OCTAVE TUNING -- TWO MODES OF PERCEPTION

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ABSTRACT

Our experiments suggest that there may be at least two modes of perception of tuning of melodic octaves, connected with degree of "mistuning" and "sharp/flat" judgments, respectively. Our data imply that in musicians,"sharp/flat" judgments are more variable between subjects than "mistuning" judgments, are more register-dependent, and show more octave stretch. Though the pure 2:1 (1200 cent) octave was not especially favored on either measure, among our musicians the preferred degree of 'octave stretch' was very small (circa 2.5 cents) for judgments of degree of "mistuning"; it was much larger and more variable for "sharp/flat" judgments. This implies that pitch perception by highly trained musicians is not a matter of simply "placing" what is heard in a one-dimensional pitch or chroma/octave space, as is often assumed in music theory and psychology, but rather may be the integration of differently organized modes of perception. The presence of at least two, sometimes contradictory modes of tuning perception make it likely that full answers to questions of musical tuning will require study of more aspects of musical experience than are assumed by present psychoacoustic or exclusively 'cognitive' theories.

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After the unison, the octave is certainly the most fundamental musical interval. In not only Western but also in almost all musical cultures (Nettl, 1971), the octave functions as a musical equivalence relation. Of the octave Aristotle wrote, "both tones are saying the same thing." He pointed out that in choruses women sing an octave higher than men without seeming to sing a different pitch (Jeans,1968). Awareness of the octave can be documented back even further. Tuning directions found on a Babylonian clay tablet dating from 1800 B.C. (Kilmer et al., 1976), give a circle-of-fifths scale consisting of seven notes of a single octave, the octave (from Greek *okta*, meaning eight) being the eighth. However, recent experimenters (Allen, 1967; Deutsch, 1971: Thurlow and Erchul, 1977) have noted that perception of octave equivalence depends on musical context, and may not be easily demonstrated in musically untrained listeners.

The octave being the most elemental musical interval, questions of octave perception go to the roots of psychology and psychoacoustics. Since at least the time of Pythagoras, the octave was associated with the ratio 2:1. It was not, however, until the late sixteenth century (Drake,1970) that the 2:1 ratio was clearly identified as a ratio of vibration frequencies, and no longer confused with the 2:1 string-length ratios which generate octaves on stringed instruments.

Helmholtz (1863) realized that two complex harmonic tones an octave apart have all their overtones in common, and suggested that this could explain the experience of octave equivalence. As he pointed out, when we hear a melody repeated an octave higher, "we hear again part of what we heard before,... and at the same time we hear nothing that we had not previously heard." (Helmholtz, 1954, pp.253-54).

Is the subjective octave 2:1?

Stumpf and Meyer (1898) seem to have been the first to test whether indeed the perceived "in tune" octave corresponds to an exact 2:1 frequency ratio. They found, as have all more recent experimenters, that the subjectively "in tune" octave, or the 'subjective octave,' was apt to be "stretched" beyond the theoretic 2:1 (1200¢) ratio by a small, but musically significant amount (1-5%).

Most modern studies of octave perception have used a *method of adjustment*, in which a fixed lower tone alternates with a variable-pitched upper tone, which the subject attempts to adjust to a subjective "octave" above the lower tone. Using this measurement, Ward (1954) sought to explore the mapping of physical frequency to subjective pitch using tuning of octaves (2:1 frequency ratios) in contrast to Stevens and Volkman's (1937) ("sounds half as high") subjective-ratio method of pitch scaling.

Ward reported that the exact size of the set 'subjective octave' varied from observer to observer, from ear to ear, from frequency to frequency, and from day to day, consistent with the variability in diplacusis, (discrepancy in inter-aural unison pitch matching). In particular, between lower-note limits of 250 and 750 Hz, mean octave stretch rose irregularly from +10¢ to +40¢, though occasional dips below 0 ¢ are also evident in his results for individual ears.

In addition, Ward reported that one subject who had absolute pitch set individual tones (identified by note name) in accordance with her curve of octave stretch versus frequency, and that subjects set subjective double-octaves equal in width to the sum of two successive set octaves. Thus, Ward proposed, octave stretch represents a measure of the innate distortion in the pure-tone-frequency-to-subjective-pitch conversion within the ear and/or auditory system. In this view, the 'subjective octave' is an internal measure of *fixed* size relative to an internal one-dimensional scale of 'subjective pitch.'

Ward also reported that the method of adjustment with the two tones sounding simultaneously gave a subjective octave 5-10¢ smaller than using alternating low and high tones, but that this shrinking of octave stretch was present even at frequencies at which the subject's subjective octave was already less than 1200¢. Thus even the the harmonic "in tune" octave could not be thought of as centered on a precise 2:1 frequency ratio.

Walliser (1969), using Ward's method of adjustment, found that the subjective musical fifth is also stretched from its theoretical ratio of 3:2. Ignoring the individual differences discovered by Ward(1954), Walliser proposed a normative frequency-to-pitch conversion scale which shows an accelerating deviation from linearity of 5% (nearly a semitone) in the five octaves between 125 and 4000 Hz.

The studies of Terhardt (1969/70, 1971, see 1974) sought to demonstrate that octave stretch is caused by peripheral factors, e.g. the influence of neighboring harmonics in complex harmonic sounds on each other's place of resonance on the basilar membrane. He theorized that through learning to synthetically extract fundamental pitch of speech, intervals occurring between the lower harmonics of speech sounds come to be perceived as 'natural.' Owing to the relative predominance of octaves in the harmonic overtone structure, the octave comes to be readily identifiable, even when it occurs as a melodic (non-simultaneous) interval. The octave is preferred 'stretched' to match the way in which harmonics in speech (and other harmonic sounds) are spread apart in subjective pitch by the peripheral frequency-to-pitch transformation.

Elfner (1964) investigated octave stretch for high (2000, 4000, 8000 Hz) pure tones. He used a *method of limits*, in which a subject was asked to judge whether a presented interval was a "flat, sharp, or pure" octave, and the width of the next interval presented was adjusted accordingly. Instead of jumping or skipping from the low to the high tone of the interval, the intervening frequencies were swept upwards. Elfner reported that this made the task much easier. Subjects were also given extensive practise before testing began.

As measured by this technique, octave stretch increased by several percent after sleep-deprivation, but immediately decreased again after administration of amphetamine. Elfner argued that since octave stretch is variable with state of arousal, it must be centrally mediated, perhaps in the reticular formation. He noted that day-to-day variability, and also the mean octave stretch in the 2000-4000 Hz octave, were distinctly smaller using his method than previously reported by Ward (1954).

The study of Lindqvist and Sundberg (1971) employed two methods of measurement-- the method of adjustment and also a *method of judgement* (often called method of constant stimuli), in which subjects were asked whether or not the interval between two successively presented tones was or was not a "pure octave." They reported, but did not explore differences between these two methods. Their principal aim was to investigate the effects of timbre and volume on octave stretch. They found that change in volume of one of the tones of the octave caused contrary changes in the size of the subjective octave depending on whether the tones were pure or complex. They concluded that these results support the importance of 'temporal' as opposed to or in addition to 'place' coding of pitch.

In a later paper, Sundberg and Lindqvist (1973) noted that the mean octave stretch versus frequency curve fits rather well the usual stretched tuning of pianos; it also fit the way in which several wind instrumentalists adjusted the natural tuning of their instruments when playing musical passages. They also found that using highly musical subjects and 'music-like' complex tones instead of pure tones resulted in a smaller average octave stretch (0-10¢) in the 200-1000 Hz low-tone region.

Whereas Terhardt's work suggested that octave stretch may originate in the mechanics of place of representation on the cochlea, recently, Ohgushi and Kamiya (1979) have claimed in a brief report that precise measurement of interspike interval histograms of neural responses to single pure tones shows a systematic distortion quite compatible with the degree of octave stretch seen at different frequencies by Ward, Terhardt and Walliser. They report that the *subharmonic* interspike intervals generated in the nervous system in response to single pure tones show a systematic enharmonic stretch paralleling the observed octave stretch, and increasing with increasing frequency within the pitch-following region (up to 1 or 2 kHz).

Unfortunately, their report includes neither the species more the neural site examined. But their finding, if true, would again suggest that non-linear temporal rate-matching processes play a vital role in musical and harmonic pitch perception, and that octave perception amounts to accurately matching inter-spike intervals corresponding to the fundamental frequency of the lower tone of the octave and the electrophysiologically generated first subharmonic of the upper tone. In this view, an octave that is perceived as "in tune," rather than being a 2:1 acoustic frequency ratio, instead is one which matches the almost exact 2:1 ratio of firing rates in the auditory nerve.

What is the experience of the octave?

The above studies have considered the subjective octave as a fixed internal measure along a one-dimensional scale, subjective pitch, mapped, in the case of pure tones, from the one-dimensional scale of physical frequency. In what ways is this conception of the octave insufficient for understanding the musical experience of the octave? How might a richer conception explain the variations in size of octave stretch reported by Ward, Walliser, Lindqvist and Sundberg using different tuning tasks? And to what extent is the octave an exclusively musical phenomenon? The following thoughts were starting points for our own experiments:

1) What comes to the central nervous system from the ears is *not* simply a series of repeated measures of instantaneous frequency, intensity and timbre. Recent auditory electrophysiology has emphasized the complex multi-dimensional nature of the processing that occurs in parallel at relatively low levels of the auditory system (Møller, 1981). It is possible that octave perception makes use of multiple overlapping physiological transforms or channels of afferent information. Different tuning perception tasks might tap different combinations of auditory information channels, and thus give different behavioral results.

2) The "intuneness" of an octave could depend on the subject's *mode* of listening. Mode of perception ('analytic' versus 'wholistic' or 'affective') has recently been shown to alter hemispheric dominance in musical tasks as measured by a variety of behavioral and physiological methods (Bever and Chiarello, 1974; Sugarman, Ley, and Bryden, 1980; Peretz and Morais, 1980), and might also alter the types or channels of information given most weight in making perceptual distinctions.

3) Even apart from musical context effects, which have not been considered at all in the above octave studies, explicit judgements of the degree to which "an octave" is "in tune" are necessarily *musical* judgements, since the phrase "in tune octave" only has meaning in musical contexts. Consciously setting or judging "an octave" is therefore at heart a *projective* task, in which one is asked to perceive the sounds one hears in terms of a musical concept.

4) Hence, octave stretch might depend at least partially on musical or aesthetic taste-- octaves being preferred slightly stretched so as to sound somehow 'active' or "brilliant"[1].

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[1] This idea was dismissed, somewhat enigmatically, by Ward (1954).

5) A projective view of tuning perception suggests important musical context effects may exist, whereby a tuning which sounds "out of place" in most musical contexts may be projectively perceived within a particular dynamic musical context, and thus actually "sound in tune." For instance, Boomsliter and Creel (1963) reported that the eighth note of the well-known French anthem, "The Marseillaise," is preferred a comma (22¢) higher than an octave above the first notes of the song, apparently to fit the 'proud, energetic' emotional quality of the phrase.

6) Acquired sensitivity to small changes in octave tuning might transfer to *other* projective octave perception tasks, tasks in which the subject was *not* self-consciously making musical judgements. For example, one might ask listeners to hear the tones of an octave interval as "tones of voice of two speakers," and to respond in terms of the psychology of an imagined interchange between them.

7) The fine structure of *affective* response to variations in octave tuning might also be preserved in such tasks. A similarity of responses in projective musical ("hear these sounds as an octave") and non-musical ("hear these sounds as a tone of voice") octave perception tasks might give insight into the communicative power of music-- the ways in which an octave is 'more than musical,' i.e. is capable of conveying emotion.

In sum, taking into account complex 'feedback' between auditory sensitivity, interpretive concept, perceptual flux, and perceived context may be essential to understanding the experience of the octave, as it surely is to understanding of musical experience in general.

As a first step in investigating these ideas, we decided to obtain parallel "degree of mistuning" and "sharp/flat" judgements of melodic pure-tone octaves in the central musical pitch range. To *set* an "in tune" interval, one must simultaneously or alternatingly make a series of both types of judgements. However, given the complex and highly evolved multiplicity of auditory sensitivities, we suspected these two judgements might not be equivalent, either neurophysiologically or behaviorally.

Experiment 1

Nine subjects, university upperclass and graduate music students, were asked to rate the tuning of 484 computer-generated melodic octaves. Two responses were collected for each stimulus pair. First, subjects were asked to give their "immediate, global impression" of the degree to which each octave was 'in tune.' They recorded their answer by circling one item on a six-point scale marked:

O---X---X---X---X---X
in tune mistuned

Then, subjects were asked to indicate on a second scale whether the second tone they heard was 'sharp' or 'flat' in relation to an 'in tune' octave of the first tone:

X -------- X
flat sharp

If they had judged the interval 'in tune' on the first scale, they were nonetheless asked to guess in which direction the octave might have been mistuned. The experiment consisted of two one-hour sessions, during which responses were collected to twenty-two blocks of twenty-two intervals each. The first experimental block was preceded by a practise block similar in every respect to the trial blocks.

Stimuli

Stimuli were sine tones synthesized with equal amplitude using a VAX 11-780 computer with a 48K sampling rate and 16-bit D-to-A resolution, and recorded on magnetic tape using a high quality Ampex tape recorder. Pitch intervals, both ascending and descending, were constructed in eleven widths, varying in 4¢ steps from 1180¢ to 1220¢. Tones were 1.719 seconds in length, and were separated by a 1.062 second ISI. After the second tone of each interval, subjects were given 4.5 seconds to record their responses (see Fig. 1).

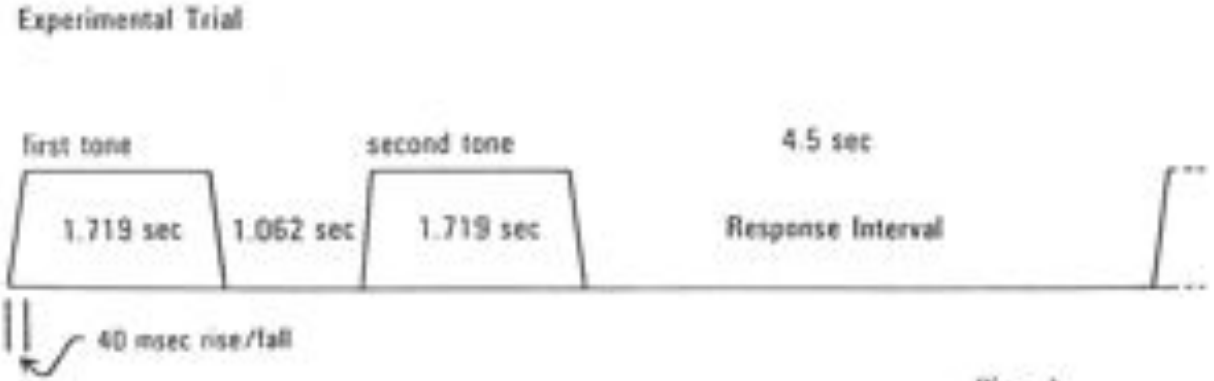

Fig. 1

Blocks were composed of one interval in each of the twenty-two categories, order initially randomized and then counterbalanced over the 22 trial blocks. The frequency of the first note of each stimulus pair in each block was chosen at random in the range 250-750 Hz. This meant that the total range of pitches used in the experiment was 250-1500 Hz. This corresponds roughly to the musical range shown in Fig. 2.

Fig. 2

Pitches were constrained to differ by at least 8% (nearly one and a half semitones) from any of the pitches in the previous four intervals of the block.

Method

Prior to the expement, subjects were given a training block, and were told that the range of tunings heard in the training block would match that of the actual trial blocks. They were not otherwise informed of the composition of the blocks, but were encouraged to use the full six-point "mistuning" scale. Subjects were given pauses between blocks, for rest and to ready new response sheets. Stimuli were played to groups of 2 to 4 subjects at moderate levels in a sound-treated room through multiple loudspeakers. Subjects completed the experiment in two one hour sessions, and were paid for their participation.

Results

Degree of "mistuning" judgements

Fig. 3 shows mean "degree of mistuning" responses as a function of interval size and direction. The dotted line represents the quadratic regression of "mistuning" on interval size. Note that the quadratic regression curve fits the pooled data very well. The minimum of the regression curve is at 1204.4¢. This implies that the degree of octave stretch on the "mistuning" measure was quite small. Indeed, 1204¢ octaves were judged least "mistuned" of any interval size, were most often judged to be "in tune," and also showed the smallest standard deviations of "mistuning" judgement. This was true for both ascending and descending 1204¢ intervals. Thus by the "degree of mistuning" measure, octave stretch in this frequency range was very small (circa one quarter of one percent).

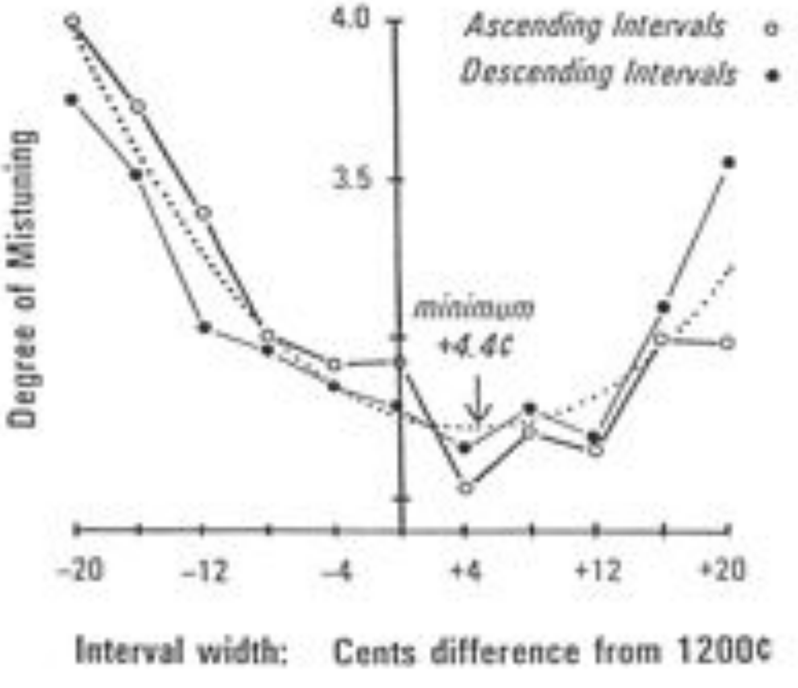

Fig. 3

Fig. 3 - Mean "degree of mistuning" as a function of interval size and direction ("In tune" = 1, most "mistuned" = 6). Each point represents the mean of 22 judgements for each of nine subjects.

Fig. 4 shows quadratic regressions of "mistuning" on interval size for each of the nine subjects. The individual curves are very consistent; eight of the nine show "mistuning" minima between 1200¢ and 1206¢.

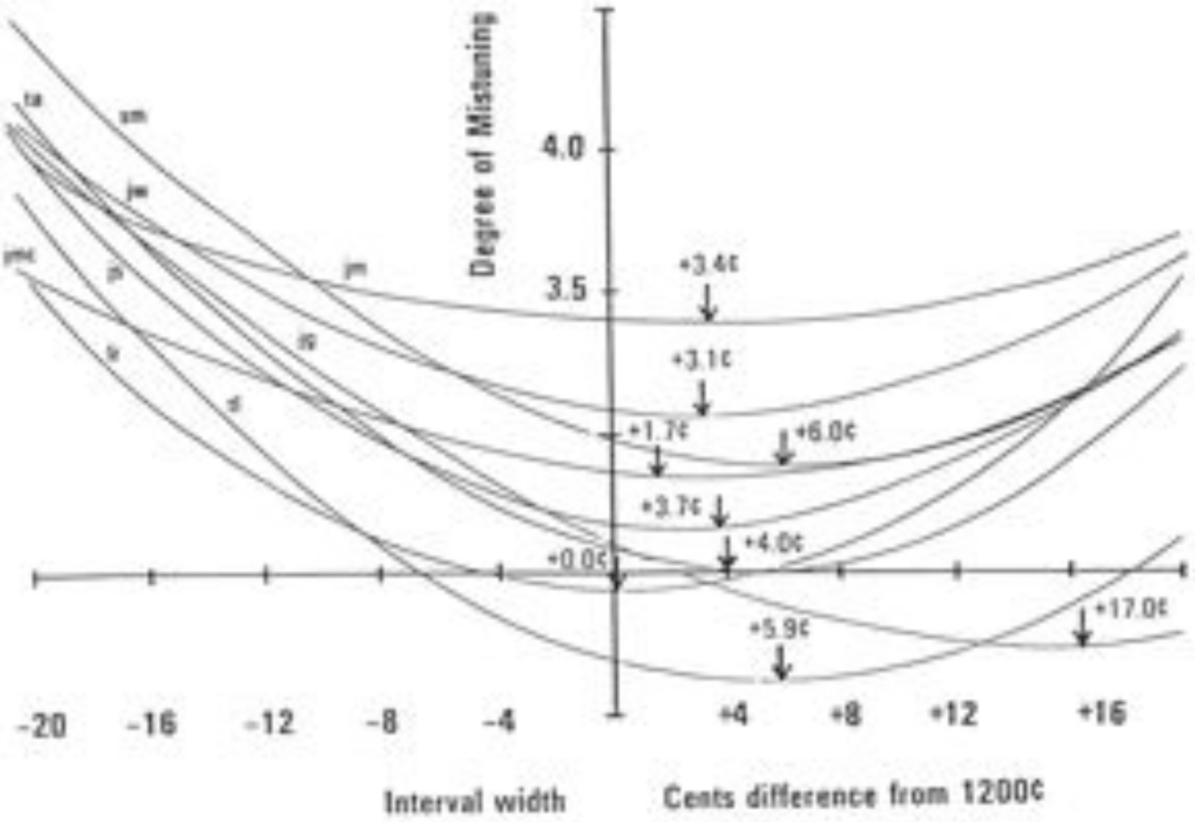

Fig. 4

Fig. 5 shows quadratic regressions over all subjects in four separate frequency ranges. By the "mistuning" measure, octave stretch is seen to gradually increase with increasing fundamental frequency. This increase matches that of Sundberg and Lindqvist (1973), who used a method of adjustment of complex tones. However the amount of increase is quite small, compared with the 20-30¢

increase seen in the same frequency range in the pure-tone octave setting data of Ward and Walliser.

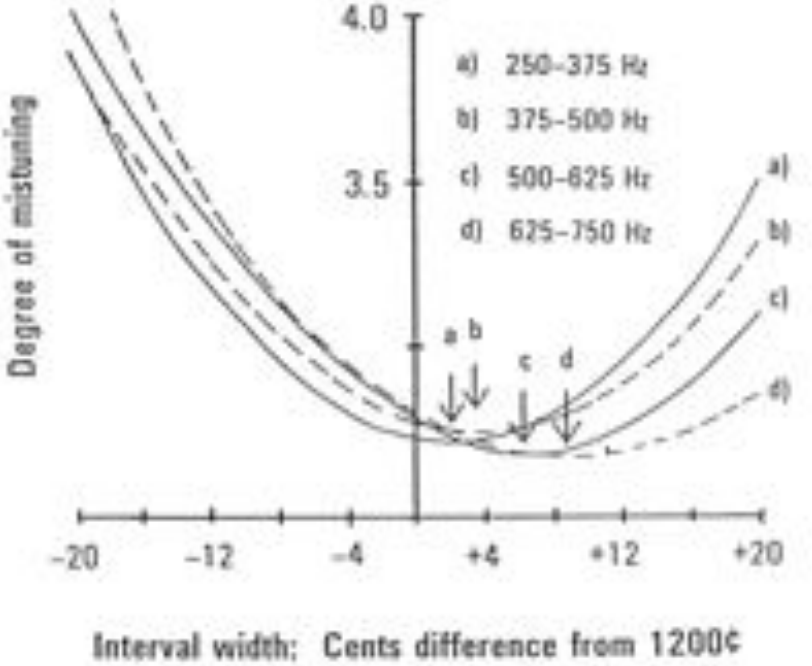

Fig. 5

There was no main effect of interval direction in either the "mistuning" or the "sharp/flat" data. However, note in Fig. 3 the systematic discrepancy in degree of "mistuning" between ascending and descending intervals with respect to interval size. This (Direction x Interval size) effect was significant across subjects in an ANOVA comparison (p=.004). It implies that regardless of direction, octaves whose second tone was *flat* relative to a "least mistuned" octave, were judged to be "more mistuned" than octaves whose second tone was the same number of cents *sharp* relative to a "least mistuned" octave. Thus, subjects judged as "more mistuned" both *narrow* octaves (<1200¢), and also octaves whose second tone was *flat*.

The "second tone flat" effect has been re-plotted in Fig. 6, which shows the mean "degree of mistuning" for intervals whose second tone was sharp or flat relative to a 1204¢ octave.

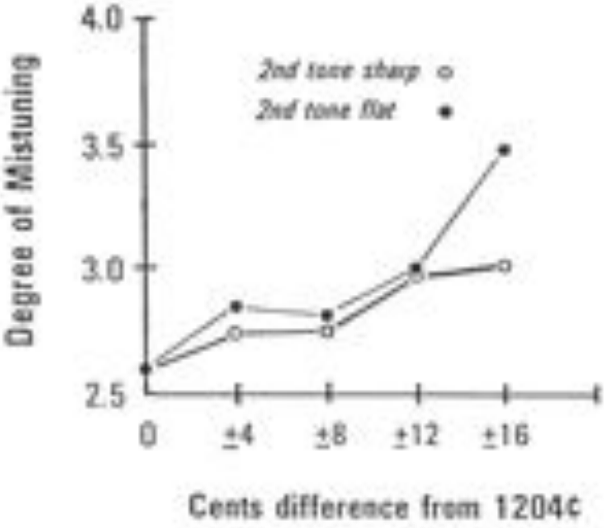

Fig. 6

This significant general tendency to judge "more mistuned" intervals whose second tone was flat was also seen in the distribution of those octaves judged to be "in tune." In particular, intervals that were called "in tune" were more apt to be wide (>1204¢) ascending intervals (with second tone sharp) than wide descending intervals (with second tone flat)[2].

In sum, in this experiment, subjective "degree of mistuning" judgements were *not* wholly independent either of interval direction nor of direction of mistuning of the second tone. Therefore, a "subjective in-tune octave" cannot be thought of as simply a fixed internal measure along a one-dimensional continuum ("subjective pitch").

"Sharp/flat" Judgements

Judging the second tone of a descending octave to be "sharp" is logically equivalent to judging the interval to be "narrow;" for an ascending octave, a "second tone sharp" judgement is logically equivalent to judging the interval to be "wide." For convenience, in Fig. 7, "sharp/flat" judgements have been transformed to equivalent "wide/narrow" judgements by reversing the responses to descending intervals. Note that the logical equivalence between sharp/flat and wide/narrow judgements does not necessarily imply that the two questions would have given equivalent behavioral results. We have transformed our data from sharp/flat to wide/narrow merely for convenience in display and discussion.

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[2] This sub-comparison came close to significance across subjects ($p = .058$).

As shown in Fig. 7, transformed "wide/narrow" judgements were nearly monotone with respect to interval size, and showed a much larger mean octave stretch (circa 14 ¢) than "degree of mistuning" judgements.

Fig. 8 shows linear regressions of "wide/narrow" judgements on interval size for each of the nine subjects. Note that the implied octave stretch (the zero-crossings of the regression lines) varies dramatically across subjects. This contrasts with the consistently small "mistuning" minima shown for the same subjects in Fig. 4.

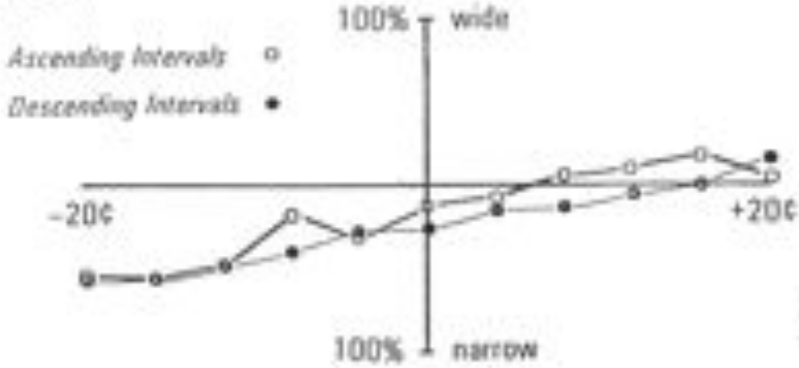

Fig. 7

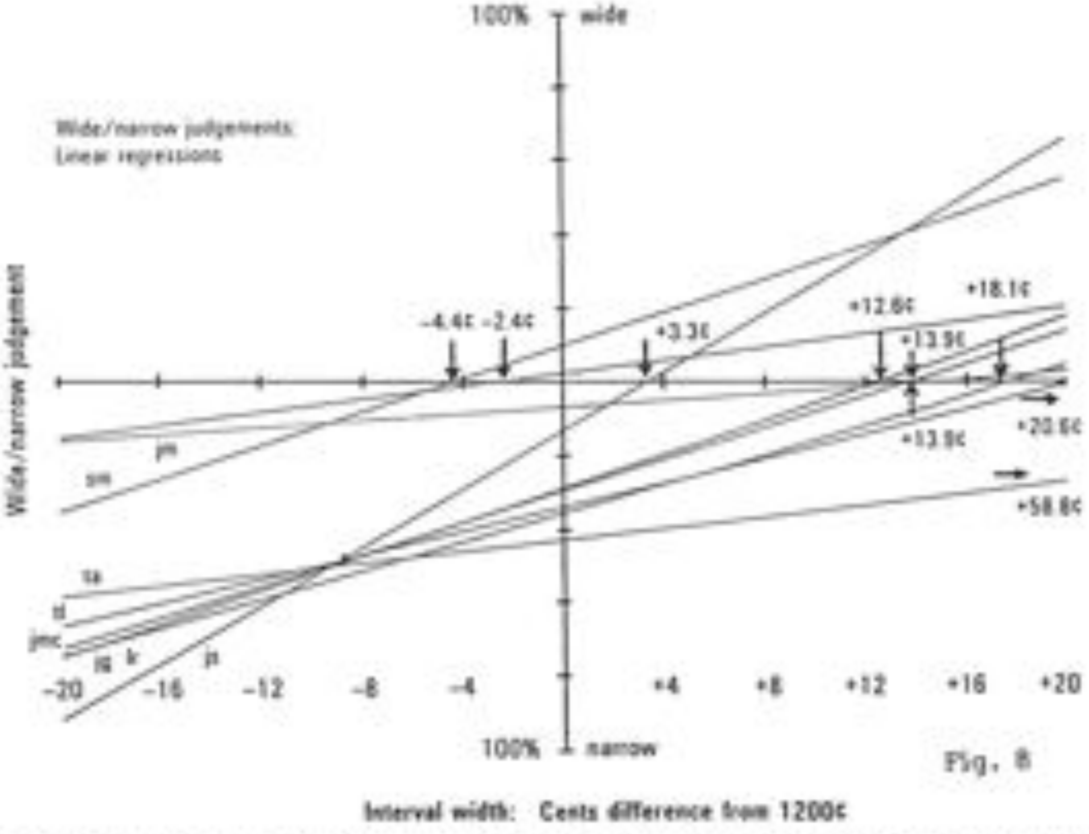

Fig. 8

Fig. 9 shows octave stretch estimated from the regression curves of the two tasks in four frequency ranges. Rather than show the expected increase, the "wide/narrow" judgement data actually show a dramatic decrease in octave stretch with increasing frequency. High octaves were more often judged to be 'wide' whenever they exceeded 1200¢, though our lowest octaves needed to be at least

1220¢ before they tended to be judged to be "wide."

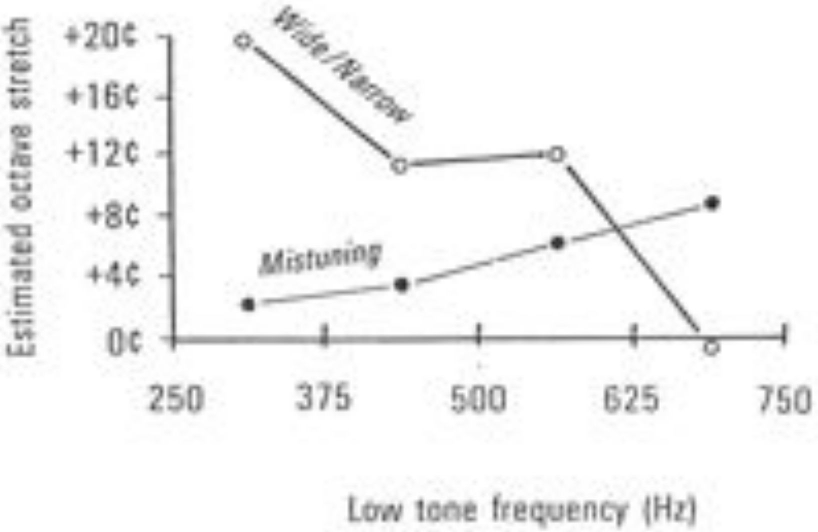

Fig. 9

The "wide/narrow" judgements of ascending and descending intervals do not differ significantly (see Fig. 7). Their coincidence implies that subjects made no more "flat" than "sharp" judgements and were *not* more sensitive to 'flatness' in this task, contrary to the "degree of mistuning" results (cf. Fig. 3).

Discussion

Results of Experiment 1 suggest that there may be at least two modes of perception of tuning of melodic octaves, connected with degree of "mistuning" and "sharp/flat" judgements, respectively. Our data imply that in musicians, "sharp/flat" judgements are more variable between subjects than "mistuning" judgements, are more and oppositely register-dependent, and show more mean octave stretch than do judgements of "degree of mistuning."

Though the pure 2:1 (1200¢) octave was not especially favored on either measure, among our musicians the preferred degree of octave stretch was very small for judgements of degree of "mistuning" (circa 4.4¢); it was much larger and more variable for "sharp/flat" judgements.

These results imply that pitch perception by trained musicians is not a matter of simply "placing" what is heard in a one-dimensional pitch or chroma/octave space, as is often assumed in music theory and psychology, but rather may result from integration of differently organized modes of perception. One might say, "Musicians can't tell sharp from flat, but they know what they like." And the octave they judge "least mistuned" in the musical middle-frequency range is very close to a precise 2:1 frequency ratio.

Our "mistuning" results are in fact in line with those obtained by Lindqvist and Sundberg (1971) by asking subjects to judge whether or not a pure tone octave was "pure." In the low tone frequency range 390-470 Hz (using 6¢ steps, and only a 30 msec. inter-tone interval), they reported a mean octave stretch of 5.6¢. This compares well with our "mistuning" judgments in the 375-500 Hz range of 2.5¢. They also found no significant differences between judgements of ascending and descending intervals, but did not test for the (Direction x Interval size) effect.

We have said that the "mistuning" process is more sensitive to flat pitch than sharp pitch; the evidence for this is in the significant (Interval size x Direction) interaction on the "mistuning" judgements. The "sharp/flat" judgements tell us further that the apparent differential sensitivity of the "mistuning" process cannot be accounted for by any kind of response bias for saying "flat", since "sharp" and "flat" categories were apparently used equally often by our subjects. Greater sensitivity to "mistuning" in flat notes did not lead to greater likelihood of calling a mistuned note "flat". If the "mistuning" and "sharp/flat" judgements were simply two faces (outcomes) of a unitary process, this could not have occurred. If the process that was more sensitive to "second note flat" were also the source of explicit "sharp/flat" judgements, then the latter should have also been differentially sensitive to 'flatness.' But the 50/50 response outcome actually observed belies this. Taken together with the large differences between tasks in octave stretch, variability, and form of dependence on register, our evidence strongly indicates two separate processes for the two types of judgement.

Our finding of greater sensitivity to "second tone flat" is not without precedent. For instance, Siegel and Siegel (1977), using 480-720¢ intervals and 20¢ steps, found that 'sharp' intervals were called "in tune" more often than 'flat' intervals. Further, 'sharp' intervals were called too "flat" nearly as often as too "sharp," whereas 'flat' intervals were only very rarely called "sharp."

Asymmetrical sensitivity to pitch 'flatness' may be a specific case of a more general biologic or psychoaesthetic principle. Recent experiments in several modalities have reported a greater alertness to decrease in a continuous stimulus than to increase. Madsen et al.(1969) found that musicians detected slow downward frequency modulation more quickly than slow upward modulation. Kuhn (1974) found a greater acuity for tempo decrease than tempo increase. Recently, Moore (1982) found that musicians detected a gradual decrescendo more accurately than a gradual crescendo.

Biological control systems often operate through parallel opposed uni-directional channels (Clynes, 1969). It is quite possible that opposite channels in any perceptual system might have differing sensitivity characteristics in both amplitude and frequency domains. The greater sensitivity to 'second tone flat' found in the present experiment might thus reflect a more general principal of sensory organization. However, any interpretation which would ascribe the effect to a "processing limitation" may be premature. It is possible, rather, that the "second note flat" sensitivity, or "second note flat" *in*sensitivity, represents an aesthetic, or even an evolutionary attentional bias. Experiment 2 investigated these ideas in more detail.

Experiment 2

We have argued above that "octave" setting and judging are themselves projective tasks. In the context of classical psychophysics, this view might arouse controversy. However, we feel that modelling perception as the end result of a mechanistic transduction of energy dynamics through the ear to a presumed central "receiver" in the brain has limited scope and usefulness for exploring questions of experience. More in line with contemporary psychology, we believe, are models of perception linking the dynamics of sensory input to evolved and/or learned interactions with, or 'resonances to' the myriad of previous reactions-to-experience (Gibson, 1979; Grossberg, 1980). These resonances may involve and relate at least two modes of experience, the so-called 'analytic' and 'affective' (Zajonc, 1980; Makeig, 1982). Moreover, such 'resonances' to experience, once established, may tend to organize experience without necessarily involving conscious awareness of their presence or origins.

Such models suggest that an interaction of a multiplicity of processes may co-occur in judgements of musical tuning. And if the octave is truly a universal basis element of music, then acquired sensitivity to octave tuning, as well as the whole structure of affective responses to octave tuning, should also structure one's interpretation of human intentions expressed through speech in which octaves occur. This suggests a technique for exploring musical experience which, though on the surface quite different from the usual psychophysical methods, yet possibly is essentially related to them. We make no claim that the octave *is* used in normal speech to indicate specific intentions, although we know of little or no research having been conducted on such questions. Rather than use speech stimuli in which octaves occur, we here report the use of pure tone stimuli which we ask subjects to *imagine* as speech.

Methods

In order to explore more fully the experience of the "subjective octave," a second experiment was carried out by the first author, using a projective method and two of the subjects in Experiment 1. This experiment was conducted on a modest scale, and is reported here partly to suggest possible directions for future research.

Each of two subjects were played a total of 44 of the stimuli used in Experiment 1. Subjects now were *not* told to imagine that they were hearing musical intervals. Instead, they were asked to imagine that the two tones of each stimulus pair represented "*tones of voice of two speakers*." The first tone of the stimulus pair was to be thought of as representing the tone of voice of a first speaker making a statement, the second tone then representing the tone of voice of a second speaker replying to the first speaker.

Subjects were asked to consider, "To what extent do you feel the second speaker *sincerely confirms* the statement of the first speaker?" This "degree of confirmation" paradigm was specifically chosen to be consonant with the role of the octave as a "musical equivalence," (cf. Aristotle's, "in the octave, both tones say the same thing.").

Subjects were first given a rating scale marked:

X------------X------------X------------X------------X
hardly somewhat fairly mostly truly
confirms confirms confirms confirms confirms

and asked to circle one of items corresponding to the degree of confirmation they heard in the second tone. Then subjects were asked to describe the conversation they had imagined, and their comments were written down by the experimenter.

In projective tasks involving imagining personalities, it is important to pace the tasks slowly; demanding too rapid a shift to a new projective imagination makes the task difficult or impossible and the responses less rich and certain. In this experiment, each subject responded to 44 intervals during a one hour session under the same listening conditions as in Experiment 1. Subjects were not told whether or not the stimuli were the same as any of those used in the first experiment.

Despite initial scepticism, subjects reported the task to be surprisingly easy. One commented at the end of the session, "It's fun to keep the analytic mind out of it." Subjects claimed that they became focused on the task as stated, and were not aware of thinking or perceiving in musical terms.

Results

Responses collected in these open-ended projective tests suggest that these musicians' sensitivity to degree of "confirmation" in Experiment 2 at least equalled sensitivity to degree of "mistuning" in Experiment 1. Each subject responded to two intervals in each (Width x Direction) category. Table 1 shows one of two responses of each subject to ascending intervals of each width. The selection of quotes in Table 1 was made to illustrate the potential power of the experimental method for determining the multi-dimensional affective meanings of subjective musical percepts such as "in-tune octave."

Table 1 - Projective Responses to Ascending Intervals

Cents	Subject DL	Subject JM
1220	second speaker more emphatic, some sort of discord	no real ring, extra energy, questionable intention
1216	second speaker made same statement but worded it better	definite confirmation but mechanical, not really true
1212	both equally convinced both positive	a real confirmation for me, though second speaker added a fair amount of energy, but not overly so
1208	both equally self-assured, second speaker more emphatic	doesn't ring as true, mechanical, couldn't give the warmth of the first
1204	second speaker just a little bit less assured	second adds energy, verges on over-energetic, but I feel no qualms about it being truly confirming
1200	second speaker a little less assured	really rings clear and true
1196	second speaker not quite as sure	confirming, but wasn't really vibrant, almost routine
1192	second speaker clearly not as confident	doesn't quite confirm, a little routine
1188	second speaker emphasized the negative	doesn't confirm or deny, weak
1184	second speaker negative, discouraged, disgusted	half-hearted
1180	second speaker weakest so far, but with hostility, clearly not so sure	starting to border on countering the first, focused against it

Note the sensitivity which these musicians displayed in making finely-graded semantic distinctions, without conscious reference to the musical quality of the interval between the tones.

Most interestingly, in the projective tests both subjects mentioned that they imagined "extra energy" in a sharp second tone of an ascending octave pair, but did not find it objectionable, (see Table 1, heavy boxes), whereas second tones which were flat (i.e. intervals < 1200¢) were often described as distasteful. When subjects indicated they could hear "extra energy" in the 1204-1212¢ intervals, this did not cause them to consider these intervals as less than perfectly "confirming." This parallels the finding in Experiment 1 that wide ascending intervals were more apt to be judged "in tune" than either narrow or descending intervals. The fact that these two subjects did mention "extra energy" in tones which they still called "truly confirming" in turn suggests that the more general principle of greater sensitivity to decrease in any of number of sound parameters (Moore, 1982) might not be due to a limitation in perceptual processing, but might rather reflect a tendency of differently weighting of parallel modes or channels of attention.

Examination of the whole body of responses collected in Experiment 2 suggests that octaves with second tones 'sharp' versus 'flat' were affectively perceived in terms of *amount of energy* ("forceful, assertive' versus 'energy-less, weak or passive'). The affective distinction between 'wide' versus 'narrow' octaves seems to have been expressed in terms of *positive versus negative intentions*. Second tones of narrow octaves were perceived as expressing 'disgust, discouragement, and cynicism,' whereas second tones of wide octaves were perceived as making (more or less forceful) positive statements. That is, wide octaves are not only preferred in a musical sense, they were heard in this projective task as expresssing positive intentions-- i.e. in this task, 'wide' octaves 'mean what they say,' while narrow octaves do not.

Discussion

In a fascinating study in which subjects listened to music played on a "laboratory quality victrola," then gave their open-ended verbal recollections of their experiences, Meyers (1927), defined four general categories of musical experience. These related to (1) awareness of objective features of sound, harmony, etc., (2) experiences of energy, either in the music or within the listener, (3) dream-like or imaginative experiences e.g. of dramatic scenes, and (4) direct experience of attributes of human character-- personality, moods and intentions.

Of the four, Meyers valued the character aspect most highly. It is, however, the area perhaps least explored by modern music psychology. The projective methodology introduced in Experiment 2 may hopefully be able to be developed into a tool capable of making useful contributions to the study of this truly affective aspect of musical communication.

The 'wide/narrow' and 'sharp/flat' affective distinctions suggested by our small body of data are remarkably reminiscent of the very general 'good/bad' and 'active/passive' dimensions which have been shown by affective psychologists to be major dimensions underlying all sorts of affective judgements and connotations (Osgood et al., 1957; Russell, 1980).

Some recent work in experimental psychology (see Zajonc, 1980) implies that divergence of affective and analytic aspects of perception occurs very early into the afferent nervous system. The results of Experiment 2 leave open the possibility, suggested by results of Experiment 1, that octave perception involves integration of differing modes of pitch and interval perception.

The evident sensitivity of the two musicians in Experiment 2 to 4¢ steps in octave size corresponds to the U-shaped "degree of mistuning" and near-monotonic "sharp/flat judgement" curves of Experiment 1. Their latitude in rating wide intervals as "truly confirming" parallels their responses in the "sharp/flat judgement" task of Experiment 1. Yet their comments about "extra energy" in slightly sharp second tones of ascending octaves are compatible with the degree of sensitivity to deviations from a near-2:1 minimum in the "mistuning" data of Experiment 1.

The near-equivalence of responses in Experiments 1 and 2 suggests that both tap an underlying perception of the octave, whether that perception was developed first through musical training, through learning to track the pitch of speech (Terhardt), or through training in affective sensitivity, or was genetically innate. These alternatives might be distinguished by testing subjects who have no musical training but are skilled at making judgements of intent (for instance, actors, lawyers, or clinical psychologists).

The strength of this projective technique could be investigated by testing various projective paradigms, looking for commonalities in responses. It is important to note that the linking of octave perception with intentions may well be specific to this particular projective task. (Hearing a soprano sing a notably narrow octave would not ordinarily lead us to suspect her intentions, though we might well have some other sort of negative feelings!).

What light does the second experiment shed on the hypothesis that octaves are "preferred" stretched in order to sound somehow more 'active' or 'brilliant?' Our two subjects' projective responses suggest that they heard sharp second tones as 'active,' and 'flat' second tones as the opposite, that wide intervals were heard as 'positive intentioned' or truthful, narrow intervals as 'ill-intentioned' or untruthful. To the extent that this affective structure transfers to musical preception of octaves, their comments then confirm that at least a part of the tendency to prefer 'stretched' octaves is based on affective response, particularly since in Experiment 1 we saw that degree of octave stretch has at least different two sizes, connected with at least two modes of perception.

It is possible that the projective methodology used in Experiment 2 could be developed to explore the topology of affective perception of the basic elements of music. Additional tools now available include multi-dimensional scaling and other multi-factor statistical procedures. Experiment 2 can only be seen as a pilot experiment. It remains for future work to further explore the multi-dimensional character of the "subjective octave."

Experiment 3

In Experiment 1 a marked divergence was found between "mistuning" and "sharp/flat" octave judgements. In Experiment 3 we tested whether differences in lateralization of these two measures might be found using monaural stimulation to alternate ears. Since the left cortical hemisphere is believed to be more strongly involved in analytic judgements, and perhaps in "use of codes" in general (Goldberg and Costa, 1981), and the right hemisphere both in affective judgements in general (Heller and Levy, 1981), and in complex harmonic timbre and pitch perception (Sidtis, 1980,1981) in particular, we hypothesized that "sharp/flat" judgements might be made more accurately using the right ear, while conversely "mistuning" judgements might be made more accurately using the left ear.

Methods

The same stimuli used in Experiment 1 were played to six subjects, all right-handed musicians, through ear-enclosing headphones at moderately low listening levels. None of the subjects had been a subject in Experiments 1 or 2. Four were graduate students of music. One had been a professional trumpet player. One was the second author. Instructions to subjects were as in Experiment 1. Subjects were tested in small groups. Subjects rotated their headphones at the end of each block, and exchanged headphones in the middle of the experiment to counterbalance any acoustic mismatch.

Results

Since the scales used in making degree of "mistuning" and "sharp/flat" judgements were dissimilar, no direct comparison of 'accuracy' between the two tasks was possible. Therefore, we tested for an ear effect in size of standard deviations of responses over intervals and across subjects. That is, the standard deviations of responses to the two tasks were computed for each interval size, and these were then run in an ANOVA comparison. We reasoned that laterality of processing might lead to smaller contralateral standard deviations of responses, since ipsilateral auditory channels are thought to provide less precise acoustic information than contralateral channels (Nebes, Madden and Berg, 1981).

One subject[3] was found to have given essentially random "degree of mistuning" judgements; his data was then dropped from the analysis. The responses from the remaining five subjects were pooled and a standard deviation computed for each interval size, task, and ear of presentation. An ANOVA comparison was then run, using interval size as the random factor. The (Task x Ear) interaction was significant (p=.023) in the predicted direction.

Standard deviation of responses to intervals heard through the left ear was smaller for the "degree of mistuning" judgement. The "sharp/flat" judgement resulted in smaller standard deviation of response for stimuli heard through the right ear. This finding is consistent with the hypothesis that global, affective, "degree of mistuning" judgement is a task more apt to be carried out in the right hemisphere, while the more analytic "sharp/flat" judgement task may be more suited to left hemispheric processing or 'personality.' However, when the ANOVA comparison was run again with subjects as the random factor, pattern of results was similar, but did not reach significance. This indicates the effect was too variable, given the small number of subjects, to be statistically reliable, though present in the pooled data.

Discussion

In most laterality experiments, subjects show a wide spectrum of lateralized responses. Thus our finding of the (Ear x Task) effect being non-significant over our five subjects is not surprising. Neither does it imply that the predicted effect is strong, if it exists at all. To provide more conclusive evidence, we should either replicate Experiment 3 using a much larger group of subjects, and/or obtain parallel, physiological evidence for hemispheric differences between these two tasks. Physiological indications of brain lateralization in musical tasks have been recently obtained using a variety of measures (Shucard et al., 1977; Duffy et al., 1981).

We know of one previous test of laterality in octave perception. Shanon (1980), using musicians as subjects, presented pure tone melodic intervals to one ear simultaneous with noise bursts to the other ear. Tones were drawn from two octaves of a tempered chromatic scale. Accuracy and reaction times were recorded to subjects' identification of intervals as an 'octave' or as 'not an octave.' After left ear presentation, subjects were significantly quicker to respond "not an octave," than after right ear presentation. This finding seems consistent with our hypothesis of greater sensitivity to "mistuning" in the right hemisphere.

When Shanon presented trials consisting of three successive tones, an octave occurring between either the first two tones, the last two tones, or neither pair, the left ear again was quicker to respond, "no octave" than the right ear. In this task, only right ear presentations led to above chance accuracy. Shanon interpreted the right ear (left hemisphere) advantage for this task as being due to its more difficult 'analytic' nature.

Current interest in hemispheric laterality points to yet unexplored questions of bi-hemispheric integration. Our finding in Experiment 1 of divergence between "mistuning" and "sharp/flat" judgements, consistent with lateralization possibly observed in Experiment 3, suggests that even such an elemental perceptual activity as pure tone octave judgement is psychologically and neurologically a richly multi-natured task.

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[3] not the second author!

General Discussion

We have seen, as have 'music psychologists' since at least the time of Pythagoras, that in the middle musical frequency range, the subjectively "least mistuned" melodic octave is indeed very close to an exact 2:1 frequency ratio. The psychoacoustic literature has modelled the fine structure of octave perception based on mechanics of the inner ear. Elfner (1964) emphasized that central effects possibly covarying with level of arousal are also involved. Our experiments imply that octave perception is yet more complex. Even apart from influences of specific musical context, the question of how or what we perceive when we hear "an octave" appears like the mythical Hydra-- cut off one head and several more appear.

We have found that young musicians display extreme sensitivity to 2:1 octave tuning when "degree of mistuning" judgements alone are asked for. When judgements of "sharp" versus "flat" are called for, their responses are much more variable, and their subjectively "neither sharp nor flat" octave is rather wider than their subjectively "least mistuned" octave. When given the same stimuli and a quite different projective task involving judgements of (projectively imagined) human intentions, again two of our subjects seemed to show the sensitivity seen in their "mistuning" judgements.

Both the 2:1 basis for the octave, and also a small octave stretch which increases with frequency, are seen in our "degree of mistuning" data. Combining our "mistuning" and "sharp/flat" judgement results might lead one to predict that our subjects might "set" subjectively "in tune" octaves between the 1204.4¢ of their "mistuning" judgements and the 1214¢+ of their "sharp/flat" judgements.

This would seem consistent with the octave stretch and variability reported by Ward (1954). What is not obvious is why the estimated octave stretch of our "sharp/flat" judgements declined with rise in frequency, whereas a pronounced general trend for increased size of "set" octaves has usually been seen in previous experiments. However, to our knowledge ours is the first experiment to look at "sharp/flat" octave judgements separately.

Results of our pilot projective Experiment 2 suggest that the structure of affective perception of octaves may be similar to the structure of affective perception in general (Russell, 1980), 'sharp/flat' being perceived in terms of an 'active/passive' affective dimension, and the 'wide/narrow' distinction being perceived in terms of 'good/bad.'

Our lateralization experiment, while not conclusive, suggests that differing modes of octave perception may tend in some persons to be lateralized along the "analytic" versus "affective" dimensions which are now thought to characterize the capabilities of the left and right hemispheres, respectively, in many or most persons.

Finally, note we have studied octaves in isolation from specific musical contexts. How sensitivity to octave tuning, and affective response to variations in octave tuning may depend on musical context are questions not here explored.

As we have seen in our Experiment 2, "mistuned" octaves also have affective meaning. Musically, therefore, there can be no one 'right' way to tune an octave; correct or optimum tuning must be at least as variable as one's range of emotional intentions. However, in the musical mid-range, the particular feeling of "intuneness" or "confirmation" between tones an octave apart seems to be most pure when the octave is only very slightly wider than a 2:1 frequency ratio.

Implications for Musical Education

What implications have our experiments for musical training? Certainly they emphasize the richness of musical perception as involving simultaneous, even conflicting modes of experience. The success of subjects in the projective experiment at making fine "musical" judgements *without* focusing their awareness specifically on a musical context suggests a potential value to further exploration of teaching methods using suggestion and guided imagery. The relative greater consistency of responses to the "degree of mistuning" question emphasizes the wisdom of relying on intuitive, affective awareness, even in performing such basic skills as judging intonation.

One might say that to play in tune, it is not enough to know "which way is up"; to hear an octave "in tune," you "gotta have heart." In fact, many or even most musicians know that they stay better in tune through feeling their music than through thinking about it. Yet ideally, affective, intuitive awareness must be linked to and balanced with analytic awareness. A good musician must also be able to correctly adjust his or her pitch "sharp" or "flat" as need arises. Thus harmonious balance of "heart" and "head" remains a worthy goal-- in perception as well as in behavior.

La Jolla,
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