ABSOLUTE PITCH
AND THE PERCEPTION OF
SEQUENTIAL MUSICAL INTERVALS

by

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ABSTRACT

The perception of musical intervals by musicians can be envisaged as being accomplished in one of two ways. Most musicians appear to have only one method for identifying musical intervals: they directly evaluate the musical interval between two notes. Musicians with absolute pitch (AP) appear to have two methods available for identifying intervals: they can either directly evaluate the musical interval, or they can first identify the two pitches, and then infer the musical interval between them. This study investigated the perception of sequential musical intervals by two groups of musicians, one group with AP and the other without AP. In the first of four experiments, most subjects in both groups were able to name accurately standard sequential musical intervals based on the equal-tempered scale. In the second experiment, most subjects in the AP group were able accurately and consistently to name notes of the equal-tempered scale, whereas subjects without AP were not able to name them consistently or accurately. In the third experiment, subjects with AP identified, with varying degrees of accuracy and consistency, single notes spaced in 20-cent increments over a 9.4 semitone range, using the standard musical note names. This experiment also demonstrated that not all subjects had the same internal pitch reference. In the final and major experiment, subjects identified sequential musical intervals ranging in 20-cent steps from 260 to 540 cents, using the standard musical interval names. Subjects, both with and without AP, appeared to identify the intervals by directly evaluating the musical interval between the two notes, rather

than first identifying the two pitches and then inferring the musical interval. One subject in the AP group showed a strong tendency to use the latter method, but only in certain contexts, the reason for which remains unexplained. Although more research is needed for stronger conclusions to be drawn, it appears that most musicians with AP do not use this ability in the identification of sequential musical intervals, relying instead on their sense of relative pitch.

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CHAPTER 1

INTRODUCTION

Pitch is the subjective correlate of the physical parameter of frequency. It plays a central role in music, along with rhythm, timbre, and loudness. Because pitch is a major aspect of music, musicians work hard at learning to recognize pitch relationships. Most musicians develop relative pitch, the ability to identify a specific tone by its musical name when compared to a given reference tone, or the ability to identify the musical interval separating two pitches without a reference tone. Only a small percentage of musicians possess absolute pitch, the ability to identify a specific tone by name without comparing it to a reference tone. Most people who are not musically trained are unable to identify musical intervals or notes with any degree of accuracy or consistency.

Musicians without absolute pitch have only one strategy available for identifying musical intervals: the listener directly evaluates the musical interval between the two notes. Musicians with absolute pitch, on the other hand, can use two strategies in the identification of musical intervals. In one strategy, like musicians without absolute pitch, the listener directly evaluates the musical interval between the two notes without first labelling them ("relative pitch strategy"); in the other strategy, the listener first identifies the individual notes, and then infers the musical interval separating them ("absolute pitch strategy"). Musicians with absolute pitch have

been observed to use the former strategy in situations where two notes constituting a sequential musical interval are close together in time (less than one minute silence between the notes) and are both categorized with the same musical note name (e.g. D + 20 cents and D - 20 cents are closest to the note D, and would both be categorized as D by a musician with absolute pitch and standard reference). Musicians with absolute pitch have been observed to use the latter strategy in situations where the two notes are far apart in time (at least one minute silence between the notes) and both categorized with different note names (i.e. the two notes are each closest to a different note). It would be of interest to investigate which of these two strategies possessors of absolute pitch use when the two notes of the musical interval are relatively close together in time (two seconds between the notes), but would be labelled with different musical note names. If the notes constituting the intervals did not correspond with the notes of the standard equal-tempered scale, incorrect identification of some intervals could be expected with the absolute pitch strategy, caused by compounding of the two successive rounding errors inherent in this strategy.

With the relative pitch strategy, only one evaluation is necessary for the identification of a musical interval: the pitch difference between the two notes is rounded up or down to correspond with the closest interval. On the other hand, three evaluations are necessary for the identification of a musical interval with the absolute pitch strategy: first, each tone is rounded up or down to the closest note, and then the interval is inferred from these notes. By rounding two components instead of

one, errors can be compounded in some situations, resulting in incorrect identification. For example, with the relative pitch strategy, the two notes $C\# + 40$ cents and $F - 40$ cents would be categorized as a minor third (300 cents), the interval closest to the 320-cent pitch difference between them. With the absolute pitch strategy, however, $C\# + 40$ cents would be labelled as $C\#$, and $F - 40$ cents would be labelled as F , and the inferred musical interval between the two notes would be a major third (400 cents).

CHAPTER 2

REVIEW OF THE LITERATURE

2.1 Introduction

A number of research areas are involved in the study of absolute pitch and the perception of sequential musical intervals. Section 2.2 reviews definitions of absolute pitch and describes research into the pitch perception abilities of possessors of absolute pitch. Section 2.3 discusses theories of pitch coding in absolute pitch possessors, and describes research pertaining to perception of musical intervals by possessors and nonpossessors of absolute pitch. Section 2.4 describes the main tuning systems of Western music, and possible effects of tuning systems on musical interval judgment.

2.2 Absolute Pitch

Absolute pitch is usually defined as the ability to identify a specific tone by frequency or musical name, or the ability to adjust the frequency of a variable tone to some designated frequency, without comparing the tone to any objective reference tone. The accuracy and consistency of pitch recognizing ability necessary for absolute pitch is a matter of contention, however.

Seashore (1938) states that absolute pitch varies through degrees from the ability to name a piano note without reference

to any other note, to the ability to tell when an instrument is tuned "1/10th vibration" too high. He reports that the ability to name single notes on a familiar instrument is quite common among trained musicians, likely due to the timbre of the instrument. He also states that absolute pitch can attach itself to a particular note, and other notes may be identified with reference to this internal standard.

Bachem (1955) defines absolute pitch as the ability to recognize and define the pitch of a tone without the use of a reference tone. This recognition and definition of pitches is fast, definite, accurate to tones and semitones, accurate over at least a limited range if not the whole musical range, and may be strongly inclined to octave errors. Bachem also describes what he labels "pseudo-absolute pitch" and "quasi-absolute pitch". Pseudo-absolute pitch is simply estimation of pitches based on how high or low they sound, with an average error of five to nine semitones. Although this error can be narrowed through practice, the pitch estimation is still poor. Singers who compare the pitch of a tone to the limits of their vocal range, or violinists who compare pitches with a remembered A440 are said by Bachem to have quasi-absolute pitch. The comparison is relatively slow and the pitch estimation is again poor. Pseudo and quasi-absolute pitch are therefore based on the height of the tones and only absolute pitch itself is based on chroma or the subjective "color" of pitches.

Absolute pitch, according to Brady (1970), is a term applied to the ability of certain people to recognize musical notes and identify them by name, or to sing any desired note. Brady also

believes that people with absolute pitch perform with different levels of accuracy: some remembering a few notes and reconstructing scales; and others having memorized all notes. In his opinion, the general population appears to be divided between those who can identify randomly presented tones with accuracy far beyond chance, and those with no facility at this at all.

Davies' (1978) view of absolute pitch is that it is present in varying degrees among possessors. In its extreme form, absolute pitch is the ability to name instantly any note played, while in more moderate cases the possessor can identify the key in which a piece of music is played.

Spender, in The New Groves Dictionary of Music and Musicians (1980), defines absolute pitch as the ability to name the pitch of a note without reference to any previously sounded note (recognition), or to sing a named note without reference to a previously sounded note (recall), with recognition being easier than recall. According to Spender, no time is needed to relate the pitch to some standard: for those with absolute pitch, recognition is instantaneous. Absolute pitch is distinguished from "absolute tonality", the ability to name the key of a chord or harmonic passage without previously heard reference notes. With this ability, different keys are said to have "distinctive colours or flavours" (not the same for different absolute tonality possessors) that are instantly recognized. As reported by Spender, Teplov (1966) classified absolute tonality as a sub-stage of absolute pitch since all those with absolute pitch would necessarily have absolute tonality, but not vice versa.

According to Spender, average error in the task of naming notes or chords should be less than a semitone.

In Deutsch (1982), Ward and Burns define absolute pitch as the ability to attach labels to isolated auditory stimuli on the basis of pitch alone. In Ward's opinion (1963b), absolute pitch abilities are on a continuum.

Four methods of assessing absolute pitch have been commonly used in reported research. These are: musical categorization, method of constant stimuli, method of adjustment, and non-musical categorization. In experiments using musical categorization, subjects are presented with series of musical tones which they are asked to identify. The crudest measure of performance is the number of tones correctly identified. Results of musical categorization experiments show that many individuals with absolute pitch can correctly identify the notes over the middle 3/4 of the piano.

Weinert (1929; cited by Ward and Burns, 1982) presented 85 piano tones from A0 to A7 presented in random order to 22 subjects with absolute pitch on five separate occasions. Percentage error, including octave errors, ranged from 5.2 to 75% with a median of 25%. Bachem (1937), using the same method as Weinert with 90 subjects possessing absolute pitch found seven subjects who he described as "infallible". It was not clear in his description, however, whether or not he included octave and/or semitone errors. 65 professional musicians with absolute pitch were tested by Wellek (1938; cited by Ward and Burns, 1982) using Weinert's paradigm, and none were infallible.

Oakes (1955) investigated pitch naming and pitch discrimination abilities in 88 subjects. In the pitch naming task, 75 recorded piano tones were presented to four groups of students who were asked to give the pitch name and octave of each note. The four groups of subjects were: music students with absolute pitch; music students without absolute pitch; arts students with some musical training; and arts students with no musical training. Oakes found that the distribution of performance on the pitch naming test was on a continuum, with a correlation factor of .64 between months of musical training, and pitch naming and discrimination ability.

After considerable self-training to develop absolute pitch, Brady (1970) had his wife play a random computer-selected note on piano each day as he awakened for 57 consecutive days. Brady's task was to name the note by chroma (note-name) only, disregarding the tone-height (octave). His naming distribution was 65% correct, 31.5% semitone error, and 3.5% wholetone error. Brady classifies this as "near-perfect semitone discrimination".

Using the method of constant stimuli, names of musical notes are still used to identify pitches, but in this case the series of stimuli is closely spaced around a note, and the subject judges whether the stimulus is too high, too low, or on pitch. This experimental method gives a more accurate picture of the pitch judgment abilities of absolute pitch subjects.

Abraham (1901; cited by Ward and Burns, 1982) used as stimuli a series of frequencies in 2-Hz steps, each presented 24 times. His task as subject was to decide whether the note

presented was too high, too low, or on pitch for a specific musical note. Abraham could identify $1/4$ semitone with 75% accuracy, and $1/2$ semitone with 95% accuracy.

Van Krevelen (1951) studied absolute pitch in 17 students who had correctly identified oscillator tones corresponding to the 48 notes in the middle 4 octaves of the piano. They were presented with tones from 404 to 478 Hz in 2-Hz steps and were asked to respond with "too high", "too low", or "on pitch" relative to G#4, A4, or A#4. The standard deviation of the average subject's judgments was 6.4 Hz for A4 and slightly higher for the other two pitches, or an average error of approximately 30 cents. Extrapolating on this information, Ward (1963) computed that for a 95% correct judgment, the stimuli would have to be separated by a semitone. However, van Krevelen's best subject performed at about the same level as Abraham, or 95% accuracy for quarter tones.

Siegel (1972) asked 10 absolute pitch subjects and 10 control subjects whether a stimulus tone was too high or too low to correspond to a particular note of the equal-tempered scale. A modified staircase method was used, whereby the stimulus changed in response to the subject's previous response, as follows: if the subject indicated that the stimulus was too low, the following stimulus would be a constant amount higher, and vice versa. In this way, the subject would bracket his pitch "standard" for that particular note. Results indicated that absolute pitch and control subjects differed significantly in variability of their judgments ($p < .01$), but not in accuracy of judgments ($p > .05$). Siegel interpreted this to indicate "that

variability, rather than accuracy of production is a good indicator of absolute pitch." (Siegel, 1972, p. 84) She also states,

Apparently, absolute pitch subjects' mapping of musical notes onto the pitch continuum may differ considerably from that of the well-tempered scale....Because of such idiosyncratic differences..., accuracy of pitch production is not a very good measure of AP [absolute pitch] ability. (Siegel, 1972, pp. 84-85)

With the method of adjustment, the subject must set an instrument to a certain pitch. Experiments of this kind reveal how accurately a subject with absolute pitch can produce a desired note. In some studies, the subject is allowed to bracket, in which case he can search for his "indifference point" and set the control somewhere between too high and too low. In other studies, bracketing is not allowed.

In Petran's (1932) experiment, subjects with absolute pitch were required to set a tonvariator to A4 without bracketing. Petran found that once they entered a "zone of uncertainty", they tended to stop. Although the best subject showed only a 1/4-tone difference between ascending and descending judgments for a given note, the average difference for a given subject was about two semitones.

Van Krevelen's (1951) 17 subjects were asked to adjust, using bracketing, an oscillator 100 times to 3 target tones: G#, A, and A#. The results of this test were not significantly different from the "too high", "too low" judgments in her experiment using the method of constant stimuli: errors were in the range of 30 cents for the adjustment of notes.

Brammer (1951) required 42 randomly-chosen violinists to a) direct an experimenter in tuning the A string of a violin, b) tune the A string themselves, and c) direct an experimenter in tuning the clarinet; each of these 5 times. The 17 subjects claiming absolute pitch did better on average than the rest, but there was overlap between those claiming absolute pitch and those not claiming absolute pitch. Variability on the clarinet was significantly higher than on the violin. Unfortunately, Brammer did not report any details on the variability of individual subjects.

If subjects are musically untrained, arbitrary stimulus and response categories, or nonmusical categorization, is an appropriate method of testing absolute pitch. With musical subjects, this method avoids the ambiguity of black notes, e.g. the difference between the concept of G# and Ab, and also avoids the differences in inferred tuning of the subjective musical scale (Ward, 1963b).

Pollack (1952) was the first to apply information theory techniques to pitch. The information in a signal is given by the log to the base 2 of the number of alternatives from which it might have been selected. If the listener always identifies the signal correctly, then the information transmitted is equal to that of the signal. The more errors that are made, the lower the amount of information that was transmitted. The possible stimuli are defined to the listener, then presented each an equal number of times for the subject to attempt to identify. The responses are tabulated, and information transmitted (I_r) can be calculated. By raising 2 to the power I_r , an estimate of the

number of stimulus categories that should have been used in order to have perfect identification can be made.

Pollack presented musically untrained subjects with tones between 100 and 8000 Hz. He found that no naive listeners could exceed $I_r = 2.7$ bits, or seven tones, no matter how many tones were presented, and that most subjects could discriminate a maximum of five tones.

Ward (1953) used Pollack's procedure, but with a subject possessing well-developed absolute pitch. The subject was presented with 10 pure tones and could write down whatever she wanted to in order to remember each pitch. In succeeding trials, distance between stimuli was manipulated. Over 6 bits of information were transferred via pitch, that is, over 70 different frequencies in the 50 to 4500 Hz range could be identified 10 out of 10 times. Maximum information transfer was reached when the stimuli were one semitone apart: no errors were made, including octave errors, if stimuli were separated by intervals of one semitone or more. Ten adjacent 1/4-tones as stimuli resulted in occasional errors of $\pm$ one category (80% correct). At the extremes of the musical range, information transfer dropped.

Controversy remains regarding what constitute the best stimuli for investigations of absolute pitch. Baird (1917), testing for absolute pitch with piano, organ, tuning fork, flute, clarinet and sung pitches, found that performance was best on the piano, even though more alternatives were given on this instrument. Seashore (1919) claimed that piano notes should be

used as stimuli on tests investigating absolute pitch, because musicians are most familiar with them.

Sergeant (1969) proposed that stimuli for identification should be presented on a variety of instruments, since different subjects are exposed to different instruments as children and may have more ability at pitch naming on the instrument they first played.

Ward and Burns (in Deutsch, 1982) suggest that piano tones are the easiest of all instruments to identify because of extraneous cues. However, depending on the force with which the piano key is struck, the relative intensities of the partials may change, making it unclear what role pitch plays in the identification of piano tones. Ward (1963a) proposed that if one is interested in the ability to classify auditory events on the basis of pitch alone, pure tones should be used as stimuli. Since octave errors may be the result of harmonic structure, they should be very small with pure tones.

From the literature on absolute pitch, it appears that there is general agreement among authors that absolute pitch is the ability to name the pitch of a note without reference to any previously sounded note. There is, however, disagreement as to whether : (a) stimuli presented should be tones played on a familiar instrument or pure tones; (b) recognition/production should be instant or compared to one (or more) memorized reference note(s); (c) absolute pitch is restricted to the ability to name notes or whether the ability to determine the key

of a piece of music should be classified as absolute pitch; (d) accuracy for semitones should be near 100% or "far beyond chance".

2.3 Strategies for naming notes and intervals

The equal-tempered scale divides each octave into twelve logarithmically equal steps, so that the musical interval of a semitone, a frequency ratio of 1.0595:1 separates adjacent notes from one another.

Only a few musicians, those with absolute pitch, learn to identify the frequency of a single tone presented in isolation. Because melodies may be transposed into a different key, it is the relationship of the notes that is important in our system. Thus most musicians acquire relative pitch, the ability to identify the frequency ratio of two notes on an absolute basis. Each of the standard intervals is assigned a name, such as unison, tritone, major third, or octave, and "ear training" consists at least in part of learning to identify the standard intervals. (Siegel and Siegel, 1977b, p. 400)

Because they are able to accurately assign musical note names to frequencies, it appears that subjects with absolute pitch have at their disposal two methods of labelling musical intervals. In one case, they may be able to compare the two frequencies on the basis of their absolute difference without first labelling the individual tones, and in the other case, they may first label the individual tones and subsequently calculate the intervallic relationship of the tones. Research by Bachem, and Siegel and Siegel has shown that possessors of absolute pitch use both of these strategies.

In a frequency discrimination experiment, Bachem (1954) compared the performance of ten absolute pitch subjects and ten subjects with musical training but without absolute pitch. A standard tone was followed by a comparison tone with a silent period of from one second to one week between the two tones, and subjects were asked to indicate whether the tones were the same or different. For each length of silence, Bachem determined the frequency difference necessary for subjects to maintain a threshold level of performance, that is, for the subject's judgments to be correct 75% of the time. For silent periods of less than one minute, absolute pitch and control subjects had approximately the same threshold. At silent periods greater than one minute, the threshold for the absolute pitch subjects remained comparable to what it had been at one minute, whereas the thresholds of the control subjects continued to increase as the silent period between the two tones increased. Bachem attributed these differences to the existence of two mechanisms for pitch discrimination.

The normal subject simply compares tone heights for identity or differences over the whole time scale. The subject with absolute pitch also compares tone heights within the short time range, but shifts to the chroma comparison as soon as this method secures better results, i.e. he makes the detour over the verbal association with the chroma, which he is able to remember with high accuracy. (Bachem, 1954, p. 753)

For silent periods of less than one minute, thresholds were attained at approximately $1/20$ semitone to $1/2$ semitone. These pitch differences would be too small for absolute pitch subjects to use a strategy in which they named the notes first, for both notes would in most cases be given the same note name.

Bachem suggested that when standard and comparison tones were sufficiently far apart, absolute pitch subjects coded them in terms of the note of the musical scale and used these codes to decide if the notes were the same or different on the judgment task. Siegel (1974) proposed that subjects with absolute pitch have two modes for processing tone frequency: a) "sensory trace mode", which maintains a sensory event in memory for a brief time; and b) "verbal mode", in which tones are labelled with musical names; and that subjects without absolute pitch have only the "sensory trace mode" for processing tone frequency.

Siegel compared the performance of absolute pitch and control subjects in judging the intervallic relationship between two tones separated by either $1/10$ or $3/4$ semitone, with a five-second "retention interval" between the standard and comparison tones, which was filled with a large number of brief tonal stimuli. Siegel reasoned that if absolute pitch subjects verbally labelled stimuli, they should be superior to the controls in the $3/4$ semitone condition, but have similar results in the $1/10$ semitone condition. Her results confirmed her predictions.

The pattern of results...corresponds to that predicted by the verbal coding theory of absolute pitch. According to that theory, absolute pitch subjects should do better than controls in the $3/4$ -semitone condition because they can relate the stimuli to different notes of the scale and store the appropriate names in memory. Such a strategy would not be an effective one in the $1/10$ semitone condition, since it is highly likely that the standard and comparison tones would be assigned to the same verbal category. Thus, absolute pitch subjects would shift their strategy to one of remembering the physical characteristics of the tones, rather than verbally coding the items on the basis of their relation to the notes of the scale. (Siegel, 1974, p. 40)

When asked to indicate their strategy in the experimental situation, all four of the subjects with absolute pitch who completed the questionnaire reported using a "verbal coding" strategy in the 3/4 semitone condition and a "sensory coding" strategy in the 1/10 semitone condition. None of the controls reported having used a "verbal coding" strategy, rather, they all reported using some form of a "sensory coding" strategy. None of the control subjects reported using different strategies in the two conditions.

Research into musical perception has revealed that musicians without absolute pitch perceive musical intervals categorically and that musicians with absolute pitch perceive frequencies in the musical range categorically.

Siegel and Siegel (1977b) studied six musicians with a good sense of relative pitch but without absolute pitch. Subjects were asked to judge 13 tonal intervals in a magnitude estimation task and a labelling task. Stimuli were spaced in 20-cent increments over a range of three musical interval categories: perfect fourth, tritone, and perfect fifth. On the labelling task, subjects categorized the stimuli into regular and symmetrical categories with little overlap between categories. Magnitude estimation task responses revealed three discrete steps corresponding to the musical intervals, indicating that subjects did not discriminate between intervals they judged as belonging to the same musical category. On average, subjects judged 37% of the intervals as out of tune, while in reality, 77% of the intervals were out of tune by at least 20 cents. Siegel and Siegel concluded that "musicians with good relative pitch can

label tonal intervals accurately on an absolute basis", that "musicians had a strong tendency to rate out-of-tune stimuli as in tune", and that their "attempts to make fine, within-category judgments were highly inaccurate and unreliable." (Siegel and Siegel, 1977b, p. 405)

In the first experiment reported in their earlier paper, Siegel and Siegel (1977a) had 32 subjects with varying degrees of relative pitch name 21 different tonal intervals, ranging over five semitone categories, from unison to major third in 20-cent steps. Subjects were asked to label each interval with one of the accepted category names from unison to major third. Results showed that musically trained subjects consistently used all five response categories, had regular, symmetrical naming distributions, and well-defined category boundaries. Musically naive subjects gave inconsistent responses except for the unison category, which can be discriminated from the other categories simply by detecting that there is no difference between the two notes in the interval. Siegel and Siegel concluded that their musically trained subjects had established a set of absolute mnemonic anchors for the standard musical intervals.

In the second experiment reported in Siegel and Siegel (1977a), seven subjects who possessed absolute pitch and four non-musicians were asked to identify single tone stimuli covering the range from C to E in 20-cent steps. Subjects were asked to name each note with one of the musical note names C, C#, D, D#, or E. Subjects possessing absolute pitch labelled the notes accurately and reliably. The performance of the non-musically-

trained subjects was reported as extremely inconsistent on this task.

The last two experiments reported in Siegel and Siegel (1977a) investigated the effect of context on the categorization of intervals in musicians not possessing absolute pitch, and the categorization of single notes in musicians possessing absolute pitch. First, subjects were presented with 21 stimuli over a certain range of intervals/notes, then without warning, the stimulus set was changed to include the eleven largest intervals/highest notes from the previous set plus ten larger intervals/higher notes. Shifting the stimuli in this way had little or no effect on the judgments of the best subjects. Thus, Siegel and Siegel concluded that musicians without absolute pitch perceive musical intervals categorically, possessors of absolute pitch perceive musical notes categorically.

Burns and Ward (1978) conducted experiments to determine whether or not categorical perception of musical intervals was dependent on experimental method. In the first experiment, identification and discrimination functions were obtained for equally spaced stimuli which covered several interval categories. Five musically trained subjects were asked to categorize into musical interval categories from major second to tritone, ascending melodic musical intervals ranging from 250 to 500 cents in increments of 12.5 cents. Burns and Ward found that all subjects were able to consistently identify the ratios as belonging to one of the five musical interval categories.

In the discrimination task, subjects were asked to judge which of two successive melodic intervals, separated by a 1-s ISI, was wider. For each discrimination function, the two melodic intervals in a given trial were adjacent ratios from the set of ratios separated by equal increments over the range from 250 to 550 cents. Three discrimination functions were obtained, for increment sizes of 25, 37.5, and 50 cents. The resulting average discrimination functions were of the form typically associated with categorical perception, i.e., better discrimination for stimuli lying well within subjective categories, and poorer discrimination for stimuli lying at category boundaries. In some cases, subjects were able to discriminate within-category stimuli much better than predicted. Burns and Ward attributed this to subjects' ability to identify intervals more precisely than semitones.

In Burns and Ward's second experiment, four subjects were presented with the same stimuli as in Experiment 1 but with varied ISI between interval pairs in the discrimination task. Discrimination functions, obtained for 25 and 50 cents with ISI of 330 ms to 3 s, were not appreciably different from the 1-s ISI condition. Therefore, no decrease in within-category discrimination with increasing ISI was found, confirming the assumption that musical interval perception is categorical.

In Burns and Ward's third experiment, the stimuli were identical to those in Experiment 1, except that the two ratios to be discriminated in a given trial were ratios separated by a variable distance in cents around a fixed interval value. This paradigm was a transformed up-down method after Zwislocki (1958;

cited by Levitt, 1971), in which interval separation converges on the value at which the subject's performance will be 70.7% correct. The task for the four subjects was to indicate which interval was wider. When the 70.7% correct threshold estimates of two consecutive presentations of the stimuli differed by 5 cents or less (asymptotic performance), another 25-cent equal-step-size discrimination function was obtained for each subject.

The initial threshold estimates showed good correlation with the 25-cent discrimination curves. However, after sufficient training, i.e. at asymptotic performance levels, this correlation had largely disappeared. Subjects showed approximately equal discrimination threshold estimates for all interval values, implying that after training, the 25-cent discrimination functions should be flat. However, after training, these discrimination functions had the same shape as the pre-training 25-cent discrimination functions. Burns and Ward stated that

The correlation between the initial DL [differential threshold] estimates and the 25-cent discrimination functions, and the fact that many more trial blocks were required to reach asymptotic performance at within-category ratios than at between-category ratios, both indicate that categorical perception is more than an epiphenomenon associated with the equal-stimulus separation discrimination paradigms usually used. However, the finding that subjects could, in general, be "trained" so that within-category DL's were equal to between-category DL's, but that even after such training the equal-stimulus separation discrimination functions still indicated pronounced categorical perception, shows that the phenomenon is to a large extent dependent on experimental procedures. (Burns and Ward, 1978, p. 462)

Burns and Ward suggested that, although the existence of categorical perception is linked with experimental procedure, the concept is not necessarily without utility.

If it can be shown that the experimental procedures which tend to elicit categorical perception more closely approximate conditions found in "real life" perception, e.g. perception of running speech, or music in performance, then studies of categorical perception should provide insight into higher levels of auditory processing, involving, e.g., attention and memory. (Burns and Ward, 1978, p. 464)

Burns and Ward tentatively concluded that categorical perception of musical intervals "is related to the degree of stimulus uncertainty associated with the procedures used." In the equal-step size discrimination task (Experiment 1), stimuli in a given trial could be in one of five possible perceptual categories, and were chosen at random. Thus uncertainty in the task was much higher than in the adaptive procedure (Experiment 3), where stimuli in any given trial were in the region of one or two musical interval categories and the stimuli followed in a predictable manner based on the subject's responses. Burns and Ward proposed that

...since stimulus uncertainty in "real world" perception is, in general, high, it might be expected that categorical perception of musical pitch would be the normal situation. This conclusion is supported by the results of various investigations of intonation in performance. (Burns and Ward, 1978, p. 466)

2.4 Tuning Systems

Ward (in Tobias, 1970) describes three main systems of tuning used in Western music: equal temperament, just intonation, and Pythagorean tuning. In equal temperament, the octave, a frequency ratio of 2:1, is divided into 12 equal logarithmic steps, each called a semitone. The semitone is divided into 100

equal logarithmic steps, each called a cent, making an octave 1200 cents wide.

Other scales have slightly irregular spacing. In one version of just intonation, the steps in an octave are determined by small whole-number ratios. For example, in this tuning system, the interval of a perfect fifth is a frequency ratio of 3:2, for a frequency difference of 702 cents rather than 700 cents as in equal temperament. The frequency ratio of a major third in just intonation is 5:4, for a frequency difference of 386 cents instead of 400 cents as in equal temperament.

The Pythagorean system is based on a series of successive perfect fifths (3:2 ratio). G, a fifth above C, is 702 cents higher than C. A fifth above G is D, $702 + 702 = 1404$ cents above C. Subtracting 1200 cents gives D a value of 204 cents instead of the 200 cents in equal-tempered tuning. A fifth above D gives A a value of 906 cents above C, and so forth. Going upward from C for half the intervals, and downward from C for half the intervals results in a 1200-cent octave with slightly irregular spacing between the notes (see Table I).

TABLE I

Comparison of the major theoretical systems of temperament

Numerical values indicate the distance in cents (1/1200 octave) between the unison and the scale step concerned.

	Solfeggio	Just	Equal	Pythagorean
unison	do	0	0	0
minor 2nd		112	100	90
major 2nd	re	204	200	204
minor 3rd		316	300	294
major 3rd	mi	386	400	408
fourth	fa	498	500	498
tritone		590	600	612
fifth	sol	702	700	702
minor 6th		814	800	792
major 6th	la	884	900	906
minor 7th		996	1000	996
major 7th	ti	1088	1100	1110
octave	do	1200	1200	1200

(Ward, in Tobias, 1970, p.414)

Proponents of just intonation and Pythagorean tuning emphasize the preference of small ratios between notes, for two reasons: (a) if the fundamental frequencies of two simultaneously played complex tones have a small-number ratio, many of the partials will coincide, so that a minimal number of "beats" will occur when notes are tuned to small-number ratios; and (b) it is hypothesized that humans prefer pairs of tones for which the frequencies of neural discharge agree (Meyer, 1898; cited in Ward, 1970).

Proponents of equal temperament suggest it is preferable in that an instrument tuned in equal temperament can be played in any key, whereas one tuned in just intonation or Pythagorean tuning has to be retuned for different keys (Ward, in Tobias, 1970). Pianos are normally tuned in equal temperament while singers and many instrumentalists can choose which tuning system to use.

Ward (in Tobias, 1970) reports on studies by Greene (1937), Nickerson (1948), Mason (1960), and Shackford (1961, 1962a), which indicate that string and woodwind players generally play musical intervals slightly sharper than indicated by equal temperament. Even the octave, which is a ratio of 2:1 or 1200 cents in all three tuning systems, is identified as "best" at about 1210 cents for pure tones (Ward, 1954). Generally, the tuning used by musicians in these studies corresponds fairly closely to equal temperament, but with a small amount of sharpening of all tones in relation to the tonic.

Although it is said to be tuned to equal temperament, the tuning of a piano is always stretched to some extent because piano strings vibrate in such a way that the partials are not exactly harmonically related. For example, the second partial of the A4 string on a good piano is about 1201 to 1202 cents higher than the fundamental, so when a piano tuner matches the A5 fundamental to the A4 second partial, the scale is automatically stretched. Ward suggests that

Perhaps the stretched scale of the piano is at least partially responsible for the fact that the internal scale of musical pitch is also stretched. Indeed, perhaps the correspondence (except for stretch) between musical pitch and equal temperament is due to the extensive experience all musicians have had with the universal piano. (Ward, in Tobias, 1970)

Possibly because of the variety of tuning systems that musicians are exposed to, intersubject variability in judgments of musical intervals has been observed. Zatorre and Halpern (1979), in a study in which subjects identified simultaneous musical intervals ranging from a minor third to a major third in seven equal logarithmic steps, observed that for the eight musically trained subjects, the major category was narrower than the minor category for thirds, that is, the musicians studied had a stricter criterion for accepting major than minor thirds. Zatorre and Halpern attributed this

...either to a learned narrower tuning of the major third, or to some physical characteristic of the major third [e.g. its place in the harmonic series, or that the major third approximates the bandwidth of a critical bandwidth in hearing (Scharf, 1970)]. (Zatorre and Halpern, 1979, p. 388)

Siegel and Siegel (1977a) reported idiosyncratic differences between subjects in categorization of musical intervals. Some

subjects produced categories that were wider or narrower than they should have been according to predictions from the equal-tempered scale. Burns and Ward (1978) also found a relatively large intersubject variability to be characteristic of musical-interval judgments, and that the location of category boundaries varied among subjects. They reported that averaging of subjects' data somewhat obscured the information seen in the data of individual subjects.

Since there are many different systems of tuning and relatively large intersubject differences in musical interval judgment, it appears that judgments should be compared with "ideal" categorization functions for each possible strategy predicted from the equal-tempered scale, and that data from each subject should be examined individually.

CHAPTER 3

AIMS OF THE EXPERIMENT

In the study of musical interval perception as it relates to possessors of absolute pitch, some questions are: Does a musician with absolute pitch perceive and identify musical intervals in the same manner as a musician without absolute pitch? Can a musician with absolute pitch suppress the identification of notes and directly evaluate musical intervals? What ability does the musician with absolute pitch rely on most heavily in a given situation, absolute pitch or relative pitch?

Studies on the perception of music have demonstrated that categorical perception occurs (a) in the identification of musical intervals by musicians without absolute pitch, and (b) in the identification of pitches by musicians with absolute pitch. Two strategies are available to musicians with absolute pitch for identifying sequential musical intervals. With the "relative pitch strategy", the listener directly evaluates the musical interval between the two notes, whereas with the "absolute pitch strategy", the listener first identifies the two notes, and then infers the musical interval between them.

The present study investigates the strategies used in the identification of sequential musical intervals by musically trained subjects with and without absolute pitch. These subjects are asked to identify intervals which do not correspond to the

standard equal-tempered interval categories, some of which should be correctly identified with the relative pitch strategy but incorrectly identified with the absolute pitch strategy. In preliminary experiments, subjects are asked to identify sequential musical intervals which correspond to standard musical interval categories, and to name single notes which correspond to standard equal-tempered pitches, so that their sense of relative pitch and absolute pitch can be evaluated. In order that their internal pitch reference can be determined, subjects who demonstrate that they have absolute pitch are then asked to identify single notes which correspond to 20-cent increments on the equal-tempered scale, using the standard note names of the equal-tempered scale. Finally, subjects are asked to identify sequential musical intervals ranging from 260 to 540 cents in 20-cent steps, into the standard musical interval categories. Depending on the strategy used, a given subject's identification of these intervals should correspond to some extent with one of two sets of predicted responses: the first set would correspond to the relative pitch strategy, based on the pitch difference between the two notes, and the second set would correspond to the absolute pitch strategy, based on naming the two notes in relation to an internal reference and then inferring the musical interval between them.

This study attempts to discover the following:

1. Which of the two strategies is used by each subject with absolute pitch when judging sequential musical intervals?
2. Is there an evident difference in the way the two groups of subjects identify intervals?

CHAPTER 4

MATERIALS AND METHODS

4.1 Preparation of Stimuli

All stimuli consisted of single puretones or of pairs of puretones which were synthesized, using a DEC PDP-12 computer. Their frequencies corresponded either to notes of the equal-tempered scale or to frequencies between these notes, in 20-cent steps. A program which synthesized puretones at specified frequencies was used to generate each one of these notes. Each puretone was generated as a sequence of 12-bit words, which were stored on a digital tape, and later played back via a D-to-A converter.

All notes were 500 ms in length. Amplitude envelopes were shaped to produce rise and decay times of 25 ms, resulting in smooth, rapid rise and decay of the stimuli. Sampling rate was set at 4096 samples per second. Since the highest frequency synthesized was close to 600 Hz, this sampling rate was more than adequate to meet the Nyquist criterion and would have in fact accommodated higher frequencies. A sampling rate of 4096 Hz was chosen because the digital (LINC) tapes used were divided into 256-sample blocks, and thus a 500-ms note would fit exactly into a full number of blocks with no spill into adjacent blocks, making it easier later to transfer whole blocks from digital tape to audio tape.

In order to (a) distract and disorient the subject and to some extent "erase" his/her memory of a previously heard pitch; and (b) to alert the subject to an upcoming stimulus and to help him/her keep track of his/her place on the tests, "pitch eraser" tones were used between stimuli. These "pitch eraser" tones were short durations of either one of two computer-generated complex tones which give the impression of continuously descending or continuously ascending (Shepard, 1964; Risset, 1971). Hereafter, they are referred to as "ascending" or "descending pitch erasers". The "pitch erasers" were transferred from analog audio tape to digital tape via a 10-bit A-to-D converter using WAVES, a set of computer programs written by Lloyd Rice at U.C.L.A. The sampling rate was also 4096 samples per second. The D-to-A'd signal was low-pass filtered at 1650 Hz to prevent aliasing. 200 blocks, or 12.5 seconds of each of the ascending and descending complex tones were sampled and stored on the digital tape. The starting point of each "pitch eraser" tone was randomly chosen, and, depending on the test, its length was randomly varied between 1 and 4.4 seconds.

4.2 Preparation of Test Tapes

All tones were D-to-A'd with a 10-bit D-to-A converter and bandpass filtered by a General Radio Universal 1952 Filter set to pass only frequencies in the range appropriate for the stimuli. The signal was then fed to a Nagra IV-D full-track reel-to-reel tape recorder and recorded on professional quality Ampex audio

tape at a low level, in order to eliminate problems of print-through.

The puretones and "pitch erasers" were transferred from digital onto audio tape, using the WAVES programs. With these programs, it was possible to play back the tones in any order required. The silent period between two notes in a melodic interval was precisely timed, using multiples of 62.5 ms, corresponding to a full number of blocks. The tones were moved to the appropriate positions on the digital tape, then transferred to the audio tape. The frequency of each note was tested on the audio tape (played on the Nagra tape recorder) with a Korg WT-12 quartz chromatic tuner and found to be accurate to within 3 cents of the desired frequency. From one to five buffer items, chosen at random from among the test items, but following the ordering constraints of the particular test, were recorded at the beginning and end of each test tape.

4.21 Tape for Test 1

The purpose of this test was to screen subjects for their ability to name musical intervals. The subset of six intervals from minor third to minor sixth was felt to be sufficiently difficult and varied to demonstrate ability to name musical intervals.

Stimuli for Test 1 consisted of two sequentially presented notes of frequencies corresponding to the notes of the equal-tempered scale between C4 (261.63 Hz) and C5 (523.25 Hz). The

two notes of each stimulus were separated by one of six musical intervals: minor third, major third, perfect fourth, tritone, perfect fifth, and minor sixth.

There were 120 test items in Test 1, arranged in two blocks of 60 stimuli. The 60 stimuli consisted of 10 tokens from each of the six musical interval categories listed above. In those cases where ten different examples of a specific interval could not be made using frequencies between C4 and C5, intervals from the centre of the frequency range were repeated for that category (see Table II). Half of the stimuli were presented as ascending intervals, and the other half were presented as descending intervals. The stimuli were arranged in pseudo-random order with the constraint that two adjacent stimuli had to be from different interval categories, and that the second note of a stimulus had to be different from the first note of the following stimulus.

Each stimulus consisted of two 500-ms tones separated by a 1-s silent period. Between each stimulus and the next, there was a 6.5-s silent period. Following every fifth stimulus, there was a 6.5-s silent period, a "descending pitch eraser", and another 6.5-s silent period. The starting point of each "pitch eraser" was randomly chosen from the first 130 blocks of "descending pitch eraser" on the digital tape, and the length of each "pitch eraser" was randomly varied between 60, 65, and 70 blocks, corresponding approximately to 3.8, 4.1, and 4.4 seconds.

TABLE II

Stimulus types for Test 1. "(a)" indicates an ascending interval, and "(d)" indicates a descending interval.

<u>Min3</u>	<u>Maj3</u>	<u>Perf4</u>	<u>Tritone</u>	<u>Perf5</u>	<u>Min6</u>
C ,Eb(a)	C ,E (d)	C ,F (a)	C ,F#(d)	C ,G (a)	C ,Ab(d)
C#,E (d)	Db,F (a)	C#,F#(d)	C#,G (a)	C#,G#(d)	C#,A (a)
D ,F (a)	D ,F#(d)	D ,G (a)	D ,Ab(d)	D ,A (a)	D ,Bb(d)
D#,F#(d)	Eb,G (a)	Eb,Ab(d)	D#,A (a)	Eb,Bb(d)	D#,B (a)
E ,G (a)	E ,G#(d)	E ,A (a)	E ,Bb(d)	E ,B (a)	E ,C (a)
F ,Ab(d)	F ,A (a)	F ,Bb(d)	F ,B (a)	F ,C (d)	C ,Ab(d)
F#,A (a)	F#,A#(d)	F#,B (a)	F#,C (d)	C#,G#(a)	C#,A (a)
G ,Bb(d)	G ,B (a)	G ,C (d)	D ,G#(a)	D ,A (d)	D ,Bb(d)
G#,B (a)	Ab,C (d)	D#,G#(a)	D#,A (d)	Eb,Bb(a)	D#,B (a)
A ,C (d)	E ,G#(a)	E ,A (d)	E ,Bb(a)	E ,B (d)	E ,C (d)

4.22 Tape for Test 2

The purpose of this test was to screen subjects for the ability to name single puretones. Stimulus frequencies covered a two-octave range so that the frequency distance between two stimuli could be more varied, making it more difficult for subjects to use relative pitch in naming single notes.

There were 60 test items in Test 2, arranged in five blocks of 12 stimuli, each block in a different pseudo-random order. Each of the twelve notes of the equal-tempered scale was presented five times in the two-octave range from C3 (130.81 Hz) to C5 (523.25 Hz), twice in one octave and three times in the other octave. Each octave was equally represented, with 30 notes from the lower and 30 notes from the higher octave (see Table III). Adjacent stimuli were separated by a pitch distance of at least 5 semitones.

Each stimulus consisted of a 500-ms puretone. The length of time between the beginning of two successive stimuli varied between 8 and 10 seconds. The interval between successive stimuli consisted of (a) a 2.5-s silent period; (b) a "descending pitch eraser", the starting point of which was randomly chosen from the first 130 blocks of "descending pitch eraser", and the length of which was randomly varied between 3.8, 4.1, and 4.4 seconds; and (c) another 2.5-s silent period. After every fifth stimulus, in the place of the "descending pitch eraser", there was an "ascending pitch eraser", with a similarly randomly-chosen starting point and length, to help the subject keep his/her place on the test.

TABLE III

Number of tokens by stimulus type for Test 2.

<u>Stimulus Type</u>	<u>Octave C3-B3</u>	<u>Octave C4-B4</u>
C	3	2
C#/Db	3	2
D	3	2
D#/Eb	3	2
E	2	3
F	2	3
F#/Gb	3	2
G	2	3
G#/Ab	2	3
A	2	3
A#/Bb	3	2
B	2	3

4.23 Tape for Test 3

The purpose of this test was (a) to determine how subjects possessing absolute pitch would categorize tones that were at frequencies between those of the notes of the standard equal-tempered scale and (b) to try to determine each subject's pitch centre to the nearest 20 cents.

Test 3 consisted of 215 test items, arranged in five blocks of 43 stimuli, each block in a different pseudo-random order. The stimulus types were 43 single puretones based on the equal-tempered scale in 20-cent steps. These puretones were also used for the two-note stimuli in Test 4, to be described in the next section. These two-note stimuli included all the notes from A#3 + 60 cents (241.30 Hz) to G#4 + 0 cents (415.30 Hz) in 20-cent steps, with the exception of the notes between B3 + 40 cents and C4 + 60 cents (see Table IV). Ordering constraints required that adjacent stimuli be at least 80 cents away from one another.

Each stimulus was a 500-ms puretone. The length of time between successive stimuli varied from 6 to 7 seconds. The interval between successive stimuli consisted of (a) a silent period of 3 seconds; (b) a "descending pitch eraser", the starting point of which was randomly chosen from the first 175 blocks of "descending pitch eraser" and the length of which was randomly varied from 1 to 1.5 seconds; and (c) a silent period of 1.5 seconds. After every fifth stimulus, there was (a) a silent period of 3 seconds; (b) an "ascending pitch eraser", the

TABLE IV

Stimulus types for Test 3. All notes are in the range between A#3 +60 cents (241.30 Hz) and G#4 +00 cents (415.30 Hz).

<u>-40/+60</u>	<u>-20/+80</u>	<u>0</u>	<u>-20</u>	<u>-40</u>
A# +60	A# +80	B +00	B +20	B +40
-	-	-	-	-
C +60	C +80	C# +00	C# +20	C# +40
C# +60	C# +80	D +00	D +20	D +40
D +60	D +80	D# +00	D# +20	D# +40
D# +60	D# +80	E +00	E +20	E +40
E +60	E +80	F +00	F +20	F +40
F +60	F +80	F# +00	F# +20	F# +40
F# +60	F# +80	G +00	G +20	G +40
G +60	G +80	G# +00		

starting point of which was randomly chosen from the first 130 blocks of "ascending pitch eraser", and the length of which was randomly varied between 3.8, 4.1, or 4.4 sec.; (c) a 1.5-sec. silent period; (d) a silent period of 3 seconds; (e) a "descending pitch eraser", the starting point of which was randomly chosen from the first 175 blocks of "descending pitch eraser" and the length of which was randomly varied from 1 to 1.5 seconds; and (f) a silent period of 1.5 seconds.

4.24 Tape for Test 4

The purpose of this test was to determine how subjects would categorize into standard musical interval categories sequential intervals whose component tones were not always consistent with equal-tempered tuning. More specifically, this test was designed to determine which of two strategies possessors of absolute pitch tend to use: one in which the listener directly evaluates the musical interval between the two notes, or one in which he/she first identifies the individual tones, and then infers the musical interval separating them.

Test 4 consisted of 165 stimuli. The stimuli consisted of two sequentially presented notes ranging from A#3 + 60 cents (241.30 Hz) to G#4 + 00 cents (415.30 Hz), which created melodic musical intervals closest to the categories of minor third (260 to 340 cents), major third (360 to 440 cents) and perfect fourth (460 to 540 cents). Three sets of 55 sequential musical intervals were created: the frequency of the bottom notes ranged, in 20-cent steps, from 40 cents below to 40 cents above one of

the three notes B3 (246.94 Hz), C#4 (277.18 Hz), or D#4 (311.13 Hz); the frequency of the top notes ranged, in 20-cent steps, from D4 (293.66 Hz) to E4 (329.63 Hz) for the set with bottom note B3, from E4 (329.63 Hz) to F#4 (369.99 Hz) for the set with bottom note C#4, or from F#4 (369.99 Hz) to G#4 (415.30 Hz) for the set with bottom note D#4 (see Table V). Each set of intervals was different only in terms of which note of the scale it was centred around. The tones that made up the intervals were spaced around the 0 reference in the same manner, and the relationships between the tones were the same across the three sets of musical intervals. Thus, if one ignores the fact that the three sets of intervals are centred around different pitches, one could say that there were 55 stimulus types, each repeated three times. The 165 stimuli were presented in a pseudo-random order, with an ordering constraint which required that adjacent stimuli be from different interval sets. Of the 165 stimuli, 85 were presented as ascending intervals, and the remaining 80 were presented as descending intervals.

A short pilot test was conducted to determine a suitable intra-stimulus interval for Test 4. It was a concern that the intra-stimulus interval be long enough for the subjects to be able to name the component tones before comparing them, but short enough for the subjects not to be forced to use this strategy, and such that the silence between notes in an interval was a length of time that was plausible in a real musical situation. The pilot test presented a selection of intervals that were to be used in Test 4, and compared the effects of an intra-stimulus interval of .0625, 2, 5, and 10 seconds. The results of this

TABLE V

Stimulus types for Test 4. Three sets of 55 intervals which made up the 165 stimuli. "(a)" - ascending intervals; "(d)" - descending intervals.

Intervals with bottom note A# +60 to B +40	Intervals with bottom note C +60 to C# +40	Intervals with bottom note D +60 to D# +40	Distance in cents
A# +60, D +00 (a)	C +60, E +00 (d)	D +60, F# +00 (a)	340
A# +60, D +20 (d)	C +60, E +20 (a)	D +60, F# +20 (d)	360
A# +60, D +40 (a)	C +60, E +40 (d)	D +60, F# +40 (a)	380
A# +60, D +60 (d)	C +60, E +60 (a)	D +60, F# +60 (d)	400
A# +60, D +80 (a)	C +60, E +80 (d)	D +60, F# +80 (a)	420
A# +60, D# +00 (d)	C +60, F +00 (a)	D +60, G +00 (d)	440
A# +60, D# +20 (a)	C +60, F +20 (d)	D +60, G +20 (a)	460
A# +60, D# +40 (d)	C +60, F +40 (a)	D +60, G +40 (d)	480
A# +60, D# +60 (a)	C +60, F +60 (d)	D +60, G +60 (a)	500
A# +60, D# +80 (d)	C +60, F +80 (a)	D +60, G +80 (d)	520
<u>A# +60, E +00 (a)</u>	<u>C +60, F# +00 (d)</u>	<u>D +60, G# +00 (a)</u>	<u>540</u>
A# +80, D +00 (a)	C +80, E +00 (d)	D +80, F# +00 (a)	320
A# +80, D +20 (d)	C +80, E +20 (a)	D +80, F# +20 (d)	340
A# +80, D +40 (a)	C +80, E +40 (d)	D +80, F# +40 (a)	360
A# +80, D +60 (d)	C +80, E +60 (a)	D +80, F# +60 (d)	380
A# +80, D +80 (a)	C +80, E +80 (d)	D +80, F# +80 (a)	400
A# +80, D# +00 (d)	C +80, F +00 (a)	D +80, G +00 (d)	420
A# +80, D# +20 (a)	C +80, F +20 (d)	D +80, G +20 (a)	440
A# +80, D# +40 (d)	C +80, F +40 (a)	D +80, G +40 (d)	460
A# +80, D# +60 (a)	C +80, F +60 (d)	D +80, G +60 (a)	480
A# +80, D# +80 (d)	C +80, F +80 (a)	D +80, G +80 (d)	500
<u>A# +80, E +00 (a)</u>	<u>C +80, F# +00 (d)</u>	<u>D +80, G# +00 (a)</u>	<u>520</u>
B +00, D +00 (a)	C# +00, E +00 (d)	D# +00, F# +00 (a)	300
B +00, D +20 (d)	C# +00, E +20 (a)	D# +00, F# +20 (d)	320
B +00, D +40 (a)	C# +00, E +40 (d)	D# +00, F# +40 (a)	340
B +00, D +60 (d)	C# +00, E +60 (a)	D# +00, F# +60 (d)	360
B +00, D +80 (a)	C# +00, E +80 (d)	D# +00, F# +80 (a)	380
B +00, D# +00 (d)	C# +00, F +00 (a)	D# +00, G +00 (d)	400
B +00, D# +20 (a)	C# +00, F +20 (d)	D# +00, G +20 (a)	420
B +00, D# +40 (d)	C# +00, F +40 (a)	D# +00, G +40 (d)	440
B +00, D# +60 (a)	C# +00, F +60 (d)	D# +00, G +60 (a)	460
B +00, D# +80 (d)	C# +00, F +80 (a)	D# +00, G +80 (d)	480
<u>B +00, E +00 (a)</u>	<u>C# +00, F# +00 (d)</u>	<u>D# +00, G# +00 (a)</u>	<u>500</u>
B +20, D +00 (a)	C# +20, E +00 (d)	D# +20, F# +00 (a)	280
B +20, D +20 (d)	C# +20, E +20 (a)	D# +20, F# +20 (d)	300
B +20, D +40 (a)	C# +20, E +40 (d)	D# +20, F# +40 (a)	320
B +20, D +60 (d)	C# +20, E +60 (a)	D# +20, F# +60 (d)	340
B +20, D +80 (a)	C# +20, E +80 (d)	D# +20, F# +80 (a)	360
B +20, D# +00 (d)	C# +20, F +00 (a)	D# +20, G +00 (d)	380
B +20, D# +20 (a)	C# +20, F +20 (d)	D# +20, G +20 (a)	400
B +20, D# +40 (d)	C# +20, F +40 (a)	D# +20, G +40 (d)	420
B +20, D# +60 (a)	C# +20, F +60 (d)	D# +20, G +60 (a)	440
B +20, D# +80 (d)	C# +20, F +80 (a)	D# +20, G +80 (d)	460
<u>B +20, E +00 (a)</u>	<u>C# +20, F# +00 (d)</u>	<u>D# +20, G# +00 (a)</u>	<u>480</u>
B +40, D +00 (a)	C# +40, E +00 (d)	D# +40, F# +00 (a)	260
B +40, D +20 (d)	C# +40, E +20 (a)	D# +40, F# +20 (d)	280
B +40, D +40 (a)	C# +40, E +40 (d)	D# +40, F# +40 (a)	300
B +40, D +60 (d)	C# +40, E +60 (a)	D# +40, F# +60 (d)	320
B +40, D +80 (a)	C# +40, E +80 (d)	D# +40, F# +80 (a)	340
B +40, D# +00 (d)	C# +40, F +00 (a)	D# +40, G +00 (d)	360
B +40, D# +20 (a)	C# +40, F +20 (d)	D# +40, G +20 (a)	380
B +40, D# +40 (d)	C# +40, F +40 (a)	D# +40, G +40 (d)	400
B +40, D# +60 (a)	C# +40, F +60 (d)	D# +40, G +60 (a)	420
B +40, D# +80 (d)	C# +40, F +80 (a)	D# +40, G +80 (d)	440
B +40, E +00 (a)	C# +40, F# +00 (d)	D# +40, G# +00 (a)	460

test combined with subjects' observations indicated that an intra-stimulus interval of 2 seconds should be sufficient for subjects to name the notes in the interval, without forcing them to use this strategy.

Each stimulus in Test 4 consisted of two 500-ms puretones separated by a 2-s silent period. The length of time between successive stimuli varied between 8.5 and 9 seconds. Each stimulus was followed by (a) a 3-s silent period; (b) a "descending pitch eraser", the starting point of which was randomly chosen from the first 175 blocks of "descending pitch eraser" and the length of which was randomly varied between 1 and 1.5 seconds; and (c) a 1.5-s silent period. Every fifth stimulus was followed by (a) a 3-s silent period; (b) an "ascending pitch eraser" the starting point of which was randomly chosen from the first 130 blocks of "ascending pitch eraser" and the length of which was randomly varied between 3.8, 4.1, and 4.4 seconds; (c) a 1.5-s silent period; (d) a 3-s silent period; (e) a "descending pitch eraser", the starting point of which was randomly chosen from the first 175 blocks of "descending pitch eraser" and the length of which was randomly varied between 1 and 1.5 seconds; and (f) a 1.5-s silent period.

4.3 Subjects

Unpaid volunteer subjects were recruited from among friends and acquaintances of the experimenter, and from the Departments of Music of both the University of British Columbia and Douglas College. A group of ten adults who believed they had absolute

pitch (S1 to S10) and a group of five adults who believed they did not have absolute pitch (S11 to S15) participated in the experiment. All subjects answered a questionnaire, a sample of which is found in Appendix A.

Six females and four males made up the first group. Piano was the first instrument played by all the subjects in this group. Nine subjects began playing the piano between the ages of three and five, and one subject (S2) began playing the piano at age seven. Five of the subjects (S1, S3, S4, S5, and S8) reported first learning to play the piano by ear, three (S2, S7, and S10) reported both playing by ear and reading written music when first learning the piano, and the remaining two subjects (S6 and S9) reported first learning to play the piano by reading written music. Two subjects (S2 and S4) had studied no instrument other than the piano, and the other eight subjects had studied one to four other instruments. Piano was still the major instrument for five of the subjects (S2, S3, S4, S9, and S10). Two subjects stated that their major instrument was now voice (S1 and S8); one reported the trumpet as his major instrument (S5); one reported the synthesizer keyboard as his major instrument (S6); and one subject (S7) reported his major instruments as the organ and voice.

Subjects in the absolute pitch group were asked how they discovered their abilities at pitch naming. Most reported that they had been surprised at some point to find out that not everyone could name pitches as they could. Three subjects (S2, S4, and S8) reported being able to hear a piano piece and subsequently play the piece by ear in the correct key. Two

subjects (S2 and S6) reported playing games with family members in which they named notes after they were played, without looking at the keyboard. One subject (S6) discovered he had absolute pitch after he was accused of cheating on a music test. One subject (S1) reported noticing that she could find the A to tune her violin within her head, while other violinists needed to hear a note played. One subject (S7) stated that he knew what pitch to start on in a choir, before the pitch had been played. One subject (S9) reported noticing if a choir was singing sharp or flat, and one subject (S5) reported noticing differences in the sounds of different keys.

Subjects generally found it difficult to describe what they thought happened when they named pitches. Four subjects (S1, S3, S4, and S6) reported that it was seemingly automatic and that the name for the note seemed to pop into their heads without them having to think at all. One subject (S2) reported that she visualized playing a piano keyboard. Two subjects (S5 and S7) stated that some notes came automatically to them and they used relative pitch to relate other notes to the ones that came automatically. One subject (S9) reported finding a "muscular memory" in her throat to which to relate the pitches. Two subjects reported that naming pitches was usually automatic but when the pitches were not in tune, they each had a different strategy: one (S8) imagined the sound of an A and then related the pitch in question to the A; and the other (S10) pictured a piano keyboard to find the closest note to the pitch he heard.

Subjects also found it difficult to describe the way in which they named intervals. Three subjects (S1, S4, and S10)

reported naming the two notes and then calculating the interval between them. Three subjects (S2, S8, and S9) stated that they did not name the notes, but listened to the pitch difference between the two notes. Three subjects (S3, S5, and S7) reported that they used a combination of the aforementioned strategies, and one subject (S6) reported that he first thought of a chord that the two notes would be found in, named the two pitches, and finally calculated the interval separating the two notes.

Three females and two males made up the group of subjects who believed they did not have absolute pitch. Piano was the first instrument played by four subjects, who all reported starting to play at an age of four to five years. Flute was the first instrument played by the remaining subject (S14); she began learning to play the flute at age eight. One subject (S12) reported that she first learned to play by ear, two subjects (S11 and S13) stated that they played both by ear and from music when first learning, and the remaining two subjects (S14 and S15) reported beginning by learning from written music.

Subjects in this group had all studied from two to six other instruments. One subject (S11) reported that his main instrument was the piano; one subject's main instrument was the harpsichord (S12); one subject's main instrument was the guitar (S13); one subject's main instrument was voice (S14); and one subject's main instruments were the piano and voice (S15).

Subjects in this group also had difficulty describing their strategies for naming intervals. All subjects reported naming intervals by deciding the size of the interval between the two

notes; none reported attempting to name the notes first and then infer the interval. One subject (S11) reported usually naming intervals automatically, but if he was in doubt, confirming his judgement of the interval with a set of "tonal associations" (for example, a perfect fourth sounded like "dominant to tonic"). One subject (S12) reported using solfeggio to name intervals. One subject (S13) reported using mnemonics in the form of familiar tunes that contained known intervals, and matching the interval to the song. One subject (S14) reported checking intervals melodically both ascending and descending, to verify her naming of an interval. One subject (S15) reported arbitrarily choosing the name of the first note of the interval, and then automatically visualizing the two notes on the keyboard.

None of the subjects reported any known or suspected hearing problems.

4.4 Test Procedure

The subjects were seated, one at a time, in a sound treated room with the experimenter. The test tapes were played on a Nagra IV-D full-track reel-to-reel tape recorder and presented over Beyer Dynamic DT-48 headphones at a level of 60 to 65 dB SPL, as measured on a Bruel and Kjaer 6 cm³ 4152 artificial ear. A comfortable level was determined first as the test tape was played over TDH-49 Maico headphones, and found to be between 58 and 63 dB. A subjectively equal intensity was then determined for the Beyer headphones. This level was measured through the Beyer headphones using an adaptor custom-made to allow the

headphones to fit over the artificial ear. The resulting measurement was higher by approximately 2 dB. The 60 and 65 dB marks were noted on the volume control of the Nagra tape recorder and the volume was set between these two marks for the test sessions.

Subjects were instructed verbally, from a written set of instructions, to listen to each note/interval and to mark the correct or closest note/interval on the answer sheet (see Appendix B for complete instructions, and Appendix C for sample answer sheets for each of the tests). Answer sheets for Tests 1, 3, and 4 were similar. For each item on the test, a range of answer choices was printed on the answer sheet, and subjects were asked to circle or underline the choice they thought best fit the note or interval that was presented. The answer sheet for Test 2 consisted of item numbers with blank spaces adjacent to them. Subjects were asked to write the name of the note that best fit the note that was presented. Subjects were requested to mark an answer for each item on every test, even if they found it difficult to decide on an answer.

The total test time for the four tests was approximately one and a half hours. Subjects could choose either to do all four tests in one session, or to do the first two tests at one session and the last two tests at another session.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Data Sorting

Raw data were entered into a computer, organized in a visually logical display, printed, and analyzed. The display for the data of each test is described in the sections following.

5.2 Test 1

As stated in section 4.21, the purpose of this test was to determine each subject's ability at naming standard sequential musical intervals. Subjects were asked to name 120 sequential musical intervals corresponding to the categories minor third, major third, perfect fourth, tritone, perfect fifth, and minor sixth, using the standard musical interval names. The six categories were defined relative to the standard equal-tempered scale.

The data of each subject were rearranged so that responses for each interval category were grouped together. For each interval category, the data were divided into two columns, one for ascending, the other for descending intervals. Each of these columns was further subdivided into two columns, one for each block of stimuli. Examination of the data did not reveal that either manner of presentation (ascending or descending) or

position in the presentation order had any noticeable effect on subjects' responses. Scores on Test 1 for the ten subjects with absolute pitch ranged from 80 to 100% correct, with a median of 96%. Scores for the five subjects without absolute pitch group ranged from 83 to 100% correct, also with a median of 96%. Seven of the absolute pitch subjects (S1, S2, S3, S7, S8, S9, and S10), and four of the non-absolute pitch subjects (S11, S12, S14, and S15) had scores of over 90% correct on Test 1. These scores are shown in Table VII below.

5.3 Test 2

As stated in section 4.22, the purpose of this test was to determine each subject's ability at naming single puretones. Subjects were asked to name 60 single puretones corresponding to notes of the equal-tempered scale, using standard musical note names.

The data were reordered so that the five responses to each note were displayed adjacent to each other in rows. Each response was compared to the correct response for that stimulus, and the distance between them in semitones was calculated. The results of Test 3 (to be described in the next section) indicated that the internal pitch reference of most subjects was not centred exactly on one note, but located between two notes of the equal-tempered scale; it ranged (S to S) from 40 cents below to 20 cents above the standard equal-tempered tuning. Because of

this variability, it was felt that a response to a given stimulus should be regarded as correct if it was within one semitone (up or down) from the expected response. Since individual pitch references could be either above or below the standard pitch reference, it was necessary to determine for each subject whether the semitone above or the semitone below the expected response would be regarded as correct. The number of responses which were one semitone above the expected response were counted, as were the number of responses which were one semitone below the expected response. The larger of these two sums was added to the unadjusted score, resulting in an adjusted score revealing the percentage of items correct $\pm 1/2$ semitone. One subject (S6) had an internal pitch reference which was one whole semitone below the standard: the majority of his responses on Test 2 were one semitone above the correct response, and Test 3 results confirmed this internal pitch reference. Therefore, for this subject, expected responses were one semitone below the standard equal-tempered tuning.

For the absolute pitch group, % correct $\pm 1/2$ semitone ranged from 62 to 100% with a median of 90%. Five subjects in this group (S1, S6, S8, S9, and S10) surpassed the 90% mark. One subject who believed she had absolute pitch (S2) was unable to accurately name the puretones in Test 2, achieving only 62%. She reported that she felt the lack of harmonics in the stimuli hindered her naming of the notes. She was the only subject in the absolute pitch group to score below 85% on Test 2. For the group without absolute pitch, scores on Test 2 ranged from 23 to 60% with a median of 32%. Thus, there were two quite distinct

distributions of scores, one for each group of subjects. In all but one case (S2), the results confirmed the subjects' own judgements of their absolute pitch abilities. Scores for Test 2 are shown in Table VII below.

5.4 Test 3

The purpose of this test was to determine how, and with which accuracy and consistency, subjects in the absolute pitch group could name puretones in 20-cent frequency increments using the twelve standard note name categories of the equal-tempered scale, and also to determine each subject's internal pitch reference. Subjects were asked to name the notes corresponding to 5 blocks of 43 puretones. There were only twelve possible responses to the 43 different stimulus types, forcing subjects to use the names of the closest standard notes.

Responses were converted to numbers from 1 to 12, corresponding to the notes from A to G#, and then rearranged so that the five responses for each stimulus type were displayed adjacent to each other. For each subject, the mean of the five responses for each stimulus type was calculated, and these means were plotted on a graph, an example of which is seen in Figure 1.

For each subject, the standard deviation from the mean for each stimulus type and the mean of these standard deviations were calculated. The mean of the standard deviations ranged from 0.15 to 0.78 semitones, with a median of .41 semitones. A subset of Test 3 data for S1 with a mean standard deviation of less than

Figure 1

Test 3 data, S1

0.5 semitones is shown below, in Table VI. SD's for all subjects are shown in Table VII.

TABLE VI

Example Test 3 data (S1), showing standard deviations and mean of standard deviations.

Stimulus type	1	2	Token 3	4	5	Mean	SD	Mean of SD's
E+60	9	9	9	9	9	9.0	0.0	
E+80	9	9	9	9	9	9.0	0.0	
F+ 0	9	8	9	9	9	8.8	0.4	
F+20	9	9	9	9	10	9.2	0.4	
F+40	9	9	10	9	11	9.6	0.9	

0.34

Using a best-fit program, a straight line $y = mx + h$ was fitted through the data points of each subject; another straight line was calculated for the predicted data. The ordinates of the subject's data regression line were compared with those of the predicted line at three points along the line, each corresponding to the centre of one of the three sets of intervals to be used in Test 4. The difference between the ordinates of the predicted data and the subject's data was taken to be equal to the number of cents by which the internal pitch reference of the subject differed from 0 at each one of these three points. It was assumed that the internal pitch reference of the subject at each of the three points was representative of the subject's internal pitch reference across that whole set of intervals in Test 4.

Much individual variation was observed in internal pitch references. Six subjects (S2, S3, S4, S8, S9, and S10) had

internal pitch reference shifts which were consistent over the whole range of stimuli. These reference shifts ranged from - 40 cents to 0 cents. The remaining four subjects had internal pitch reference shifts which varied, over the 9.5 semitone range of Test 3, by as much as 40 cents. Results for all subjects on Tests 1, 2 and 3 are shown in Table VII.

5.5 Test 4

Test 4 was the main test of this study. Its purpose, as stated in Section 4.24, was to determine how subjects would categorize sequential musical intervals whose component tones were not always consistent with equal-tempered tuning, and to determine which of two possible strategies these subjects would use. Subjects were asked to name 165 sequential musical intervals which ranged in 20-cent steps from 260 cents to 540 cents.

Responses were converted to numbers from 2 to 6, corresponding to the intervals major second (2), minor third (3), major third (4), perfect fourth (5), and tritone (6). The data were rearranged into three matrices according to the lower note of each stimulus (B, C#, and D#). There was one data matrix for the set of intervals with bottom note from 40 cents below to 40 cents above B, one for the set of intervals with bottom note from 40 cents below to 40 cents above C#, and one for the set of intervals with bottom note from 40 cents below to 40 cents above D#.

TABLE VII

Scores for all subjects on Test 1, Test 2, and Test 3.

Subject	Test 1 % correct	Test 2 % correct +/- 1/2 semit	SD	Test 3 Reference in cents		
				B	C#	D#
(a) Absolute pitch group						
1	92	93	.49	0	-20	-20
2	93	62	.78	-20	-20	-20
3	89	87	.36	0	0	0
4	100	88	.46	-40	-40	-40
5	84	85	.46	-40	-20	-20
6	80	92	.31	-20	0	+20
7	99	88	.29	0	-20	-20
8	99	93	.25	-40	-40	-40
9	100	93	.67	-20	-20	-20
10(1)	100	100	.15	0	0	0
10(11)	-	-	.18	+20	+20	+20

(b) Non-absolute pitch group

11	100	37	-	-	-	-
12	93	60	-	-	-	-
13	83	23	-	-	-	-
14	96	30	-	-	-	-
15	100	32	-	-	-	-

Each of the subject's data matrices was compared to two matrices which would each be predicted by a particular strategy: (a) a matrix representing the "relative pitch (RP) strategy", in which the difference between the two tones in semitones and cents would be determined, and then rounded off to the closest interval, and (b) a matrix representing the "absolute pitch (AP) strategy", in which the two tones would each be first rounded off to the closest semitone, and then the difference between the two notes would be calculated. For the AP strategy, five prediction matrices were made, corresponding to five internal pitch references: - 40 cents, - 20 cents, 0 cents, + 20 cents, and + 40 cents. The RP strategy matrix and the five AP strategy matrices are displayed in Table VIII. For each data matrix of each subject, only two prediction matrices were used in the comparison, the RP strategy matrix and one of the five AP strategy matrices, namely the one which corresponded most closely with the subject's internal pitch reference for that data matrix as determined in Test 3.

Using the AP strategy, because the two notes are first rounded off to the closest note and then the difference between them calculated, rounding errors can be compounded, causing the incorrect identification of some intervals. For example, if a subject with absolute pitch was presented with the interval C + 60 cents to E + 20 cents (360 cents), one would expect that, using the AP strategy, this subject would, because of a strong tendency to name the notes first, identify the notes as C# and E, and then identify the interval between those notes as a minor third (300 cents). Using the RP strategy, the actual pitch

TABLE VIII

Prediction matrices for Test 4. Marked cells are outlined. Bottom note (BN) is from 40 cents below to 40 cents above the note B, C#, or D#. Top note (TN) is in cents from bottom note 0.

1. AP strategy with - 40 cent reference

BN	TN	300	320	340	360	380	400	420	440	460	480	500
-40		3	4	4	4	4	4	5	5	5	5	5
-20		3	4	4	4	4	4	5	5	5	5	5
0		3	4	4	4	4	4	5	5	5	5	5
+20		2	3	3	3	3	3	4	4	4	4	4
+40		2	3	3	3	3	3	4	4	4	4	4

2. AP strategy with -20 cent reference

BN	TN	300	320	340	360	380	400	420	440	460	480	500
-40		3	3	4	4	4	4	4	5	5	5	5
-20		3	3	4	4	4	4	4	5	5	5	5
0		3	3	4	4	4	4	4	5	5	5	5
+20		3	3	4	4	4	4	4	5	5	5	5
+40		2	2	3	3	3	3	3	4	4	4	4

3. AP strategy with 0 cent reference

BN	TN	300	320	340	360	380	400	420	440	460	480	500
-40		3	3	3	4	4	4	4	4	5	5	5
-20		3	3	3	4	4	4	4	4	5	5	5
0		3	3	3	4	4	4	4	4	5	5	5
+20		3	3	3	4	4	4	4	4	5	5	5
+40		3	3	3	4	4	4	4	4	5	5	5

4. AP strategy with + 20 cent reference

BN	TN	300	320	340	360	380	400	420	440	460	480	500
-40		4	4	4	4	5	5	5	5	5	6	6
-20		3	3	3	3	4	4	4	4	4	5	5
0		3	3	3	3	4	4	4	4	4	5	5
+20		3	3	3	3	4	4	4	4	4	5	5
+40		3	3	3	3	4	4	4	4	4	5	5

5. AP strategy with + 40 cent reference

BN	TN	300	320	340	360	380	400	420	440	460	480	500
-40		4	4	4	4	4	5	5	5	5	5	6
-20		4	4	4	4	4	5	5	5	5	5	6
0		3	3	3	3	3	4	4	4	4	4	5
+20		3	3	3	3	3	4	4	4	4	4	5
+40		3	3	3	3	3	4	4	4	4	4	5

6. RP strategy

BN	TN	300	320	340	360	380	400	420	440	460	480	500
-40		3	4	4	4	4	4	5	5	5	5	5
-20		3	3	4	4	4	4	4	5	5	5	5
0		3	3	3	4	4	4	4	4	5	5	5
+20		3	3	3	3	4	4	4	4	4	5	5
+40		3	3	3	3	3	4	4	4	4	4	5

difference of 360 cents would be rounded off to the closest interval, a major third (400 cents).

Two measures were devised to show how close subjects' data matrices were to each of the prediction matrices. Each AP strategy prediction matrix differs from the RP strategy matrix only on a certain number of entries (12 to 14). These are outlined in Table VIII and referred to as 'marked cells' or 'marked entries'. The cells that differ between any AP strategy prediction matrix and the RP strategy prediction matrix always correspond to one of the following two groups: (a) one group of intervals which, in terms of actual pitch difference using the RP strategy were 40 cents away from a standard interval category, but would be identified as the neighbour interval 60 cents away with the AP strategy (called NI60 intervals); and (b) another group of intervals which, in terms of actual pitch difference using the RP strategy were 20 cents away from a standard interval category, but would be identified as the neighbour interval 80 cents away with the AP strategy (called NI80 intervals).

The first measure, D1, gives NI80 intervals a weight of 25, NI60 intervals a weight of 5, and unmarked entries a weight of 1. It identifies for each data matrix, those entries which are different from the corresponding entry in the prediction matrix (RP or AP), and computes the sum of the weights corresponding to these entries, thus yielding one distance to the RP prediction and one distance to the AP prediction. Each one of these numbers is taken to be the "preliminary distance" to the said prediction. In order to subtract out the effects of random error, the maximum sum of the preliminary distance to the RP strategy and of the

preliminary distance to the AP strategy without random error (MSWRE) is determined. This is done by adding together the weights of all the marked entries. For example, the maximum sum of the preliminary distance to the RP strategy plus the preliminary distance to the AP strategy for a pitch reference shift of -40 cents is $(5 \times 25) + (9 \times 5) = 170$. There are 5 NI80 intervals each with a weight of 25, and 9 NI60 intervals each with a weight of 5. Without random error, these are the only entries which should differ between the two prediction matrices, and each entry should differ on only one of the two prediction matrices. It can be assumed that the number by which the sum of the two distances of each data matrix exceeds the MSWRE is the rate of random error. One half of this random error rate is subtracted from each of the "preliminary distances" for the given data matrix. The two resulting numbers are taken to be the "distances" to the prediction matrices.

The second measure, D2, uses no weights. It computes the error rate on the unmarked entries and assumes the error rate to be similar for the marked entries. The "distance" computed in this case is the sum of marked entries differing from the marked entries in the prediction matrix (RP or AP), decreased by the product of the error rate by the number of marked entries.

D1 and D2 distances were normalized by dividing the total of the two distances for each data matrix by the sum of the two distances, resulting in scores from 0 to 100. Table IX reports normalized scores using measures D1 and D2. It is evident that scores on the two measures are quite well correlated. All but three of the 64 data matrices have distances which are closer to

TABLE IX

Test 4 results, showing normalized distances D1 and D2 to RP and AP strategies.

Subject	Matrix	Offset	D1		D2	
			To RP	To AP	To RP	To AP
(a) Absolute pitch group						
1	B	0	28.57	71.43	26.47	73.53
	C#	-20	30.36	69.64	34.54	65.46
	D#	-20	23.21	76.79	55.72	44.28
2	B	-20	5.36	94.64	5.71	94.29
	C#	-20	8.93	91.07	18.47	81.53
	D#	-20	1.79	98.21	0.45	99.55
3	B	0	35.71	64.29	50.00	50.00
	C#	0	25.71	74.29	44.74	55.26
	D#	0	32.14	67.86	36.11	63.89
4	B	-40	0.00	100.00	11.69	88.31
	C#	-40	-7.14	107.14	-2.36	102.36
	D#	-40	-3.57	103.57	6.37	93.63
5	B	-40	37.50	62.50	24.32	75.68
	C#	-20	42.86	57.14	50.00	50.00
	D#	-20	16.07	83.93	-3.85	103.85
6	B	-20	23.21	76.79	15.55	84.45
	C#	0	32.14	67.86	39.82	60.18
	D#	+20	43.93	56.07	24.00	76.00
7	B	0	53.57	46.43	60.18	39.82
	C#	-20	17.86	82.14	24.23	75.77
	D#	-20	12.50	87.50	27.48	72.52
8	B	-40	17.86	82.14	21.26	78.74
	C#	-40	0.00	100.00	9.68	90.32
	D#	-40	3.57	96.43	22.58	77.42
9	B	-20	48.21	51.79	45.50	54.50
	C#	-20	30.36	69.64	35.24	64.76
	D#	-20	37.50	62.50	54.70	45.30
10(i)	B	0	92.86	7.14	94.74	5.26
	C#	0	7.14	92.86	-2.36	102.36
	D#	0	57.14	42.86	71.32	28.68
10(ii)	B	+20	1.79	98.21	-24.32	124.32
	C#	+20	63.57	36.43	78.95	21.05
	D#	+20	11.79	88.21	20.51	79.49

TABLE IX (continued)

Subject	Matrix	Offset	D1		D2	
			To RP	To AP	To RP	To AP
(b) Non-absolute pitch group						
11	B	(0)	25.00	75.00	16.44	83.56
	C#	(0)	32.14	67.86	39.82	60.18
	D#	(0)	14.29	85.71	27.63	72.37
12	B	(0)	28.57	71.43	31.31	68.69
	C#	(0)	7.14	92.86	9.27	90.73
	D#	(0)	25.00	75.00	16.44	83.56
13	B	(0)	48.21	51.79	63.86	36.14
	C#	(0)	30.36	69.64	37.18	62.82
	D#	(0)	8.93	91.07	18.92	81.08
14	B	(0)	21.43	78.57	50.00	50.00
	C#	(0)	25.00	75.00	19.45	80.55
	D#	(0)	7.14	92.86	16.67	83.33
15	B	(0)	35.71	64.29	50.00	50.00
	C#	(0)	10.71	89.29	19.45	80.55
	D#	(0)	14.29	85.71	31.31	68.69

the same prediction matrix, whether using D1 or D2. Table X gives examples of scores for entries in a hypothetical data matrix which gradually change from being exactly in accordance with one strategy to being exactly in accordance with the other strategy, without random errors. Based on Table X, it was decided that distances would be classified in the following manner: data matrices on which either distance D1 or D2 was below 10.00 would be called "very close" to a given strategy; data matrices on which either distance D1 or D2 was between 10.00 and 33.33 would be called "close" to a given strategy; and data matrices on which either distance D1 or D2 was between 33.33 and 50.00 would be called "mixed" between both strategies.

If a subject used the RP strategy, his/her distances to RP should be low and his/her distances to AP should be high. If a subject used the AP strategy, these trends should be reversed. It was the hope of the experimenter that subjects would clearly use one or the other strategy, across all three matrices. For five subjects in the absolute pitch group (S1, S2, S4, S6, and S8) and three subjects in the non-absolute pitch group (S11, S12, and S14) all three data matrices corresponded closely or very closely with the RP strategy. For four subjects in the absolute pitch group (S3, S5, S7, and S9) and two subjects in the non-absolute pitch group (S13 and S15) at least one data matrix corresponded closely or very closely with the RP strategy, and at least one data matrix corresponded to a mix of both strategies.

No correlations with scores on other tests could be found to differentiate these two groups of results. Individual variation in the perception of musical intervals, discussed in Chapter 2,

TABLE X

Examples of distances to RP and AP in relation to the number of entries differing from each prediction matrix.

Strategy used	D1		D2	
	To RP	To AP	To RP	To AP
All RP	0.00	100.00	0.00	100.00
1 NI60 to AP	3.57	95.71	8.33	91.67
1 NI60, 1 NI80 to AP	21.43	78.57	16.67	83.33
2 NI60, 1 NI80 to AP	25.00	75.00	25.00	75.00
2 NI60, 2 NI80 to AP	42.86	57.14	33.33	66.67
3 NI60, 2 NI80 to AP	46.43	53.57	41.67	58.33
4 NI60, 2 NI80 to AP	50.00	50.00	50.00	50.00
5 NI60, 2 NI80 to AP	53.57	46.43	58.33	41.67
6 NI60, 2 NI80 to AP	57.14	42.86	33.33	66.67
6 NI60, 3 NI80 to AP	75.00	25.00	75.00	25.00
7 NI60, 3 NI80 to AP	78.57	21.43	83.33	16.67
7 NI60, 4 NI80 to AP	95.71	3.57	91.67	8.33
8 NI60M 4 NI80 to AP	100.00	0.00	100.00	0.00

may have caused the results to correspond more or less closely with the RP strategy.

Only one subject, S10(1), who had shown the strongest absolute pitch ability in the first three tests, had results that corresponded with the AP strategy; however, this correspondence was not constant over all three data matrices. His results had a very close correspondence with the AP strategy on the "B" stimulus set, a very close correspondence with the RP strategy on the "C#" stimulus set, and a close correspondence with the AP strategy on the "D#" stimulus set. These results are puzzling, as the responses seem to indicate that one strategy was used for one set of intervals, and the opposite strategy was used for another set of intervals, although these intervals were randomly interleaved in the test.

A third prediction matrix for the data of S10 was made, based on his responses to the single note stimuli of Test 3. The three data matrices were each compared to the RP matrix and to the above prediction matrix, in the same manner as they had been compared in the D2 measure. Results of this comparison only confirmed the earlier results.

In order to attempt to clarify his strategy for identifying intervals, S10 was asked to repeat Tests 3 and 4, approximately one month after his first test session. New results for Test 3 indicated the same high degree of accuracy and consistency of note naming as on the first test session. The subject's internal pitch reference shift was now closer to + 20 cents, as opposed to 0 cents on the first test session, but was again consistent over

the entire range of stimuli. Table IX (S10(ii)) shows his results in Test 4 for the second test session. The distances D1 and D2 show patterns which are the reverse of those of the first session: on the B and D# matrix, responses correspond very closely and closely to the RP strategy, and on the C# matrix, responses correspond closely to the AP strategy. Figure 2 shows the distances D2 for three subjects: S8, whose data matrices corresponded closely to the RP strategy; S3, whose data matrices corresponded to a mixture of RP and AP strategies; and S10 (i) and (ii), whose data matrices have been described above.

S10's absolute pitch ability appeared to be the strongest among the absolute pitch subjects in the study, and thus he might be expected to be the most inclined to use the AP strategy; however, examination of the results from all tests could not give an explanation for the changing of strategy from one set of intervals to the other. SD's for both Test 3 sessions were examined for each note, in each set of intervals. S10's use of different strategies does not appear to correlate with certainty or uncertainty of note naming, since variability was very low across all the notes on both test sessions. Random errors for both Test 4 sessions were examined. These remained approximately the same across all matrices and across both test sessions. It appears that S10 was using both strategies, but it is unclear why he seems to have changed his strategy depending on which pitches were used in the stimuli, and also puzzling that the strategies used should have reversed between test sessions.

Figure 2
Distances D2 to RP and AP

5.6 Summary

The present study examined the perception of musical intervals by musicians with and without absolute pitch. Previous research into the perception of music has established two points: (a) musicians without absolute pitch perceive musical intervals categorically, that is, all musical intervals in small increments over a certain range are consistently identified as the same interval (Burns and Ward, 1978); (b) musicians with absolute pitch perceive pitches categorically, that is, all notes in small increments over a certain range are consistently identified as the same pitch (Siegel and Siegel, 1977a). In order for these two points to be true the intervals, respectively pitches, being identified must be effectively rounded off to the closest standard interval/note. In the perception of intervals, musicians with absolute pitch presumably use either of the aforementioned modes of categorical perception: (a) the RP strategy, directly evaluating the interval, and rounding it off to the closest standard interval; or (b) the AP strategy, first rounding off the two notes to the closest standard notes and then inferring the musical interval between them.

Most subjects in the present study appear to evaluate musical intervals directly using the RP strategy. One subject appears to use the AP strategy in the context of specific pitches, and the RP strategy in the context of other pitches. His use of a specific strategy for specific pitches does not remain constant over different test sessions. No reasonable explanation can be found for this behaviour.

Since the use of the AP strategy in interval identification would result in no better identification of intervals than the RP strategy, and in fact would result in incorrect identification of intervals in some cases, it would be to the advantage of a possessor of absolute pitch to suppress the identification of notes and to directly evaluate intervals. It would appear that those subjects with the most consistent absolute pitch would be more likely to use the AP strategy, as they would have the most confidence in their absolute pitch abilities. It would also seem that subjects who had not played tunable instruments would be more likely to use the AP strategy than subjects who had played tunable instruments, because they may have had less experience using relative pitch. For example, in order to play a well-tuned musical interval on the piano, the player has only to find the location of the two notes and play them. Since a professional piano tuner tunes the piano, usually according to the equal-tempered scale, the pianist does not have to concern himself with the tuning of each note. On the other hand, when playing a musical interval on the violin, after determining the general location of the notes the player must listen closely to the two notes to create an "in-tune" interval, be it in the equal-tempered, just, or another tuning system. When playing with other instruments, the violinist must listen to the relative pitch between the notes he plays and those played by the other instrumentalist, to create "in-tune" intervals.

For a future study, it might be wise to do a preliminary test to discover each subject's pitch reference shift, and then create and present only the intervals that would be identified differently depending on the strategy used. With the equipment used in the present study this would be very time-consuming, as it would be necessary to make individual audio tapes for each different pitch reference shift. However, with the use of a computer and of programmable sound-generating hardware, with which the stimuli could be presented to the subject directly from the computer terminal and possibly modified as a function of the previous response(s), this could be very manageable. One could present each interval a greater number of times in each testing session without fatiguing the subject, as intervals which would be identified the same way regardless of strategy would not have to be presented, rather, only those intervals which would yield information regarding strategy would be presented. In this way, more precise knowledge might be gained about the strategies used in the identification of musical intervals by possessors of absolute pitch.

More research is needed for stronger conclusions to be drawn; however, it appears that most musicians with or without absolute pitch use their relative pitch ability to identify musical intervals. It remains to be seen whether any musicians with absolute pitch consistently use their absolute pitch in the identification of musical intervals.

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APPENDIX A

Questionnaire

Identities of all subjects will remain confidential.

1. Name: _____ Subject # _____
2. Phone: _____ Date: _____
3. Age: _____ Address: _____
4. Sex: _____
5. What was the first instrument you played? _____
6. At what age did you start playing this instrument? _____
7. Did you begin by playing written music or playing by ear? _____
8. What other instruments have you studied? _____
9. What is your major instrument now? _____
10. Do you believe you have absolute pitch? _____
If yes, please answer a and b below:
 - a. How did you realize you had absolute pitch? _____

 - b. Please try to describe what happens when you hear a note and name it: _____

11. Please try to describe how you name intervals: _____

12. Do you have any hearing problems? _____
If yes, please describe: _____

APPENDIX B

Instructions to Subjects

I'm looking at how people with absolute pitch and people without absolute pitch perceive single notes and melodic intervals. You will hear single notes and intervals made of pure tones. Each note or interval will be played once, and you will have 3 or 4 seconds between items to decide on your answer.

There will be 4 tests which take about 1 hour and 30 minutes in all. You may take a break after each test if you wish. If for any reason you feel you must stop during the test, please say "Stop", and I will stop the tape. However, items will not be repeated.

Before we start, I'd like to ask you some questions and have you read and sign this consent form. The only risk involved in this experiment is of possible boredom.

Test 1 Instructions

In this test, you are going to hear a series of melodic intervals, both ascending and descending. Each interval will be played once, followed by a silent period. After every five intervals, you will hear a descending sound which corresponds with a space on your answer sheet. This descending sound is simply a marker to allow you to confirm your place on the test.

I want you to listen carefully to each interval and circle or underline the name of each interval on your answer sheet. Please give an answer for every item, even if you find it difficult to decide on an answer.

There are 127 items on this test. After the first five items, if you have any questions, just say "Stop" and I will stop the tape. If you wish, the first five items will be repeated, but remember, these are the only items that can be replayed.

Test 2 Instructions

You are now going to hear a series of single notes. Each note will be played once, followed by a silent period, a descending sound, and another silent period. After every five notes, you will hear an ascending sound which corresponds with a space on your answer sheet. The ascending sound is a marker to allow you to confirm your place on the test.

I would like you to write the name of each note in the space provided on your answer sheet. Please name every note, even if you find it difficult to decide on an answer. There are 66 items on this test.

Test 3 Instructions

You are now going to hear a series of single notes. You will hear a descending sound, a short silent period, then the one that I want you to name, and another silent period. After every five notes, you will hear an ascending tone to help you confirm your place on the test.

Circle or underline the name of each note on your answer sheet. Your answer sheet has all the names of the musical scale from A to G#. They are set out in alphabetical order - the order on the page has nothing to do with notes being higher or lower than each other. Please name every note, even if you find it difficult to decide on an answer. There are 220 items on this test.

Test 4 Instructions

You will now hear a series of melodic intervals, both ascending and descending. Each interval will be played once. You will hear a descending sound, a short silent period, then the melodic interval that I want you to name, and another silent period. After every five intervals you will hear an ascending tone to help you confirm your place on the test.

Circle or underline the name of each interval on your answer sheet. Please name every interval, even if you find it difficult to decide on an answer. There are 170 items on this test.

APPENDIX C

Sample Answer Sheets

T E S T 1			Subject# _____ Date _____			
1.	min3	Maj3	p4	TT	p5	min6
2.	min3	Maj3	p4	TT	p5	min6
3.	min3	Maj3	p4	TT	p5	min6
4.	min3	Maj3	p4	TT	p5	min6
5.	min3	Maj3	p4	TT	p5	min6
6.	min3	Maj3	p4	TT	p5	min6
7.	min3	Maj3	p4	TT	p5	min6
8.	min3	Maj3	p4	TT	p5	min6
9.	min3	Maj3	p4	TT	p5	min6
10.	min3	Maj3	p4	TT	p5	min6
11.	min3	Maj3	p4	TT	p5	min6
12.	min3	Maj3	p4	TT	p5	min6
13.	min3	Maj3	p4	TT	p5	min6
14.	min3	Maj3	p4	TT	p5	min6
15.	min3	Maj3	p4	TT	p5	min6
16.	min3	Maj3	p4	TT	p5	min6
17.	min3	Maj3	p4	TT	p5	min6
18.	min3	Maj3	p4	TT	p5	min6
19.	min3	Maj3	p4	TT	p5	min6
20.	min3	Maj3	p4	TT	p5	min6

T E S T 2

Subject# _____ Date _____

1. _____

21. _____

2. _____

22. _____

3. _____

23. _____

4. _____

24. _____

5. _____

25. _____

6. _____

26. _____

7. _____

27. _____

8. _____

28. _____

9. _____

29. _____

10. _____

30. _____

11. _____

31. _____

12. _____

32. _____

13. _____

33. _____

14. _____

34. _____

15. _____

35. _____

16. _____

36. _____

17. _____

37. _____

18. _____

38. _____

19. _____

39. _____

20. _____

40. _____

T E S T 3

Subject # _____ Date _____

1.

A	Bb A#	B	C	Db C#	D	Eb D#	E	F	Gb F#	G	Ab G#
---	----------	---	---	----------	---	----------	---	---	----------	---	----------

2.

A	Bb A#	B	C	Db C#	D	Eb D#	E	F	Gb F#	G	Ab G#
---	----------	---	---	----------	---	----------	---	---	----------	---	----------

3.

A	Bb A#	B	C	Db C#	D	Eb D#	E	F	Gb F#	G	Ab G#
---	----------	---	---	----------	---	----------	---	---	----------	---	----------

4.

A	Bb A#	B	C	Db C#	D	Eb D#	E	F	Gb F#	G	Ab G#
---	----------	---	---	----------	---	----------	---	---	----------	---	----------

5.

A	Bb A#	B	C	Db C#	D	Eb D#	E	F	Gb F#	G	Ab G#
---	----------	---	---	----------	---	----------	---	---	----------	---	----------

6.

A	Bb A#	B	C	Db C#	D	Eb D#	E	F	Gb F#	G	Ab G#
---	----------	---	---	----------	---	----------	---	---	----------	---	----------

7.

A	Bb A#	B	C	Db C#	D	Eb D#	E	F	Gb F#	G	Ab G#
---	----------	---	---	----------	---	----------	---	---	----------	---	----------

8.

A	Bb A#	B	C	Db C#	D	Eb D#	E	F	Gb F#	G	Ab G#
---	----------	---	---	----------	---	----------	---	---	----------	---	----------

9.

A	Bb A#	B	C	Db C#	D	Eb D#	E	F	Gb F#	G	Ab G#
---	----------	---	---	----------	---	----------	---	---	----------	---	----------

10.

A	Bb A#	B	C	Db C#	D	Eb D#	E	F	Gb F#	G	Ab G#
---	----------	---	---	----------	---	----------	---	---	----------	---	----------

11.

A	Bb A#	B	C	Db C#	D	Eb D#	E	F	Gb F#	G	Ab G#
---	----------	---	---	----------	---	----------	---	---	----------	---	----------

12.

A	Bb A#	B	C	Db C#	D	Eb D#	E	F	Gb F#	G	Ab G#
---	----------	---	---	----------	---	----------	---	---	----------	---	----------

T E S T 4

Subject # _____ Date _____

1.	Maj2	min3	Maj3	perf4	Tritone
2.	Maj2	min3	Maj3	perf4	Tritone
3.	Maj2	min3	Maj3	perf4	Tritone
4.	Maj2	min3	Maj3	perf4	Tritone
5.	Maj2	min3	Maj3	perf4	Tritone
6.	Maj2	min3	Maj3	perf4	Tritone
7.	Maj2	min3	Maj3	perf4	Tritone
8.	Maj2	min3	Maj3	perf4	Tritone
9.	Maj2	min3	Maj3	perf4	Tritone
10.	Maj2	min3	Maj3	perf4	Tritone
11.	Maj2	min3	Maj3	perf4	Tritone
12.	Maj2	min3	Maj3	perf4	Tritone
13.	Maj2	min3	Maj3	perf4	Tritone
14.	Maj2	min3	Maj3	perf4	Tritone
15.	Maj2	min3	Maj3	perf4	Tritone
16.	Maj2	min3	Maj3	perf4	Tritone
17.	Maj2	min3	Maj3	perf4	Tritone
18.	Maj2	min3	Maj3	perf4	Tritone
19.	Maj2	min3	Maj3	perf4	Tritone
20.	Maj2	min3	Maj3	perf4	Tritone