify the interval by first identifying each tone to the nearest musical pitch. Thus, AP possessors would identify the interval as a major second (2 semitones), the interval between C4 and D4. However, the distance between the two mistuned pitches is actually 2.8 semitones, which is closer to an interval of a minor third (3 semitones) rather than a major second. In contrast, AP nonpossessors should identify the pitch interval directly and so should perceive the interval correctly, as a minor third.

A recent experiment by Benguerel and Westdal (1991) tested AP possessors’ identification of intervals composed of such mistuned notes and found that 9 of the 10 AP possessors tested showed no evidence of identifying intervals indirectly by first identifying the absolute pitches of the component tones. The single exceptional subject appeared to identify some intervals indirectly, through absolute pitch identifications, but did not do so consistently. Thus, AP possessors do appear to be capable of perceiving pitch relations directly.

However, another study that directly compared interval identifications by AP possessors and nonpossessors (Miyazaki, 1988b, 1992) reported that the absolute pitches of tones forming the intervals affected both the speed and accuracy of interval identifications by AP possessors but not by nonpossessors. AP possessors identified intervals more quickly and accurately when the first note of the interval was C4 (262 Hz) compared with a mistuned C#, (268 Hz), F# (370 Hz), or a pitch halfway between D# and E4 (321 Hz). In addition, AP possessors identified intervals starting with F# and D#/E4 more slowly than did AP nonpossessors, although there was no difference between the two groups when identifying intervals that started with C4.

One interpretation of Miyazaki’s results, taken together with the results of Benguerel and Westdal (1991) discussed above, is that AP possessors may identify the pitches of the component tones of pitch intervals but that they do not use this information to identify the interval. Rather, they identify the pitch intervals directly, just as AP nonpossessors do.

There have also been several reports that AP possessors have difficulty producing transpositions in pitch (Crutchfield, 1990; Revesz, 1953; Ward, 1963b; Wilson, 1911). In pitch transpositions, pitch relations are preserved, but absolute pitches change. Therefore, if only absolute pitches are represented by AP possessors, then a transposed melody is entirely changed. However, no formal study of the comparative abilities of AP
possessors and nonpossessors to produce pitch transpositions has been undertaken.

If AP possessors do indeed have more difficulty than nonpossessors in producing pitch transpositions, there are two possible reasons. One is simply that AP possessors represent pitch structures in terms of absolute pitch rather than in terms of pitch relations. However, we suspect that AP possessors and nonpossessors do not differ in their ability to recognize transpositions but only in their ability to produce. Thus, it appears unlikely that AP possessors represent pitch structures purely in absolute terms. An alternative could be that AP possessors have difficulty producing transpositions because of the lack of correspondence between the pitches that are heard and the written pitches. An AP possessor who sees the pitch C₄ in a musical score but produces the corresponding pitch as A₄, for example, may be confused by the conflicting information between the written and sounded pitches. In contrast, AP nonpossessors are unaware of any conflict between the written score and the sounded pitches. Although there is no direct evidence to support this idea, there is evidence of a Stroop-like interference effect in AP possessors asked to identify pitches (Zakay, Roziner, & Ben-Arzi, 1984). In this experiment, AP possessors were slower and more prone to error when identifying tones sung with an incongruent pitch name (e.g., the pitch C₄ sung on the syllable “gee”) than when identifying pitches sung on a neutral syllable.

We conclude that AP possessors are able to perceive musical pitch relations just as nonpossessors do. However, absolute pitches are also perceived. This absolute perception seems to occur immediately and involuntarily and, in certain situations, can interfere with perception of pitch relations.

Etiology of AP

One of the most common questions raised about AP is its etiology. How does AP develop? Why does it develop, and why does it not develop in everyone? Although the data are insufficient to unequivocally support any theory of the etiology of AP, we believe the existing evidence points toward the early-learning theory of AP development. This theory states that AP can be acquired by anyone, but only during a limited period of development (Abraham, 1901; Copp, 1916; Jeffress, 1962; Sergeant & Roche, 1973; Ward, 1963b; Watt, 1917).

Several lines of evidence, discussed in detail below, support the early-learning theory of AP: (a) a negative correlation between age at onset of musical training and probability of possessing AP, (b) a negative correlation between age at onset of musical training and accuracy of absolute pitch identifications among AP possessors, (c) greater success in teaching AP to young children than to older children or adults, (d) a shift in the reproduction of melodies from absolute to relative features in children from 3 to 6 years of age, (e) similar shifts from absolute to relational features in other realms of perceptual development, and (f) suggestions of a residual AP ability in adults.

Correlation Between AP and Age at Onset of Musical Training

Early onset of musical training is correlated with a high likelihood of possessing AP. Sergeant (1969) found that 87.5% of musicians who began musical training around the age of 5.6 years possessed AP, whereas none of his survey respondents who began musical training after the age of 9 years possessed AP. There is a serious problem in these data, however. In Sergeant's surveys, the age at onset of musical training was confounded with the level of musical accomplishment of the subjects: The probability of respondents possessing AP increased as age at onset of musical training decreased, but also increased with increasing degrees of musical achievement. Other suggestive reports come from Miyazaki (1988a), who reported that of "a large number (p. 511)" of students in the Department of Music Education at Niigata University, "most of them had begun piano lessons as early as ages 3 to 5 and at least 50% were AP possessors" (p. 511). In a separate study of 25 AP possessors, Miyazaki (1988b) reported that all had begun music lessons between the ages of 3 and 5 years.

Other studies have also reported that AP possessors generally began musical training at an early age. Sixteen of van Krevelen's (1951) 17 AP possessors began music lessons by the age of 7 years; the mean age at onset of music lessons was 4.9 years. In Takeuchi's (1989) study, 15 of 19 AP possessors began music lessons by age 7, and the mean age at onset was 6.5 years. Although this mean age at onset is somewhat lower than in the other literature, several subjects who reported late onset of music lessons had informal music lessons before beginning formal study. Finally, Bachem (1940, 1955) reported observing five musical prodigies between 4 and 8 years of age who had begun musical training between 2.5 and 5.5 years and all of whom possessed AP.

Many AP possessors report having had AP for as long as they can remember (Carpenter, 1951; Cortiss, 1973; Takeuchi, 1989; Wynn, 1973). Profita and Bidder (1988) found that 25% of AP possessors they surveyed were aware of their ability by age 5, and 90% were aware of it by age 10. This evidence suggests that AP develops during the early years of musical experience.

In addition, the most accurate AP possessors are those who began musical training at an early age. Miyazaki (1988a) found that all of the most accurate AP possessors in his experiment had begun piano lessons between the ages of 3 and 5 years, whereas significantly fewer of the less accurate AP possessors had begun lessons by 5 years. Wellek (1938, cited in Ward & Burns, 1982) reported a correlation of .8 between subjects' age of noticing they had AP and their error rate in an absolute pitch identification task. Sergeant (1969) reported that on average, AP possessors began musical training at an earlier age than absolute tonality possessors. If absolute tonality is a weak form of AP, this evidence also supports the idea that AP is best learned at an early age.

Why might AP fail to develop even though musical training is begun at an early age? We speculate that the nature of early musical training is a crucial variable. AP may only develop if early musical training includes the association of pitch names with particular absolute pitches. If musical training focuses solely on the relational aspects of pitch—for example, the perceptual equivalence of a song and its pitch transposition—then the child may not develop AP.

The correlational data supporting the early-learning theory could simply be due to the fact that children who show musical
aptitude may tend to start music lessons at an early age and that these musically apt students are more likely to demonstrate AP. More compelling evidence for the early-learning theory comes from formal attempts to teach AP to children and adults.

There are several reports of successfully teaching AP to 3-6-year-old children (Abraham, 1901, cited in Petran, 1932; Benedik, 1914, cited in Neu, 1947; Grebelnik, 1984; Komatsu, 1940, cited in Neu, 1947; Oura & Eguchi, 1981). In contrast, efforts to teach adults AP have generally failed, as we discuss later. This contrast between children and adults supports the early-learning theory. However, a rigorous demonstration that the same techniques for training AP are more successful with children than with adults is still lacking.

The Shift From Absolute to Relative Pitch Perception

Why might the potential to develop AP decrease as the child grows older? Some data suggest that learning to perceive music relationally disrupts the ability to identify pitches absolutely. Katz (1914, cited in Neu, 1947) reported that children who learned to sing using a fixed-do system, in which a pitch name always corresponded to the same absolute pitch, acquired some degree of AP. In contrast, children trained with a movable-do system, in which a pitch name corresponded to different absolute pitches depending on the musical key of the song, did not demonstrate any AP ability. Similarly, Abraham (1901, cited in Neu, 1947) reported that two out of three 4-year-old children who were taught to sing the pitches A-4-D5 reproduced the song at the same absolute pitches, even 3 months after learning the song, which indicated an absolute memory for pitch. The third child, who attended a kindergarten in which songs were often transposed, sang the correct pitch interval, but on different pitches. That is, the third child reproduced the relative but not the absolute pitches of the song.

Sergeant and Roche (1973) taught 3- to 6-year-old children simple melodies and recorded each child's reproductions of these melodies 3 weeks later. The younger children reproduced the absolute pitches of the melodies more accurately than did the older children, suggesting that the younger children had at least greater potential for AP than did the older children. However, the older children reproduced relational aspects of the melody—the direction of change from pitch to pitch, the pitch intervals, and overall adherence to a single musical scale—more accurately than did the younger children. There thus appears to be a trade-off between reproduction of absolute and relative features of melody, and the balance shifts from absolute features to relative features as the child matures from 3 to 6 years.

More generally, children develop from having simple perceptions of individual notes of a melody to forming higher order concepts about the organization of groups of notes. Terhardt (1974) suggested that children learn to ignore the absolute pitches of the partials of a tone because to identify speech sounds, they must recognize the frequency relations among the partials of voiced speech sounds. Only the relations among the frequencies of the partials and not the absolute frequencies are important in this process. Thus Terhardt suggested that the shift in emphasis from absolute to relative features of pitch is a by-product of the process of learning to understand speech.

Children's first perception of music most likely consists of the pitches of individual tones, because pitch is generally the most salient dimension of sound. As children learn that the relations among pitches rather than the pitches themselves provide the most relevant information to understanding musical structure, they shift their focus away from individual pitches to the relations among the pitches. Wohlwill (1962) suggested that as concepts form, perception becomes increasingly selective for information relevant to the concept. This change of focus with respect to music results in a decreased ability to perceive the pitch of single tones independent of their context. Mull (1925) wrote the following:

The possession of [AP] seems to rest simply upon the giving of attention to notes as phenomena: that is to say, upon an interest in the notes themselves rather than in their melodic or harmonic relationships, which, because of their much greater musical importance, usually monopolize attention. (p. 492)

Because musical structures are based on relations among elements, musical experience and training reinforce relational perception of pitches over absolute perception of pitches. Once relational perception of pitches is developed, absolute perception of pitches is diminished, and acquisition of AP becomes difficult, if not impossible. Therefore, AP is best learned while the child is focusing on the pitches of individual tones. Adults are generally unable to learn AP because they can no longer perceive the pitch of a single tone outside of its context within other tones.

This is not to say that young children are incapable of perceiving relations among tones in a musical context. Rather, we suggest that young children prefer to process the absolute rather than the relative pitches of musical stimuli. As a child matures, this preference shifts toward relative pitch, and we speculate that as a consequence, the ability to process pitches absolutely declines.

The General Developmental Shift From Absolute to Relative Features

The shift in perception from the absolute features of a single stimulus to the relations among several stimuli is a common theme in the developmental literature (Pollack, 1969). Such a shift has been discussed with respect to changes in representational systems from concrete, iconic representations to abstract, symbolic representations that enable concept formation (Bruner, Olver, Greenfield, & Harvard University Center for Cognitive Studies, 1966; Piaget, 1966; Vygotsky, 1934/1986; Wohlwill, 1962).

There are several examples of a developmental shift from perceiving single stimuli to perceiving relations among several stimuli in realms outside of music. Gentner (1988) reported changes in children between the ages of 4 and 10 years in their interpretation of metaphors. Younger children tended to interpret metaphors on the basis of shared physical attributes. As the children matured, they increasingly interpreted metaphors on the basis of shared relational structures. Case and Khanna (1981) reported a regular increase in the number of relations that children ½ to 4½ years old could coordinate in tasks involving building blocks, following directions, matching pic-
tures, and repeating sentences. DeLoache, Sugarman, and Brown (1985) reported a similar development when children 1½ to 3½ years old nested cups of increasing size. The youngest children's error corrections focused on a single nonfitting cup, whereas older children considered the relation between two cups to correct their errors and the oldest children in the study coordinated the relations among several cups. Michie (1985) reported that in preschool children, understanding of the absolute number of items precedes understanding about ordinal relations among numbers (i.e., greater than, less than). Similarly, Gelman and Gallistel (1978) reported that preschool children determined the equality of two sets by counting the items in each set and deciding whether the resulting cardinal numbers were equal. The ability to reason about abstract amounts apparently developed some time after the ability to reason about specific numbers. Thus, there is evidence that absolute concepts precede relative concepts not only in the domain of music but also in the development of language, spatial tasks, and number comprehension.

Residual AP in Adults
Several studies suggest that adults who are not AP possessors in the sense of being able to identify or produce pitches absolutely may nevertheless have some ability to process pitch absolutely. These findings support the view that everyone initially has the potential to acquire AP.

Halpern (1989) found that adult AP nonpossessors, including both musicians and nonmusicians, consistently sang familiar songs starting on the same absolute pitch. The starting pitch varied from song to song and varied across subjects but was consistent within subjects over several repetitions of the same song, even when the repetitions were separated by 2 days. This finding suggests that AP nonpossessors encode a specific starting pitch for melodies and can retrieve this starting pitch reliably. In another study (Levitin, 1992), college students sang songs from popular recordings with which they were familiar. Ignoring octave errors, 24% of the subjects reproduced the absolute pitches of the songs, and 51% were within one semitone of the original pitches.

In a similar vein, Terhardt’s experiments (Terhardt & Sec- wann, 1983; Terhardt & Ward, 1982) showed that AP nonpos- sessors could judge whether a musical excerpt was played in the correct key at significantly above-chance levels, also suggesting some AP ability in adults.

Deutsch (1988, Deutsch, North, & Ray, 1990) described paradoxes in the perception of pitch patterns composed of tones consisting of octave-related sinusoids. These tones have a clearly defined pitch class but an ambiguous octave or pitch height. Therefore, any sequential pair of tones can be perceived as either rising or falling in pitch, depending on the perceived pitch height of the tones. In fact, perception of particular patterns as rising or falling was consistent within individuals, although it differed across individuals. Moreover, each person’s responses to a set of such patterns suggested that a particular pitch class was consistently perceived as being greatest in pitch height. Different people perceived different pitch classes as being highest. The consistency within individual subjects as to which pitch class was perceived as highest suggests that they have some ability to perceive pitch absolutely.

Previous investigations of AP have examined two other issues relevant to the etiology of AP. One issue is the possibility that there is a genetic component to the etiology of AP. A second issue is the possibility that adults can acquire AP.

Is There a Genetic Component to AP?
Some theorists have suggested that AP is an inborn ability that is inherited (Bachem, 1940, 1955; Revesz, 1953; Seashore, 1940). However, studies examining the incidence of AP in families cannot necessarily be taken as evidence supporting this view because of the confound that generally exists in these studies between heredity and environment. Because AP occurs so rarely in the general population, it is difficult to find situations in which there is no confound between environment and heredity. For example, Profita and Bidder (1988) reported that in their investigation of AP, they were unable to find any twins with AP or sets of parents both possessing AP. As an additional difficulty, these studies often rely on unconfirmed reports about the AP abilities of relatives of AP possessors, and as discussed earlier, there are no standard criteria for distinguishing AP possessors from nonpossessors. Nevertheless, several studies have examined the incidence of AP in families.

Bachem (1955) reported that 40 of 96 AP possessors claimed relatives who were also AP possessors. In one case, identical twins who were “separated relatively early” (p. 1184) had the same high degree of AP ability. Bachem concluded that heredity was therefore important for AP. More recently, Profita and Bidder (1988) reported that it was common for children of AP possessors to have AP and for several members of a family to have AP.

In contrast, only 2 of 17 AP possessors interviewed by van Krevelen (1951) reported having relatives who were AP possessors, although 14 reported having musical parents. Spender (1980) reported that 87% of a group of “specially gifted concert performers” (p. 28) claimed to have AP, although none reported siblings or parents who were AP possessors. These different results may be due to different criteria for defining AP possessors or, in the case of unconfirmed reports of AP ability, to a bias on the part of the respondents toward exaggerating or discounting the AP abilities of their relatives. Alternatively, the inconsistency may arise because there is no genetic basis for AP, whereas early environment does affect the development of AP, and heredity and early environment are generally confounded in these studies.

The higher incidence of AP among the congenitally blind than among the general population (Bachem, 1940; Oakes, 1955) raises a difficulty for the idea that AP is hereditary unless one is willing to believe that congenital blindness and AP are genetically linked. Some early proponents of the role of heredity in AP resolved this inconsistency by proposing that what is inherited is not AP itself but the predisposition toward developing AP. Thus, some people are genetically more likely to develop AP than others (Bachem, 1955; Weinert, 1929, cited in Petran, 1932). However, there is no evidence to support this claim.

To resolve the inconsistency across studies of the incidence
of AP in families, several researchers have distinguished a learnable type of AP, called either acquired AP or quasi-AP from innate or genuine AP (Bachem, 1937, 1940, 1955; Baggaley, 1974; Baird, 1917; Balzano, 1984; Revesz, 1953; Seashore, 1940; Wilson, 1911). Possessors of quasi-AP have learned a single reference pitch such as A4, the tuning pitch for orchestral musicians. Pitch identifications are made in relation to this single reference pitch. In contrast, genuine AP possessors have an inherited ability to make pitch identifications effortlessly and directly, without reference to any one particular pitch. Although the distinction between acquired and genuine AP is a convenient way of accounting for AP possessors who have no family history of AP, a detailed study of response times to identify various pitches discussed earlier (Takeuchi, 1989) produced no evidence that any AP possessors used a single reference to identify pitches.

Can AP Be Learned By Adults?

Several studies have reported that AP nonpossessors improved their accuracy of absolute pitch identification after training or practice. However, in the vast majority of cases, adults have not learned to identify pitches absolutely at a level equivalent to AP possessors.

Two general methods have been used to teach absolute pitch identification. In the first method, subjects are simply played notes, asked to identify them, and then told the correct pitch. After some practice with this task, pitch identification without feedback improves (Gough, 1922; Hartman, 1954; Lundin, 1963; Lundin & Allen, 1962; Meyer, 1899; Mull, 1925; Terman, 1965; Vianello & Evans, 1968; Wedell, 1934). In the second method, subjects are first taught a single pitch. Subjects hear this standard pitch repeatedly and learn to discriminate it from all other pitches. Early in discrimination training, the standard pitch occurs on about half the trials. As training proceeds, the standard pitch occurs less and less frequently, until all pitches have an equal probability of being presented (Brady, 1970; Cuddy, 1968). Unlike quasi-AP, in which a single reference pitch is learned and other pitches are identified in relation to the reference pitch, the procedure outlined above does not involve relative pitch. Rather, the claim is that eventually each note can be identified directly, without conscious comparison to the reference tone (Brady, 1970). However, neither of these methods has convincingly demonstrated that AP can be learned by adults.

Cuddy (1968, 1970) reported that the single-pitch method produced superior results to the random-presentation method. Gough (1922) also reported that when a single pitch was assigned special study, performance improved more than when all pitches were studied equally. However, Heller and Auerbach (1972) found no difference in efficacy between the two methods and suggested that Cuddy's results may have been due to factors other than the method of training used.

A recent study evaluated a commercially available program that claimed to teach AP (Rush, 1989). Although Rush reported that some subjects attained AP, he did not determine whether this ability was retained after training ended. Nor did he evaluate the extent to which pitches other than those in the training program could be identified. Thus, subjects could have relied on cues other than pitch to identify the tones in the training program.

One experiment (Lundin & Allen, 1962) that indicated that subjects could be trained to the level of AP possessors is questionable because the 2 subjects who correctly identified more than 95% of pitches correctly on the posttest claimed to be AP possessors at the outset, although they scored only 54% and 42% correct in the pretest. It is likely that their improvement was due to greater familiarity with the tones to be identified, the procedure, the tuning standard used in the experiment, or a combination of these factors rather than to an improved ability to perceive pitches absolutely as a result of the training procedure.

In another experiment, Brady (1970) claimed to have taught himself AP using the single-tone method. He reported 96.5% correct absolute pitch identifications within a semitone without receiving any feedback, performance comparable to that of some AP possessors. However, there were limits to his ability not generally found in AP possessors. He could not identify multiple tones sounded simultaneously, nor could he identify pitches in musical contexts other than unaccompanied melody. Although Carroll (1975) reported that Brady's performance did not differ significantly from other AP possessors in terms of response time, error rate, or type of errors made in absolute pitch identifications, Carroll's subjects heard a note played on one piano and responded by playing the matching note on a second piano. The immediate feedback provided by hearing the second piano allowed subjects to determine the correct pitch of the note and to use relative-pitch cues, rather than relying on AP, to identify the tones. Thus, an AP nonpossessor who had good relative pitch could mimic the performance of an AP possessor in Carroll's task.

Although all of the studies discussed above showed an improvement in absolute pitch identification after some training, subjects generally did not reach an unqualified level of accuracy of absolute pitch identification comparable to that of AP possessors. These studies are therefore not strong evidence that AP can be learned by adults.

Summary and Conclusions

What general conclusions can be drawn from this survey of the literature on AP? First, we showed the need for a standardized measure of AP that could be used (a) to distinguish AP possessors from nonpossessors in a consistent and objective manner and (b) to describe, in standardized form, the extent of an AP possessor's ability. The use of the measure to indicate the degree of AP is important because there are substantial differences in AP among AP possessors. Second, we brought together evidence that AP entails neither superior discrimination of pitches nor superior memory for sounds. Instead, the data suggest that memory for absolute pitches by AP possessors is mediated by verbal labels. Finally, we presented several lines of evidence supporting the view that AP may be learned, but only at some early stage in development—before approximately the 5th or 6th year. After that, it appears that relational perception takes over at the expense of absolute perception and the potential to learn to perceive absolute features of pitch is lost or at least greatly attenuated.
In closing, we note that the early-learning theory of AP, if it turns out to be valid as further data accrue, raises a dilemma regarding the proper content of early musical training. Assuming that it is desirable for a child to develop AP, emphasis should be placed on teaching the absolute qualities of pitch, rather than on pitch relations. However, musical structures of melody, harmony, and rhythm are based primarily on relations instead of on absolute features (Hulse, Takeuchi & Braaten, 1993). Thus children must learn to perceive relative features of music to understand music.

How might this dilemma be resolved? We suggest that teaching should follow the natural developmental sequence and begin by emphasizing the absolute qualities of tones and reinforcing absolute-pitch-naming behavior. Although the data are not yet conclusive, we believe the child may then develop AP. Subsequent emphasis on relations among tones should direct the child toward perceiving pitch relations directly, without first identifying the absolute pitches. Such training in relative pitch perception is desirable, and perhaps even necessary, for AP possessors because they must learn to perceive musical structures, and these structures are based on relations rather than on absolute features. Thus, we encourage early musical training of absolute pitch perception. However, such training should not supplant training of relative pitch perception, which is an indispensable part of music perception and performance.

References


ABSOLUTE PITCH

359


Received July 15, 1991
Revision received April 14, 1992
Accepted April 14, 1992