Judged similarity in pitch of octave multiples

WILLARD R. THURLOW and WILLIAM P. ERCHUL
University of Wisconsin, Madison, Wisconsin 53706

Subjects with musical training, who could identify musical intervals within octaves, were tested on their ability to identify musical intervals when the higher note was at several different octave multiples. Some subjects (but not all) showed very high scores on such cross-octave interval recognition tests. Two other groups of subjects were tested on ability to recognize pitch similarities for octave multiples. Only a few subjects showed evidence of perceiving pitch similarities. Our results do not support the hypothesis that *all* subjects perceive a common pitch-chroma at octave multiples.

In Western music, we most often use a scale of notes (labeled do, re, mi . . . or A, B, C . . .) which repeats at each octave interval. (A frequency, f_2 , is defined as an octave above another frequency, f_1 , when $f_2 = 2f_1$).

Some investigators have found evidence that notes at octave intervals are functionally more similar than notes at nonoctave intervals. Francès (1958) has found that melodies transposed an octave are more easily recognized, in short-term memory experiments, than melodies transposed by some other amount. This result might be due to the fact that notes an octave apart "sound" the same in pitch, have the same tone "chroma." A theory embodying this assumption appeared many years ago, and has been formally revived recently (Jones, 1976). (For reviews of this literature, see Licklider, 1951; Ward, 1963a, 1963b.) Of course, there may be other explanations for these results. Subjects hearing an initial melody may "code" it in terms of labels for notes of the scale in that key; a second melody an octave higher, which tends to be coded similarly, may therefore be recognized more easily.

An experiment by Deutsch (1972) showed that recognition for melodies was destroyed when notes were randomly selected from any one of three octaves instead of one octave. This evidence indicates that similarities in pitch of notes related by octaves is not sufficiently great to overcome distortions in melodic contour produced by octave-jumping. However, this procedure may destroy melody recognition because melodic intervals are changed. (For example, transposition of a note by an octave, from a pitch higher than the preceding note to one lower, changes the interval). More recently, Dowling and Hollombe (1977) have shown that the disruption of recognition produced by such octave substitution is lessened if pattern of "ups and downs" is

preserved. Idson and Massaro (1976) found under these conditions that melodies were identified as accurately when the tones were displaced by octave multiples as when the melodies were untransformed. It appears that functional similarity of octaves emerges when an "up" or "down" cue is given to the subject so that he can convert the pitch signal into a pitch shift in a direction appropriate for the melodic interval or contour. This could involve similar tone "chroma" for octaves, but does not have to.

The present experiments were designed to measure the functional equivalence of octaves by other approaches. One of these approaches is to present two-note musical intervals to subjects, intervals which have the upper note shifted upward by one or more octaves. Can these intervals be recognized? Another approach can be used for subjects who have little or no training in labeling musical intervals: a simple similarity recognition test can be given. A low note is followed by two other notes, one of which has an octave-multiple relation to the first. If the theory which states that all octaves have the same tone-chroma is correct, then subjects should have no difficulty in identifying cross-octave musical intervals or in perceiving the greater similarity of octaves in the similarity recognition test.

EXPERIMENT 1

Method

All subjects (undergraduate students) were given a brief threshold test at a low (750 Hz) and high (7800 Hz) frequency so that any case of obvious hearing problem at low and/or high frequencies might be screened out. Subjects were eliminated whose thresholds in either ear were more than 15 dB poorer than the average of the student population we have tested. All subjects were also screened with the first 17 items of the Seashore Pitch Test. Subjects making more than two errors were not tested further. These same screening procedures were used for subjects of all experiments.

Piano Interval Test. All subjects in Experiments 1 and 2 were tested with this simple test of ability to name musical intervals at several octave levels. The first note of each pair presented was

This research was supported by a grant from the Graduate School Research Committee, University of Wisconsin.

a G on the piano scale. If we designate G above middle C as G₃, then the Gs used were G₂, G₃, G₄, and G₅. The second note of a pair, which followed close to 1 sec later, was a note on the piano scale corresponding to re (A), mi (B), fa (C), or sol (D). There was a time interval of close to 5 sec between pairs. The four intervals in each octave (G-A, G-B, G-C, G-D) were tested in a random order before going on to the next octave. Octaves were tested in the order G₂, G₅, G₃, G₄. Notes used on this Yamaha piano were checked using a Conn Strobotuner. In terms of an A₃ of 440 Hz, notes showed a median value of 9 cents low, with a semi-interquartile range of 2.5 cents (there are 1,200 cents in each octave). However, ratio relations of tones were close to "in-tune": the piano was simply not tuned relative to an A of 440 Hz, but to an A slightly lower.

There were a total of 16 items, which were tape-recorded at approximately equal sound levels. (A Magnecorder, Model 728, tape recorder was used in all experiments.) The subject listened with an earphone on his right ear (as he did for all other experimental conditions) and wrote his answer as 2, 3, 4, or 5 on the answer sheet. The sound pressure level of note G₃ was close to 80 dB on the A scale of the sound level meter (B & K, Model 2203), as measured in a General Radio, Model 1560-P82, coupler. The earphone was a Telephonics, Model TDH 39, phone.

Subjects (N = 7) who made only 2 errors or less were tested further in Experiment 1. The remaining subjects (N = 9) were tested as described under Experiment 2.

Piano Cross-Octave Interval Test I. In this test, the lower note of each pair was always G₀ (where G₃ is the G above middle C). The second note of the pair was randomly selected from piano notes of G, A, B, C, and D in five octaves above the G₀. (For example, Gs used for the second note were G₁, G₂, G₃, G₄, and G₅.) Items were tape-recorded. Sound level and timing of stimuli were the same as in the Piano Interval Test.

The subject was instructed to think of the first note as the first note in the musical scale, then to indicate (by writing down 1, 2, 3, 4, or 5) whether the pitch quality of the second note sounded most like the 1st note of the musical scale, or the 2nd, 3rd, 4th, or 5th. The subject was asked to try to label the second stimulus even though it might seem to have much greater pitch height than the first.

Piano Cross-Octave Interval Test II. This test was constructed in a similar fashion to Piano Cross-Octave Interval Test I. However, for 15 items, the first note was G₂ and the second note was randomly selected from piano notes G, A, B, C, and D in three octaves above G₂ (for example, G's used for the second note were G₃, G₄, or G₅). For five other items, the first note was G₄ and the second notes were randomly selected from the first five notes of the scale in the octave above, starting with G₅. Order of items was randomized.

Tone Cross-Octave Interval Test. This test was constructed very similarly to Piano Cross-Octave Interval Test II. For 20 items, the first note was 200 Hz and the second note was randomly selected

from the first five notes of the scale in the octaves above 400, 800, 1,600, and 3,200 Hz. Sets of tones used were 400, 450, 500, 534, 600; 800, 900, 1,000, 1,068, 1,200; 1,600, 1,800, 2,000, 2,136, 2,400; and 3,200, 3,600, 4,000, 4,272, 4,800.

For 10 other items, the first note was 800 Hz and the second note was randomly selected from the first five notes of the scale in the octaves above 800—that is, 1,600 and 3,200. Sets of notes used were 1,600, 1,800, 2,000, 2,136, 2,400; and 3,200, 3,600, 4,000, 4,272, 4,800. Order of items was randomized. As in the piano cross-octave interval tests, the subject was asked to identify which note of the scale was represented by the second note of each pair.

Items were tape-recorded. Sound level was approximately constant at different frequencies. The sound pressure level of the 400-Hz tone (corresponding to G₃ in the piano tests) was 86 dB on the A scale of the sound level meter (as measured by a General Radio, Model 1560-P82, coupler). Duration of each tone of an item was 1 sec. The time interval between notes of an item was .5 sec, and the time between items was 15 sec. Timing was controlled by a Psionix, Model 2400, timer. Switching on and off of tones was controlled by Grason-Stadler electronic switches (Models 829C and 829D) with rate of onset and offset at 10 msec, for this and all other experiments using tones. Oscillators used for producing tones were General Radio beat-frequency oscillators (Models 1304 A and 1304 B).

Tone Interval Test. This test (the last one given to the subjects) was very similar to the Piano Interval Test, but constructed with oscillator tones. The first note of each pair was 200, 400, 800, 1,600, or 3,200 Hz. The second note was a note corresponding to a major 2nd, major 3rd, 4th, or 5th of the scale in the same octave as the first note. Frequency ratios used for these intervals were 9/8, 5/4, 4/3, and 3/2 (as in the Tone Cross-Octave Interval Test). Items were tape-recorded in orders similar to those in the Piano Interval Test, and were of approximately equal sound level. The level and timing of tones was the same as in the Tone Cross-Octave Interval Test.

Results

Results for Experiment 1 are summarized in Table 1. The four subjects who made no errors on the Piano-Interval Test also made very few errors in identifying cross-octave intervals. A possible explanation of the results is that these subjects do indeed hear a pitch "chroma" which is the same for all octaves of a given tone.

On the other hand, subjects who had made two errors on the Piano-Interval Test made errors on the Pure-Tone Interval Test. (Median number of errors was 4.) They also tended to make a number of errors

Table 1
Median Number of Errors for Interval Recognition, Experiment 1

	Piano Tests			Tone Tests	
	Interval ^a	Cross-Octave I ^b	Cross-Octave II ^c	Cross-Octave ^d	Interval ^e
Subjects, N = 4	0	1	0	1	1
Subjects, N = 3	2	12	9	14	4
Number of Items	16	25	20	30	20

^aPiano Interval Test: Test of ability to name musical intervals within each of several octave levels. ^bPiano Cross-Octave Test I: Test of ability to recognize similarity in musical intervals when the upper note of the interval was transposed by one or more octaves. First low note was G₀ (where G₃ designates G above middle C on the piano). ^cPiano Cross-Octave Test II: Similar to Piano Cross-Octave Test I, except that the first, low note was G₂ or G₄. ^dTone Cross-Octave Test: Similar to the Piano Cross-Octave Tests, but constructed with pure tones. Lowest note was 200 or 800 Hz. ^eTone Interval Test: Similar to the Piano Interval Test, but constructed with pure tones.

on the Cross-Octave Interval Tests. The number of correct recognitions was checked for each test and each subject by using the binomial distribution, and calculating the probability of getting r or more successes by guessing. Results were all significant (beyond .05 level) except for one subject's results with the Piano Cross-Octave Interval Test I. However, these subjects were recognizing only approximately one-half of the cross-octave intervals correctly. There were no obvious trends in the data associated with frequency level of low tones or comparison tone.

EXPERIMENT 2

Method

Subjects were tested with Piano Octave-Similarity Tests, and finally with a Tone-Similarity Matching Test.

Piano Octave-Similarity Test I. The first note of each item was G₀. The second and third notes were combinations of a G from a higher octave (G₁, G₂, G₃, G₄, or G₅) with an A or a B from the same octave. The subject was asked to judge whether the second or the third note sounded more similar to the first. He was told that the second and third pitches might be much higher in pitch height than the first low tone, but that his task was to judge pitch quality, not pitch height.

In both of the piano octave-similarity tests, order of the second and third notes was randomly determined, and overall order of items was randomized. Items were taped, and listened to by earphone at the same level as previous recorded piano tests. Each note of an item occurred at close to 1-sec intervals, and there was approximately 10 sec between items.

Piano Octave-Similarity Test II. This test was constructed in a manner very similar to the Piano Octave-Similarity Test I except that the first note was now G₂ (for 12 items) or G₄ (for 4 items). When the first note was G₂, the second and third notes were combinations of a G from a higher octave (G₃, G₄, or G₅) with an A or B from the same octave. When the first note was G₄, the second and third notes were combinations of a G₅ with either A₅ or B₅.

Tone-Similarity Matching Test. This test was given mainly to check on whether some subjects might have reliable but idiosyncratic pitch functions which departed from the 2:1 frequency ratio for octaves (cf. Ward, 1954).

The subject was told that he would hear two notes alternating in time. Each was 2.5 sec in duration. He was asked to adjust the higher frequency until its pitch quality sounded like that of the lower note. The subject was told that the higher pitch might sound much higher in pitch height, but his task was to adjust the frequency until it seemed to have the pitch quality of the lower note.

The low note was always 200 Hz. (a) The higher note was set by the experimenter at 325, 650, 1,300, or 2,600 Hz, and the subject was asked to *increase* the frequency until he obtained a pitch-quality match. (b) The higher note was set at 6,000, 3,000, 1,500, or 750 Hz, and the subject was asked to *decrease* the frequency until he obtained a pitch-quality match. The starting frequencies were set in between successive octaves, with the expectation that the subject would stop at an octave-multiple when he came to it *if* he perceived a pitch similarity to the 200-Hz low note.

Tones were produced by General Radio beat-frequency oscillators, whose dial calibrations were frequently checked between trials (with the built-in-dial-calibration checking circuits). Timing was controlled by a Grason-Stadler, Model 829D, electronic switch, with rate of turning on and off of tones set to 10 msec. Attenuators were used to keep the sound level approxi-

mately constant for the different frequency levels used. The 200-Hz standard was at a level of 70 dB, as measured in the earphone coupler, on the A-scale of the sound-level meter.

Results

Piano Octave-Similarity Tests. All but one of the nine subjects had scored above chance on the Piano Interval Test. The median number correct was 8 out of 16. (Number correct was quite uniform for all octaves tested.) Their inability to do extremely well on the Piano Interval Test would not necessarily imply that they did not hear similarity for tones related by octave-multiples. (By octave-multiple, we mean a frequency related by a ratio of 2, 4, 8 . . . to the low note). However, examination of data obtained with the Piano Octave-Similarity Tests indicated that most did not perceive greater similarity for octaves than for nonoctaves (despite the fact that these subjects all had special training in music beyond that received in a usual school education).

For each item, the subject was forced to choose one of two notes as being similar to the low standard note. The probability of choosing an octave-multiple by chance was therefore .5. It is possible to calculate (using the binomial distribution) the probability of r or more successes by chance. When this was done, it was found that three of the nine subjects had scores which were significant beyond the .05 level. One subject chose the octave-multiple 33 out of 36 times, while two subjects chose it 26 times out of 36. The latter scores, however, do not indicate a high degree of perception of similarity between octave-multiples and the low standard notes. Finally, there was no discernible tendency in the data for the proportion of choices of octave multiples to change as a function of frequency level of test tone or standard tone.

Tone-Similarity Matching Test. It was decided to define the task for these subjects as a search for octave-relations after a pretest revealed that subjects had difficulty understanding what was meant by "similar pitch." (The latter difficulty points to the conclusion that for many subjects there are no clear "chroma" similarities present at octave intervals.)

Some subjects were able to score "hits" on the target octave frequency when adjusting the comparison tone upward. (A "hit" was scored for an octave-multiple if the subject came within 5% of the target frequency, calculated on the basis of a 2:1 frequency ratio for successive octaves.) Out of 9 subjects, number of subjects scoring "hits" for target octave frequencies of 400, 800, 1,600, and 3,200 Hz was 6, 5, 3, and 0, respectively.

When adjusting the comparison tone downward, subjects tended to miss the nearest multiple by a wide margin. No subject who "hit" an octave multiple with an upward adjustment was able to hit it again with a downward adjustment. Some remarked that

they were used to tuning upwards on their instruments. These results also seem to indicate that matches are being made in terms of interval adjustment, rather than in terms of a chroma characteristic of each frequency.

Tabulation of frequency differences between matches when adjustment was upward vs. downward gave the following results: the median frequency difference for "target" octave frequencies of 400, 800, 1,600, and 3,200 Hz was 110, 590, 1,100, and 1,700 Hz, respectively. (Cases where a subject came close to matching an interval of a 5th above an appropriate octave rather than an octave were omitted from this tabulation.) These results indicated clearly that the failure of most subjects to identify similarity of octave-multiple pitches in the Piano Octave-Similarity Tests could not be attributed to *reliable*, but idiosyncratic, octave functions (with large departures from a 2:1 frequency ratio for perceived successive octaves).

EXPERIMENT 3

Method

The subjects were undergraduate volunteers who had no special musical training beyond that received by all students in school. It was decided to use puretone tests with this group, because judgment of similarity between complex notes at octave intervals might be based on similarities of spectrum rather than of fundamental pitches. A Tone-Similarity Matching Test was given to all subjects ($N = 14$) during the first session. It was possible to retest 11 of these subjects in a second session; the Tone Octave-Similarity Test was given first, followed by a repetition of the Tone-Similarity Matching Test.

Tone-Similarity Matching Test. This test was carried out in essentially the same manner as the Tone-Similarity Matching Test of Experiment 2, with the following exceptions.

First session: The low note was always 400 Hz (set at 70 dB level). The subjects were asked to move the variable frequency *upward* until they found a pitch similar to the low note. They were not told to search for octaves. Starting frequencies were 500, 1,100, 2,000, 2,200, 1,000, and 550 Hz. Ability to match a 400-Hz tone was also checked. The subjects were questioned at the end of the session on whether they understood what an octave was.

Second session: The low note was always 400 Hz. The subjects were asked to move the variable frequency *downward* until they found a pitch similar to the low note. They were not told to search for octaves. Starting frequencies were 1,500, 3,000, 6,000, 4,000, 2,000, and 1,000 Hz. Ability to match a 400-Hz tone was also checked.

Tone Octave-Similarity Test. This test was constructed similarly to the Piano Octave-Similarity Test, but with pure tones. The first tone in each item was 400 Hz. The other two tones of each item included an octave multiple of 400 (800, 1,600, or 3,200) and a nonoctave multiple (1,000, 1,200, 2,000 and 2,400). Combinations used were 800-1,000, 800-1,200, 1,600-1,000, 1,600-1,200, 1,600-2,000, 1,600-2,400, 3,200-2,000, and 3,200-2,400. Each item occurred six times (but not in succession). Order of items and order of octave-multiple stimulus in each item were randomized. Items were recorded so that sound level was approximately constant. Level of the 400-Hz standard, as measure by ear-phone coupler, was 73 dB on the A-scale of the sound-level meter. Each tone of an item was on for 1 sec, with .5 sec between tones and 15 sec between items.

Results

Tone Octave-Similarity Test. Even though these subjects had no *special* musical training beyond that given in school, it was found, at the end of the first session Tone-Similarity Matching Test, that six of these subjects reported a clear understanding of the octave concept, and most of these felt that they had used this concept in trying to make similarity matches. One of these subjects, who reported using the concept of the octave in making similarity matches, obtained a perfect score in the Tone Octave-Similarity Test, in that he always chose an octave-multiple as more similar to the low standard tone. One other subject, who also reported understanding and using the concept of octave in the Tone-Similarity Matching Test, chose octave-multiples as more similar to the low standard tone 33 times out of 48. This result would be expected by chance less than 5% of the time. Results for the other nine subjects were not statistically significant. Examination of the data also showed that there was no tendency for performance to be any better for lower frequency octave-multiples than for higher.

Tone-Similarity Matching Test. It will be recalled that during the first session, subjects were asked to make pure-tone similarity matches to a low standard tone: each subject was tested to see whether he could match to an octave multiple of 400 Hz at 800, 1,600, and 3,200 Hz. Although the subjects were not told to look for multiple-octaves as a basis for a similarity match, it was found at the end of the session that six of the subjects reported that they clearly understood the concept of octave, and most of these reported trying to use the octave concept in obtaining similarity matches. However, results showed that these subjects were unable to hit octave-multiples of the low note consistently. (A "hit" was scored for an octave-multiple if the subject came within 5% of the target frequency—calculated on the basis of a 2:1 frequency ratio for successive octaves.) During the first session, there were only two cases where subjects were able to hit an octave multiple on both test and retest. During the second session there was only one such case.

Eight other subjects who were tested reported at the end of the first session that they did not understand the octave concept or did not understand it clearly. Two of these subjects were unable to perform the matching task. The other subjects were not able to hit the octave multiples consistently. During the first session there were no cases where a subject was able to hit an octave multiple on both test and retest. During the second session (in which it was possible to retest five of these subjects), there was only one such case. We find no evidence here for tone-chroma effects.

All but three of the subjects matched the 400-Hz

tone very closely. Even these three did not deviate from a match by more than 5%. Therefore, inability to find similar pitches at octave-multiples is not due to a basic inability to match the pitch of the low note.

Could some subjects be reliably matching at frequencies removed from simple 2:1 frequency ratios? Our data indicates that the subjects simply were not matching reliably. The median frequency difference between first and second test of the second session was tabulated. Median values of 310, 350, and 900 Hz were obtained for matches to "target" octave frequencies of 800, 1,600, and 3,200 Hz, respectively. (Cases where the subject came close to matching an interval of a 5th above an appropriate octave target were not included in this tabulation.) These results agree with those obtained with subjects of Experiment 2 in showing large differences between test-retest values.

DISCUSSION

(1) Our results show that *some* subjects *can* perceive similarity in musical tones (even pure tones), though the upper note is transposed by one to several octaves. In this section, mechanisms are suggested by which this ability might be acquired.

Complex tones. (A complex tone is a fundamental frequency with overtones, typically at integer multiples of the fundamental.) It is suggested that the subject learns to make the same mediating vocal response to all complex tones whose *fundamentals* (lowest frequency components) are at octave intervals. Well-trained singers can "hear themselves sing" a vocal response without making any audible sound. The perception of the (strong) fundamental pitch of the matching vocal response then can become a prominent part of the perception of the pitch of octave multiples, and thus a basis for "tone chroma." [It has been previously hypothesized that a vocal mediating response may play a critical role in perception of the "missing fundamental"—(see Thurlow, 1963).] How is this type of response reinforced? Singers can come in on a given pitch correctly (after a rest occurs in their part) by getting a cue from another part which often is being sung at one or more octaves' distance. By learning to hum a vocal response to this other part, the singer can then estimate his own starting note as a musical interval from the note he has just hummed (and be reinforced for this, when he is correct).

Terhardt (1974) has developed a theory to explain the "missing fundamental" (and other pitch effects) in which it is hypothesized that stimulation by voiced speech stimuli is sufficient to develop patterns which the subject is able to utilize later. Terhardt's theory, however, and also Wightman's theory (Wightman,

1973) appear to predict more similarity for pitch of octave multiples than we have found. The theory outlined in this paper stresses the necessity of a particular kind of training with musical stimuli in order for the "sounds similar" octave equivalence of two stimuli to develop. While vocal mediating responses have been emphasized, it should be noted that matching responses with some other musical instrument could be involved.

Single tones. It is assumed that these musically trained subjects can adopt the strategy of responding to a single frequency as they would to the fundamental of a complex tone. How is this strategy reinforced? It is assumed, for example, that singers (a) may need to match the pitch of another singer who is singing at a different octave level, (b) may only hear the lowest (strongest) component of the vocal sound because of masking produced by other voices, (c) are then reinforced for matching this single most audible component at an octave interval (in order to produce a note at an appropriate octave level in their own singing part). This strategy is not in conflict with the strategy of responding to the whole harmonic series of a complex tone. Both can be regarded as alternatives which can be utilized as the occasion demands.

(2) A mechanism has been suggested above for understanding how subjects are able to report that stimuli related by octave-multiples "sound similar." It certainly is true that some people report that octave-multiples have a similar pitch quality. (One of the authors—W.R.T.—perceives this similar pitch quality.) Some subjects, however, might conceivably translate the problem of finding "pitch similarity" into a search for octave intervals—if they were musically trained, and aware of the ways in which octaves are treated as functionally equivalent in music. An octave interval relation does not necessarily imply pitch similarity: For example, a subject might be able to imagine the pitch change produced when he changes the response of his instrument or voice by an octave interval, as cued by musical notation. We did not ask our subjects to introspect in detail concerning the way they were reacting to the octave-multiples. If they used the octave concept in making matches, we do not know whether they were matching at octaves because octaves sounded similar, whether they were utilizing octave interval relations, or whether they were doing both. Whatever their reactions, only very few were able to find relatedness in the octave multiples of our tests.

We have recently tested another group of undergraduates, to find whether the results on the Tone Octave-Similarity Test would be markedly different if we instructed subjects to look for octave multiples vs. nonoctave multiples, instead of instructing them

to judge similarity of pitch. These 13 subjects reported that they understood the concept of octave. They were given the Tone Octave-Similarity Test twice, the second time with instructions to identify octave multiples. The results of this second test were similar to those of Experiment 3. Two subjects obtained perfect scores; one subject obtained a score of 40 out of 48. The other scores were not significantly beyond what would be expected from a guessing strategy. The median score of these remaining 10 subjects was 27 correct out of 48 items. (A value of 24 correct would be expected on the average from guessing.)

(3) It is important to note that in our Tone Octave-Similarity Test, over half of the comparisons involved choice between a stimulus at an octave-multiple and at a nonoctave-multiple stimulus in the same harmonic series (as the first low note of the test item). Those of our subjects who scored perfectly therefore were responding to similarity based on octave multiples, and not on similarity due to the occurrence of stimuli in the same harmonic series.

(4) Many of our subjects did not perform well in naming the size of simple musical intervals. While this result could be related to our sample of subjects, it may also be related to the nature of the task. Only two notes were given, and the subject had to identify the size of the interval. The subjects conceivably could have done much better had they been given the task of identifying a familiar melody, with several notes given instead of just two (cf. Attneave & Olson, 1971).

Similarly, it appears possible that octave multiples might act more effectively as cues when several of them are given in succession, especially when the subject is "set" to perceive one of a limited number of melodic sequences (cf. Dowling & Hollombe, 1977; Idson & Massaro, 1976.) In these studies, however, it is not clear whether the cueing by notes from nearby octaves is due to their being octaves or to the fact that octave frequencies occur as part of the harmonic series of complex musical tones—and can become associated in that way. Houtgast (1976) has been able to demonstrate cueing of a fundamental pitch perception from a single harmonic under appropriate conditions of "set." It should be added that no claim is made that the mechanisms suggested to explain the "sounds similar" octave-equivalence results in our experiments are necessary or sufficient mechanisms to explain these more complex cueing results. However, they could assist subjects in these more complex situations.

(5) Finally, we did not test our present subjects

at very high frequencies because tone chroma has been reported to cease in these high-frequency regions. It should be noted however, that *some* subjects are able to make pitch-interval judgments in these high-frequency regions, provided that the frequency is swept slowly from a starting to a stopping frequency (see Elfner, 1964; Thurlow, 1946, 1965). One could speculate that perhaps frequency movement detectors (Whitfield, 1965) are somehow involved in providing a special cue to distance traversed, which then can be matched to that produced by a low-frequency mediating vocal response change.

REFERENCES

- ATTNEAVE, F., & OLSON, R. K. Pitch as medium: A new approach to psychophysical scaling. *American Journal of Psychology*, 1971, **84**, 147-166.
- DEUTSCH, D. Octave generalization and tune recognition. *Perception & Psychophysics*, 1972, **11**, 411-412.
- DOWLING, W. J., & HOLLOMBE, A. W. The perception of melodies distorted by splitting into several octaves: Effects of increasing proximity and melodic contour. *Perception & Psychophysics*, 1977, **21**, 60-64.
- ELFNER, L. F. Systematic shifts in the judgment of octaves of high frequencies. *Journal of the Acoustical Society of America*, 1964, **36**, 270-276.
- FRANCÈS, R. *La perception de la musique*. Paris: Vrin, 1958.
- HOUTGAST, T. Subharmonic pitches of a pure tone at low S/N ratio. *Journal of the Acoustical Society of America*, 1976, **60**, 405-409.
- IDSON, W. L., & MASSARO, D. W. Octave convergence in melodic perception. *Journal of the Acoustical Society of America*, 1976, **60**, Supplement No. 1, S 41. (Abstract)
- JONES, M. R. Time, our lost dimension: Toward a new theory of perception, attention, and memory. *Psychological Review*, 1976, **83**, 323-355.
- LICKLIDER, J. C. R. Basic correlates of the auditory stimulus. In S. S. Stevens (Ed.), *Handbook of experimental psychology*. New York: Wiley, 1951.
- TERHARDT, E. Pitch, consonance, and harmony. *Journal of the Acoustical Society of America*, 1974, **55**, 1061-1069.
- THURLOW, W. R. The perception of the pitch of high frequencies. *American Psychologist*, 1946, **1**, 255. (Abstract)
- THURLOW, W. R. Perception of low auditory pitch: A multicue, mediation theory. *Psychological Review*, 1963, **70**, 461-470.
- THURLOW, W. R. Audition. In P. R. Farnsworth (Ed.), *Annual review of psychology*. Palo Alto: Annual Reviews, 1965.
- WARD, W. D. Subjective musical pitch. *Journal of the Acoustical Society of America*, 1954, **26**, 369-380.
- WARD, W. D. Absolute pitch. Part I. *Sound*, 1963, **2**, 14-21. (a)
- WARD, W. D. Absolute pitch. Part II. *Sound*, 1963, **2**, 33-41. (b)
- WHITFIELD, I. C., & EVANS, E. F. Responses of auditory cortical neurons to stimuli of changing frequency. *Journal of Neurophysiology*, 1965, **28**, 655-672.
- WIGHTMAN, F. L. Pitch and stimulus fine structure. *Journal of the Acoustical Society of America*, 1973, **54**, 397-406.

(Received for publication March 7, 1977;
revision accepted June 2, 1977.)